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WAYS AND WORKS IN INDIA

‘It will perhaps be as well to distinguish three species and degrees of ambition. First, that of men who are anxious to enlarge their own power in their country, which is a vulgar and degenerate kind; next, that of men who strive to enlarge the power and empire of their country over mankind, which is more dignified but not less covetous; but if one were to endeavour to renew and enlarge the power and empire of mankind in general over the universe, such ambition (if it may be so termed) is both more sound and more noble than the other two. Now the empire of man over things is founded on the arts and sciences alone, for nature is only to be commanded by obeying her.’—BACON, *Novum Organum*, cxxix.

WAYS AND WORKS IN INDIA

BEING AN ACCOUNT OF
the Public Works in that Country from
the Earliest Times up to the
Present Day, by

G. W. MACGEORGE, M.I.C.E.

||
LATE OFFICIATING CONSULTING ENGINEER TO THE
GOVERNMENT OF INDIA FOR RAILWAYS

WITH NUMEROUS ILLUSTRATIONS AND MAPS



Westminster

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AUTHOR'S PREFACE

MATERIALS for the facts and figures grouped together in this work have been mainly gathered from such official publications and Government records as are readily accessible to a writer in England, as well as from numerous published volumes or reports, dealing with separate branches of Indian Public Works, or Indian and English Engineering, and (by kind permission) from many descriptive papers on Indian subjects read at various times before the Institution of Civil Engineers. Where distinct verbal quotations have been made they are indicated by the footnotes or otherwise, but frequently where the general substance of passages, or of statistics, has been paraphrased and condensed, it has not been deemed necessary to burden the volume with constant references.

With regard to the spelling of Indian names and terms, it is feared that some unintentional deviations from the orthodox system may be found. The popular spelling of names of important and well-known places has, of course, been adhered to, and with respect to the remainder, the indulgence of those desiring severe accuracy in this matter is craved.

A precise and detailed history of Indian Public Works is a subject that would amply repay the time and labour spent on its production. The present work barely indicates even the outline of such a history, and has a far humbler and less ambitious aim. It is hoped, however, that the data contained in it may be of some service, as well as interest to the unprofessional reader, as bringing before him in a collected form much scattered information of a kind valuable to all those interested in the progress of India. Some of the principal books, reports,

and other publications consulted and freely made use of are the following :—

- Memoirs of Indian Surveys*, by Clements R. Markham (1878).
Memoirs of Indian Surveys, by E. C. D. Black (1892).
General Reports of Operations, Survey of India. Thuiller, R.E.
Moral and Material Progress Report, 1872-73. Parliamentary Paper.
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Ganges Canal. Sir Proby Cautley.
Irrigation Works of India. Buckley.
India, by F. C. Danvers.
Lectures on Irrigation Works of India. Rundall, R.E.
Lectures on Water-supply, Rainfall, etc., by Alex. R. Binnie, M.I.C.E.
Roorkee Treatise, and Professional Papers on Indian Engineering.
The Railways of India. Capt. E. Davidson, R.E.
Lecture on Bridges in the Bengal Presidency, by Sir Bradford Leslie, C.S.I., M.I.C.E.
Railway Appliances. John Wolfe Barry, M.I.C.E. (1878).
The Working and Management of an English Railway. Geo. Findlay (1891).
Our Iron Roads. F. S. Williams.
 Numerous Papers from *Proceedings of Institution of Civil Engineers*.
 Official Publications, Departmental Administration Reports, etc., etc.

G. W. MACGEORGE.

MAIDENHEAD, 1894.

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INTRODUCTION



HERE still lingers in the mind of the present generation of Anglo-Indians an old saying to the effect that if the English were to retire from, or be driven out of India to-morrow, they would leave as the only monument of their rule in that country 'The Grand Trunk Road, and a pyramid of empty beer bottles.' It need hardly be said that this satirical dictum, like many another which was once, perhaps, just pointed enough to prick,

has long since lost all semblance of epigram. At the present day no instructed person acquainted with modern India would hesitate to assert that in the whole history of governments—not excluding that of ancient Rome—no alien ruling nation has ever stamped on the face of a country more enduring material monuments of its activity than England has done, and is doing, in her great Indian dependency. Not only has she covered the face of British India with a mileage of roads, railways, telegraphs, and irrigation canals, which, bearing in mind the vast area of the country, and the financial difficulties encountered, may be truly designated stupendous, but the total number of individual works of exceptional magnitude and importance comprised in the whole, probably surpasses that to be found in any equal continuous area in any other part of the world. Other works of public utility, such as water-supply, and drainage of towns, docks, harbours, breakwaters, lighthouses, and public buildings of all kinds, although in number as yet very

far from adequate to the wants of the country, form, nevertheless, a contribution of no mean proportions to that sum-total of constructive energy, which cannot fail to leave the English name for ever indelibly imprinted on the soil of India.

In the following pages it is attempted—it is feared very imperfectly—to bring together, and rapidly sketch in as far as possible untechnical language, and in a form suited to the general reader, some of the more prominent and important public works which have been carried out in India, either by the direct or indirect agency of the Government of the country since the British occupation; and in order that the unprofessional reader may intelligently follow the necessarily very condensed account of these works, a few observations on such general principles of construction as may be needful have from time to time been introduced. It has, at the same time, been sought to convey an approximate idea of the enormous value and extent of each of the separate classes of Indian Public Works regarded as a whole.

It is obvious that such a work can only be of limited interest to the ordinary English public—outside that numerous body of persons, who in one manner or another have identified themselves with the progress and welfare of India—and none whatever to the professional engineer. To the former the subject is too remote, and to the latter the manner of treatment will be found insufficient. To the Indian engineer, although of no practical professional value, the work may possibly supply, in a convenient form, some historical or other data in connection with public works of more or less interest or utility. To the numerous body of general readers, both English and native in India, it is believed that the present volume may afford some useful and interesting information on subjects with which they are partially familiar, and with which they are brought into more or less frequent contact; and it is especially hoped that its perusal by that already large and intelligent class of natives of the country, which the spread of education has so greatly developed, may create in them a wider and more practical interest in what so intimately concerns the social and industrial progress of the people, and that it may help to instil a more cordial recognition and estimation, of the persevering

labour and skill of all those of their fellow-subjects, whether administrative officers, engineers, artisans, or labourers, whether English or native, by whose joint exertions the great public works of India have been and are being carried out.

Wherever it has been possible, attention has been directed to those works of public utility, which in the various Provinces of India have been constructed by native agency, long before the advent of British power in the country. The magnificent Mohammedan or Hindu creations, in the shape of mosques, temples, tombs, and palaces of emperors or nobles, great as many of these are, both as scientific constructions and as artistic monuments to the skill and refinement of their builders, are of necessity excluded; the scope of the volume being confined to those engineering works of general usefulness which bear directly upon the material progress of the people. In this special branch of utilitarian energy the modern Western nations stand pre-eminent, whilst they have to a great degree lost proficiency in those more graceful arts in which at an earlier period they also excelled. If we adequately picture to ourselves what was the material condition of the most advanced countries of the West hardly more than a hundred years ago, we shall not feel surprise if we find in India but few examples of those large engineering public works, which in every part of the world so eminently characterises the modern era. The political condition of the country for ages rendered it next to impossible that works of public improvement should have been attempted; the early history of India presenting an almost continued scene of internal discord, and the numerous and constantly changing divisions of territory between ambitious and despotic rulers, renders it vain to seek for, or expect, evidences of any concerted action for the public welfare. Nevertheless, especially in some of the great ancient irrigation works and reservoirs of Southern India, we shall be able to point out the existence of a very considerable engineering skill and boldness of enterprise possessed by the early Hindu race. No special selection of these works of purely native origin has been made, but such examples as the author has been able to meet with have been indicated. It is more than likely, however, that a large number which it would

have been of interest to have noted have been unintentionally overlooked.

Although the volume deals primarily with important public works of a distinctly constructional character, it has been judged appropriate to devote a little space to an outline description of the operations of the 'Great Indian Trigonometrical Survey,' which stands in the very foremost rank of magnificent human labours. Achieved in the face of impediments, and difficulties, due not only to immense superficial area, and physical obstructions, but also to the deadly effects of a climate that only the strongest can withstand, this great survey has been carried on and brought down to practical completion with unflinching pertinacity and incredible zeal over the long period of some eighty or ninety years, at a most considerable cost to human life, and at a money expenditure only commensurate with the great ends attained. To the Government, as the principal landowner of the country, the Topographical and Revenue Maps, based on the Great Trigonometrical Survey, and produced with so much careful accuracy by the surveyors of India, provide the principal basis on which the whole fiscal administration depends. The practical engineer, furnished with so much accurate and valuable data ready to his hand, can proceed to the elaboration and execution of his projects with a certainty and celerity which he could not otherwise attain, and numberless operations in other fields of labour are immensely facilitated. No one acquainted with the splendid series of maps of all classes issued to-day by the Survey Departments of India can fail to acknowledge that the vast operations by means of which these results have been attained forms in itself a monument of which any nation may be proud.

Owing to the almost complete absence of precise returns in any accessible form, it has unfortunately not been possible to outline in an adequate manner, either the early history or present extent of the chief public roads of India, whether in the case of those more important trunk thoroughfares of the first class, which, carried over enormous stretches of country, are metalled, and for the most part bridged throughout their entire length, or those still more numerous roads of secondary import-

ance. Even in the case of that interesting early work known as the 'Grand Trunk Road,' extending 1500 miles from Calcutta to Peshawur, the available information appears to be extremely meagre. The aggregate length of metalled and bridged roads throughout India, constructed by the British Government, must undoubtedly be enormous, but in the absence of any certain figures it would be exceedingly hazardous to attempt even an approximate estimate. During the last thirty or forty years a very large expenditure on common roads and bridges of all classes has been incurred, especially in the Panjab, the Central Provinces, and Bombay, and it is probable that the amount so expended, from general and local funds, has reached little short of a million and a half sterling annually.¹ The necessity for new trunk roads has in great measure been reduced by the rapid extension of railways, and road-making, except in the hills, has for many years been confined to those primarily intended to give access to railway depot; a far greater extension of such feeder roads is, however, still one of the most pressing requirements of the country.

A considerable portion of the volume is devoted to a narrative of the rise and development of the railway system; to the leading features of practical railway construction, and to a description of the larger and more important bridges and other works connected with railways in India. This is but a necessary consequence of the special importance and interest of the subject. Not only may the railways of the country be truly called the vital organs of industry and commerce, and the very mainsprings of material progress, but from their close and intimate connection with the daily life of so large a section of the people, details concerning them are probably capable of affording to the general reader a more certain and connected interest than would be the case with any other form of engineering work. The educated native of India of the present day—of sufficiently mature age—can hardly fail to recognise how greatly the material conditions of his existence have, during the course of his life, been ameliorated, how largely his

¹ Memorandum on some of the results of Indian administration during the past thirty years of British Rule in India.—Parliamentary Paper, 1889.

freedom of action, and possibilities of activity in every direction, have been increased, and to what a surprising extent the general lowering of the cost of production, since the introduction of railways, has developed and stimulated the industrial resources and commercial prosperity of the country. Admitting the considerable social and moral advancement of late years due to education and the spread of Western habits of thought, he cannot, at the same time, fail to perceive that the extraordinary progress, the patent steady advance in the average wealth and culture of the peoples of India, of which, for the last thirty or forty years, he has been the witness, has been originated and alone rendered possible, by the timely introduction and practical application in India of those various arts which have directed 'the great sources of power in Nature to the use and convenience of man'—in other words, in consequence of that enlightened policy of the English governors of the country which—especially during the last thirty years—in spite of financial difficulties and scares of all kinds, has urged them to persevere in the projection, execution, and extension over the length and breadth of India of great public works of every class.

It is outside the scope of the present volume to touch, except in the briefest manner, on the purely financial side of Indian public works; although it will be necessary, in order to represent the true magnitude and importance of many of these undertakings, to exhibit an outline of the general, commercial, and statistical results of their working. Those, and there are still some, who object to the large annual State outlay of borrowed money on works held to be reproductive, deny in the first place their real remunerative character—plead the poverty and inability of the country to pay for what they regard as the luxuries of civilisation, and maintain that the development of the resources of the country is no sufficient warrant for their construction by means of public loans, of which so very small a percentage can be—or at least hitherto has been—raised in India, and the interest on which, remitted by Indian tax-payers to English creditors, constitutes so heavy—and in their opinion so increasing, a burden on the country. No matter at what immediate sacrifice, they believe in a strict adherence to English

precedent, and would relegate all such works to private enterprise; make the confidence of investors the touchstone of remunerative probability, and leave to a speculative public, whether European or native, all profit and responsibility.

It may, however, be urged that the construction on a suitable scale, of railway and other reproductive works in India, by means of money borrowed, or guaranteed by the State, has been, under the conditions of the country, the only means by which such works could have been constructed at all. Nor does it appear that any serious economic objection to such a course can be made, unless at the same time it can be shown that the public burdens are not only temporarily, but permanently increased. A certain period of time must necessarily elapse before either railway or irrigation works become directly profitable, and a reasonable interest charge during such period, represents the price to the country of the enormous indirect benefits in the meantime secured, the direct return being at no time a fair or adequate measure of their real economic value.

There are no grounds for disputing, as a matter of fact, that the most rapid possible extension of canal irrigation and railway communication has been amply justified by the single considerations of famine protection and military necessities, nor can it be seriously disputed that the real financial results of railways, including those large indirect returns from a thousand channels, due to their interaction on the industrial progress and activity of the people—which in a country in the situation of India is of such incalculable importance—has proved them, so far as the balance of public interest is concerned, to have been no less truly reproductive works in the past than they will be in the near future, when they become a large and most important source of direct revenue to the State.

It may be allowed that the original guarantee system under which the earlier railways of the country were constructed, especially at the high rate of interest virtually imposed by the conditions of the time when it was adopted—a system which was abandoned in the year 1867—has turned out an uneconomical one. The additional burden imposed by the great reduction in the gold value of silver in recent years has, more-

over, to an extent quite impossible to have been foreseen, most severely accentuated the defects of the original bargain.

The actual financial position of Indian railways, as exhibited in the latest Administration Report by the Director-General, may be summed up as follows :—The total length of railways open for public traffic on the 31st March 1892, was 17,564 miles, and extensions to the extent of 1697 miles were under sanction, or in course of construction. The total capital expenditure on all railways up to the end of the year 1891 amounted to nearly 227 millions sterling.

During the calendar year 1891 the gross earnings on all railways were £24,040,279, and the total working expenses were £11,303,847, or 47·02 per cent., leaving as net earnings the sum of £12,736,432, or 5·61 per cent. on the capital outlay. Adding steamboat services and suspense accounts, the total return on the capital expenditure on all open lines of railway in the country is given as 5·76 per cent.

These figures represent the statistical results of working the railways during the year 1891. The final financial results to the State for the official year 1891-92 were only approximately known, but show an apparent net loss on all railways, taken together, of £384,450. The interest charges for the East Indian, Eastern Bengal, and part of the North-West railways, however, include annuities paid in England, which comprises a contribution amounting to about £325,000 on account of sinking funds, which will redeem the entire capital of these lines at the expiry of the period for which the annuity is to run, so that the *net loss* to the State during the year 1891 is given at the approximate figure of £60,000.

It is shown also that if interest on lines under construction were excluded from the above figures the results to the State from the working of the entire Indian railway system for the year 1891-92 would show a net gain of £190,000.

Referring to the various heads of loss, it is remarked that 'the loss on guaranteed railways is mainly attributable to the comparatively high rate at which the guaranteed interest has to be paid. Under its contracts with guaranteed railway companies the State has to pay interest at the guaranteed rates until the contracts terminate, and it is consequently unable to obtain

any advantage from the increasingly easy condition of the money market; that is to say, where the State could now raise money at a little over 3 per cent. to pay off loans raised at higher rates of interest, it has still to continue to pay interest at, or near, the high average rate of 4·8 per cent. on the capital raised by the guaranteed companies; and now, owing to the fall in exchange, the amount of rupees which have to be remitted to England to pay the sterling interest charges is equivalent to a payment of interest of over 6·4 per cent. on the total capital raised converted at par.'

The railway system of India may be divided into three main categories. First, there are lines which are the property of the State, and are managed and worked by it; secondly, there are lines which are the property of the State, but which are managed and worked by companies; and thirdly, there are lines which are both owned and worked by guaranteed companies, the Government retaining powers of purchase. Out of 17,564 miles of open railway the Government is the owner of upwards of 14,000, and has provided 153 out of the 227 millions sterling expended in their construction. The peculiar circumstances of the country have happily rendered it practically obligatory that the Government should be the ultimate holder and owner of all railway property—happily, because in a country situated as India has been, and still is, in economic and political condition, the entire possession in the hands of private companies of the main systems of railway communication, and their consequent working and management under the scarcely responsible influence of private interest, would in a manner not to be appreciated in homogeneous countries have been prejudicial to the true interests of the Indian public.

Under the practical conditions of railway working, too great importance is very often attached to the public benefits really derived from what is called a 'healthy competition.' Reasonable competition has no doubt some very desirable results; it prevents stagnation, and enforces those scientific developments which tend to reduction of working expenses and railway rates, but in practice, as a matter of notoriety, independent railway companies are soon compelled to combine in self-defence against undue loss on their part from competition, until practically a

single large monopoly is maintained, and this is liable to become a specially adverse monopoly where, as in the case of India, so large a portion of the working and management will necessarily be carried on from a distant country. Whoever holds the railways must of necessity hold a virtual monopoly, and it is distinctly better, perhaps everywhere, but certainly in India, that such a monopoly should be in the hands of the State than in those of private persons. The State, moreover, has it in its power to bestow on the public, to a far greater degree than private companies could do, the maximum advantages which the railways afford by means of the lowest tariffs.

Profits on railway working are in no way dependent on the high or low original cost of constructing the lines, but are solely dependent on the daily relation between the actual working expenses and receipts. However trite and obvious, it cannot be too often recollected that under purely commercial management it pays a little better to carry one unit for, say, eight annas, than to carry seven units for seven annas, that is to say, for the sake of one anna of additional profits a railway company is *bound* in the interest of its shareholders to exclude what may possibly be a very large proportion of public advantage. Nor has the public any reason to complain. The shareholders of a company do not make a railway for the purpose of conferring a maximum public benefit, but only for securing a maximum revenue—their object is merely to find and maintain within the limitations of the Government concession, the point of highest profits, no matter what may be the number of persons or tonnage of goods carried or excluded. If, for instance, the shareholders of a railway company were willing to accept a permanent diminution of a $\frac{1}{4}$ per cent. of their dividend, that comparatively small loss on their part might mean a possible reduction of tariffs, that would place the advantages and conveniences of railway transit within the reach of thousands who were before excluded, or, what is the same thing, would enable thousands to use the railway a largely increased number of times in the course of a given period. In India, the State, occupying a materially different position, will not necessarily be bound to sacrifice great public benefit for the sake of the last anna of profits. Its future direct revenue from railways will

form but a part of the whole receipts by which the Government of the country is carried on, and the reduction of a $\frac{1}{4}$ or even $\frac{1}{2}$ per cent. on its railway income, due to a largely lowered tariff, might conceivably confer a stimulus to public activity and industry, which would set in motion a more than equivalent flow of revenue from other sources, or the public, paying only the same total, would secure an important reduction in the direct cost of railway transit.

Had, however, the true interest of the Indian public been different, the construction of the railway system of India by purely private enterprise would have been equally impossible. It is certain that neither unguaranteed British capital would have been forthcoming, nor native capital with its high ruling rate of interest, and the almost complete absence of native industrial enterprise. Again, one of the most inherent peculiarities in railway outlay is the constant and inevitable growth of capital expenditure. In a commercial point of view, once in working existence, there is no such thing possible (short of closing the railway altogether) as closing its capital account. The very condition of being of a successful railway is to increase the public demands upon it, demands which can only be met by increased outlay on new works. During the time that competition between companies owning and working a number of railways serving a given district happens to be active, the tendency to extravagantly increase capital charges is irresistible, and often disastrous, as may be witnessed in the United States of America. In India, happily, the growth of capital outlay on working lines—even under the evils of the guarantee system on its main routes—can, and has been to a large extent, kept down to a healthy and normal rate, and in this respect the country derives advantage from the largely centralised control and ownership of its railway system; an ownership, moreover, which, it should be remembered, by no means includes that direct Government agency in the working and management, which is held by many to be attended with more or less real disadvantage.

The question as to the relative advantages of State or private agency in the working and management of railways in India has been much discussed. The highly successful results of the

valuable East Indian Railway, a line which, while the property of the State, is worked by a company, compares favourably, both as regards profits and percentage of working expenses, with the best State-managed lines—and it is on many grounds probable that the employment of private agency would in every case be attended with superior economy—but the question is one to be decided not only on grounds of financial, but also on considerations of political expediency; so that it would appear that the question is rather one for particular lines or systems, than for the aggregate of railways, and that, wherever political and military interests will admit, the employment of an intermediate agency in the working and management of the Government lines may be economically resorted to.

The enormous railway property of the Indian Government is steadily and year by year growing in value, and forms one of the brightest prospects in the financial outlook of the country. This property in the now near future must assuredly place at the disposal of the Administration a perennial and increasing source of revenue, which may be of incalculable importance in relieving the burden of taxation, and in admitting the carrying out of many long-desired fiscal reforms, whilst at the same time keeping open and enlarging almost every avenue of material wealth. Another and most important aspect of the especial value of Indian railways—a value in this respect of almost inconceivable amount—is the manner in which they operate to reduce and to prevent the otherwise ruinous outlay on famine relief, in a country where, without the means of a rapid transfer, of the food supply, local scarcity, or actual famine, is just as inevitable as are the uncertainties and irregularities of climate conditions, and where the burden of directly supporting a starving population in times of local distress, has been rightly accepted as an imperial and public duty. Some idea of the cost of famine relief may be gained, when it is stated that in the eleven years 1867-1877 inclusive, no less a sum than fourteen and a half millions sterling was thus expended, and the actual cost to the public of famine relief, including remission of land revenue, in the five years, 1873 to 1878, was nearly £16,500,000.¹

¹ *The Finances and Public Works of India*, by Sir John Strachey, G.C.S.I., and Buckley, on *The Irrigation Works of India*.

In the year 1880 the famine commissioners expressed their opinion that the trade of the country might be confidently left to provide for the supply of food in times of scarcity, basing this opinion on the rapid extension of the railway system. The thirteen years which have since elapsed have fully confirmed and justified this belief. Already in numerous cases where harvests have failed, and where unstinted public expenditure would have been unavoidable, the compensating action of railways has enormously mitigated, or altogether prevented, an inordinate rise of prices, and has thus—to say nothing of human life and suffering—saved probably many millions of pounds sterling to the taxpayers of India, and who can say how many millions more will in like manner be saved in the future? It is not too much to say, that probably in the lifetime of the present younger generation serious Indian famines will, under the equalising action of railways have become a memory of the past.

Who indeed can add up the enormous sum-total of the benefits conferred on humanity by railway communication? A celebrated English statesman has said, 'railways have rendered more services and received less gratitude than any institution in the land.' Their great wealth-creating power is very inadequately realised by the ordinary public, which adapts itself so quickly and so readily to every successfully improved appliance, and so rapidly forgets past difficulties, and the means by which they have been removed. This is perhaps more especially to be remarked in the case of steam locomotion, seeing that many persons now living could, if they reflected, correctly compare the old state of things with the new. Speaking of English railways, and of some of the ways in which they advance the wealth and welfare of a community, the author of '*Our Iron Roads*' states in far better words than any the writer of the present volume is able to frame. 'In their construction in the United Kingdom no less a sum than £831,000,000 of capital have been authorised by Parliament, and £745,000,000 have been paid up. It may be true that some of these railways "do not pay," in the sense that they do not give a reasonable dividend, or in some cases any dividend at all, to the shareholders who have provided the capital, but the poorest line that runs in the poorest district, is of value to

the trade, and to the people among whom it passes. The construction of every mile of railway, unlike money lavished in war, has at almost every stage enriched somebody, has enriched the nation and the world. Wealth employed on armies and fleets, or squandered in the destruction of life and property, or wasted in the luxuries of despotic rulers, is unproductive. Not so with railways, every pound of which honestly spent in due time yields a reward. The navy who receives his wages for building up embankments, forming cuttings, driving tunnels, or preparing the surface of the railways; the men who are employed on the permanent way, and who keep the ballast and rails in order, the pointsmen, and the signalmen whose duty it is to watch over the running of the trains, the guards, the porters, and the stationmasters, these all expend the wages which they receive in the purchase of the necessaries, and, in not a few instances, what but a short time since would have been regarded as the luxuries of life. The producer of the goods thus distributed makes his profit on their production, and in his turn secures a share of the money which the working of the railway system causes to be circulated through the country. In like manner the coalowner, or the ironmaster, who supplies the coal and iron; the various manufacturers who build the rolling stock; each in his turn realises profits, and accumulates some fraction of the great total of national wealth. The profits thus realised become in their turn invested in reproductive works.'

The enormous economy of railway locomotion—less however in India than in Europe—if we put to its credit the diminution in the expense of traffic since it was introduced, has been strikingly illustrated by the late Sir James Allport, manager for many years of the Midland Railway, in connection with the coal traffic in England. He says, 'The reduction in the rate of the conveyance of coal to London for the last fifteen or twenty years is equivalent to the total value of the coals themselves. Twelve months ago people were paying for coals in London less than they paid for the *mere carriage* of the coals before railways came into operation'—and speaking of the general economy of railway carriage as compared with the past, he says, 'I venture to assert that the reduction in carriage by

railways, as compared with the former charges and quantities carried, has effected a saving to the country of an amount equal to more than double the entire gross receipts of all the railways of the kingdom, or more than a hundred million sterling annually.'

The indirect saving in *time*, in the conveyance both of passengers and goods, in all commercially active countries, represents also an immense direct saving of actual money in the shape of interests and discounts. It is railways alone which have rendered possible that great postal system, which oils the whole machinery of progress in every direction, and there is no exaggeration in saying that without an adequate railway system no country could ever attain that healthy activity, wealth, and well-being, which the mighty revolution effected by the locomotive engine has engendered, and which it ever, year by year, creates in wider and increasing proportion.

It is necessary, however, to remember, that great as are the developing powers of railways, the full benefits to be derived from them will not in India be realised until agricultural improvements have reached a point more nearly on a par with the increased facilities of transport. The capabilities of India in almost every branch of agriculture are enormous, but these capabilities are as yet only partially awakened. By the aid of the practical sciences which have produced so great results in Europe, the native methods of raising and preparing the main crops of the country, such as wheat and other grains, cotton, sugar, hemp, and flax, may be vastly improved, and the out-turn of every acre very greatly increased. Much has been already attempted in this respect, but the difficulties to be surmounted in a country where agriculture still remains an empirical and traditional art, are exceptionally great.¹ What appears to be mainly desirable is less to revolutionise present methods, than, by careful observation to adapt and engraft on them such of the Western improvements as may be peculiarly fitted for the special conditions of soil and climate.

A second important accessory, hitherto but most imperfectly

¹ *Vide* Paper on 'Public Works in Bengal.' Vol. xvii. of *Proceedings of Institute of Civil Engineers*.

developed in proper relation to railways in India, is the creation in a systematic manner, of a network of good village roads, serviceable at all times of the year, converging on properly selected points. Without such a system of minor roads, connecting all the smaller centres of commerce with the larger and established markets nearest to the railway, the latter can confer only partial benefit to the districts through which it runs. For a long period the provision of feeder roads was unduly postponed, under the mistaken idea that the funds available would be more profitably expended on branch lines of railway to feed the main lines in the place of roads, forgetting the absolute impossibility, in such a wide area of country, of constructing within any moderate length of time a system of branch railways capable of superseding and rendering unnecessary the provision of common roads of secondary communication. The very low cost of inland carriage, principally due to the great cheapness of draft power during a considerable part of the year, tended in great measure to divert attention from the importance of good village and feeder roads in the earlier days of Indian railroads. From these and other causes the construction of such roads, serviceable throughout the year, has lamentably failed to keep pace with the wants of the railway system, and there still exists throughout the country, a large number of railway stations which are absolutely inaccessible to a loaded cart for five months in the year.

The true financial results of the large loan outlay incurred on irrigation canals in India, viewed as commercial undertakings, were for a long time the subject of some controversy, owing to the extreme difficulty of correctly assessing the total direct and indirect revenue brought about by the peculiarity of the conditions of land tenure in India, and by the virtual impossibility of apportioning the true share of the real indirect revenue between the canals and other causes—such, for instance, as the influence of improved road and railway communications. To a far greater extent than railways, all but the very smallest works of irrigation, or those constructed under some exceptionally favourable conditions, require to be in operation for a considerable period before a profitable direct return can be looked for. From this and other causes, the profit and loss in connection

with individual canals, or canal systems, throughout India varies enormously; some, such as those of Southern India, and the Jumna canals, for instance, owing to specially favourable circumstances, yielding an exceedingly high return, a few yielding a reasonable and even handsome return, and many as yet failing to pay their working expenses.¹ The net result of the whole system of canals in India, however, can be shown to be a fair and moderate return, after deducting working expenses, and the interest paid for the use of the capital borrowed for their construction. There appears, moreover, little reason to doubt that an absolutely true and complete adjustment of accounts between the land revenue and irrigation works, if such were possible, would be altogether favourable to the latter. The present direct return, probably with minor fluctuations, will undoubtedly for some time to come be an increasing quantity, whilst the influence of irrigation canals in famine protection, and in raising the general prosperity of the people within their sphere of action, is indisputable.

Their value in a country such as India must be regarded from several points of view. First, there is not only the complete immunity from famine over the large areas actually irrigated by those canals deriving their supply from permanent sources during years of drought, but at these seasons, the large surplus produce of the irrigated tracts is available to mitigate the severity of famine or scarcity over extensive areas outside them. Secondly, perennial irrigation canals, even in years of plentiful rainfall, are estimated to increase the food supply of the people in the case of rice cultivation, as much as 40 per cent. In the Madras Presidency the increase of produce due to irrigation is, according to crops, from four-fold to eight, and even ten-fold. In Northern India the rental of irrigated land is twice to three times that of unirrigated, and in Madras the proportion is much larger—up to twelve or fifteen times.

The only irrigation canals available for the prevention or extinction of famine, are those derived from the permanent rivers of the country. All other sources of supply, or of storage, ultimately dependent upon seasonable rainfall, will to a greater

¹ Vide *Irrigation Works of India*.—Buckley.

or less extent fail in times of greatest need. The number of perennial irrigation canals, therefore, as a means of direct famine prevention, is limited by the number of permanent river sources, and in many parts of India this limitation is exceedingly great. For the general purpose, however, of increasing the food supply of the people, the valuable influence of irrigation, from whatever source of water supply it may be derived, is enormous. Either the staple foods consumed by the people are raised in greatly enhanced quantities, or where such crops may not, or cannot be grown, other valuable and exchangeable products can be substituted, which without the aid of a plentiful supply of water could not possibly have been cultivated.¹ The utility of irrigation under both the above aspects is of course dependent upon a suitably connected system of communications, whether by road, navigable canal, or rail.

The outlay of borrowed money incurred on irrigation canals by the British Government in India, especially during the last thirty years, large as the absolute amount has been, is relatively small when compared with the wants of the country, so that within the limits assigned by the water supply of her rivers the future extension of irrigation works, and that even on a wider scale than anything hitherto attempted, must necessarily be very great, and the money thus expended will doubtless yield in the course of a certain time—whether the works are originally called ‘reproductive’ or simply ‘protective’—a substantial direct return; a return, however, which admits of but small consideration as compared with the benefits and prosperity in the meantime conferred on the country, and the relief and security which such works, in due connection with railways, afford both to the natives of India, and to the public revenues.

In the examples furnished in this volume of some of the chief town water-supply schemes carried out in India, a selection has been made of a certain number of such works, which, primarily of importance and interest in themselves, at the same time serve to illustrate special and particular *types* of construction. These examples are not to be regarded as intended in any degree to

¹ Vide *The Finances and Public Works of India*, by Sir John Strachey, G.C.S.I.

indicate, even approximately, the totality of such works, the extension of which all over India, especially during the last ten or fifteen years, has been far too great to admit of any attempt to enumerate, still less to illustrate them. The particular schemes chosen will be found to include all the main varieties of town water-supply projects, and will serve as illustrations of the numerous other works of this class, of which no special mention could necessarily be made.

Although there is an immense field open for private enterprise in India, in various branches of industrial operations, it is scarcely to be anticipated that the future will bring about any notable augmentation of such enterprise, so far as concerns the employment of European capital, independently of some form of State security. But that time will remove or greatly modify some of the causes hitherto unfavourable to a fuller employment of native capital in remunerative undertakings—such as the construction of a secondary system of railways, irrigation canals, or the development of mining and manufacturing industries, either directly or in conjunction with Government agency, is exceedingly probable.

That every possible facility and encouragement should be given to native private enterprise, no one keeping in view the best interests of the country can for a moment deny, in order that India may be enabled to assume a more independent position than heretofore, with regard to the provision and expenditure of that capital on which her material progress depends. Allowing to the full the unavoidable necessities of the past, the time has now arrived when it has become only too plainly one of the first necessities of India that she should retain for her own use, not merely the indirect benefits, but also the direct profits of all capital expended. Until, however, a more active spirit of industrial enterprise has arisen among the intelligent and wealthy classes of natives, the expensive assistance of European capitalists is in some degree inevitable, and the country must in corresponding degree submit to the loss of the greater part of the direct profits accruing from her public works.

In view of the low rates of interest prevailing for some years past, and the augmenting rates of profit earned in silver by the commercial railways of the country, there would appear to be

every prospect that the issue of rupee loans for railway extension purposes, would now meet with far greater success than heretofore among native investors, and would prove a valuable stimulus to the internal and foreign trade of India.

Some relief, however, has in the meantime been afforded by that utilisation of Government credit which has allowed the borrowing of money at low rates of interest, and has permitted the construction of numerous railways, irrigation canals, and other reproductive works by direct Government agency, and has thus secured such direct profits as may accrue from these works for the service of the country ; but the Government is burdened with many serious responsibilities in connection with defensive, protective, and other undertakings, from which little or no direct profit can be looked for, so that the net results in the shape of direct profits, from all Government works taken together, can hardly be otherwise than small.¹ The production of any large amount of hoarded native wealth for investment in remunerative public works would in a short time revolutionise the country, and raise it to a height of prosperity beyond present conception, nor is there any reason to doubt that such a production will in the course of time take place. Those who express surprise that the enormous hoards of potential wealth, either in specie or locked up by the natives of India in the form of jewellery, should not be more profitably utilised, forget that the very existence of these hoards is but the expression of that innate feeling of the insecurity of all possessions not susceptible of removal, which is the legacy left by the ancient forms of government. This feeling, engrained in the native character, the past experience of the race has tended to harden into a fixed and hereditary instinct. Already under years of settled government, less intense than formerly, this innate distrust must in the course of time grow more and more feeble, in proportion as, under a wise and judicious administration, the country is maintained in a condition of internal contentment and external security. Probably also it will gradually be more clearly perceived by the wealthy and cul-

¹ Vide *The Finances and Public Works of India 1869-1881*, by Sir John Strachey, G.C.S.I.

tivated classes of India that returns from capital employed in industrial operations, and in developing the resources of their own land, by means of public works permanently affixed to the soil, must, as their own power and share in shaping the destinies of the country, under the conditions of a growing civilisation, increases, tend to become more and more independent of minor contingencies. Under the stimulation of the growth of confidence, and of material progress, the effective desire of accumulation must steadily augment, and the high normal rate of interest will necessarily fall. It is probable therefore that a greater employment of native capital in remunerative public works is to be looked for in the near future, and that some notable proportion of that enormous amount of gold at present absorbed by the country, and devoted to the idle and unprofitable shape of concealed treasure and of ornament, will gradually be released and rendered available for both private and public benefit.

At the beginning of the year 1889 it was estimated that 'there was lying in India a stock of gold bullion wholly useless for commercial purposes, and increasing at the rate of nearly three millions annually, of the value of not less than £270,000,000 at the market, being probably two-and-a-half times as great as all the gold money in circulation in the United Kingdom.' One-half of this gold released, and put into a material form, represents the present equivalent of 14,000 miles of railway communication, yielding a probable direct return of nearly seven million pounds per annum. In the early part of the year 1892 the *Calcutta Englishman* stated that 'India still shows an unabated appetite for gold, which it continues to absorb in a wonderful way. During the last eight months the yellow metal, to the value of 356 lakhs—or £3,560,000—has been imported, and deducting the re-export of 70 lakhs, there remains 286 lakhs, or £2,860,000, which will probably go bodily as a permanent addition, mainly in the shape of jewellery, to the hoards of the country. The imports of silver amounted to 536 lakhs, and the exports to 116 lakhs, leaving a residuum of 420 lakhs.'

As yet there are but few signs that this passion for hoarding the precious metals is on the wane. It is noticeable, that the

more educated and anglicised portion of the natives of the country are less under its influence than others; something in this direction therefore has already resulted from the spread of education. Much can also be hoped from the raising of the general status and intelligence of the better classes of women. The movement in the direction of decreasing marriage expenses will also operate favourably, as well as the more extended facilities for the profitable investment of small sums of money by the Post Office and other savings banks, but the only real and important influence which will widely open the door of this treasury of hoarded wealth is the lowering of the rate of interest, in response to the growth of that settled confidence in the security of invested funds, intrusted beyond the immediate control of the owner, which lies at the root of all enterprise in any country, and the low degree of which in India is the still lingering and unhappy consequence of centuries of early oppression and spoliation. The action of this influence, operating as it has to do in the face of the inherent unenterprising spirit of an essentially agricultural country, and of climatic conditions unfavourable to the expansion of the highest energies of man, must, on the whole—although not of necessity locally—be very slow and gradual.

The Parsee community of the Bombay Presidency supplies an example of what may be done by an Eastern race in which the commercial and enterprising spirit has been freely developed under secure and liberal government. In the advanced Province of Bengal indications of a growing spirit of public enterprise have for many years been apparent, and every judicious and successful example of the remunerative employment of native capital, in works of public utility, whether in the form of railway construction, irrigation canals, mining industries, or in any other of the innumerable fields of industrial energy, will be a benefit not only to the enterprising projectors themselves, but also of incalculable service to the welfare and progress of India.

**GREAT INDIAN TRIGONOMETRICAL
SURVEY**

CHAPTER I

Meaning of the term 'Trigonometrical Survey'—Elementary example—Description of a small survey—Base line and signal stations—Base of verification—Plotting the triangles—Internal details—Network of triangles—'Gridiron' system—Well-conditioned triangles—Measurement of base lines—Method of enlarging a base—Description of Gridiron system—Recapitulation of methods of trigonometrical surveying.



POSSIBLY a few of the readers of this volume may have but a very faint idea of what is meant by a Trigonometrical Survey, others may have a general notion that it means some method of measuring the ground for the purpose of map-making; but as to how, and in what particular manner, a correct map of a country is made, they are more or less ignorant. All people, however, perfectly understand that to be of any

practical use a geographical map must be an accurate representation, on a small scale, of the exact shape of a country, and of its various divisions, and that all places marked on it must measure—by the scale attached to the map—the real and actual distances from any one point to every other, that is to say, every town, village, river, mountain, or boundary, must be placed in its true relative position the one to the other.

No one has any difficulty in seeing that distances can easily enough be measured on the ground—along a given line for instance, supposing there are no obstacles in the way—or similarly along any number of lines, but further than this most people, unless previously conversant with the methods of surveying, fail to perceive how all these measurements are to be *combined* and tied together on paper so as to form a correct

whole answering to the real form of the country, and within the most minute limits of error, exact in all its linear dimensions, measured in every possible direction.

Now, as it is our purpose to give an outline sketch of the operations of the 'Great Indian Trigonometrical Survey,' a few words of general explanation to the entirely uninitiated reader, which will enable him to understand in a general way what is meant by a Trigonometrical Survey, will, as a preliminary, be desirable.

First of all, then, the word 'Trigonometry' means *measurement of triangles*—from the Greek words *τρίγωνον*, a triangle, and *μέτρησις*, measurement (from *μέτρον*, a measure) so that a trigonometrical survey means a survey made by means of the measurement of triangles. In what way the '*measurement of triangles*' enables us to carry out a geographical survey will now be explained as simply as possible.

Let it be assumed that a reasonably correct plan or map of a small island is required, and that a survey party—which we are privileged to accompany—has been formed to execute the necessary field-work. Further, to eliminate all disturbing conditions, let it be assumed that the island has a generally plain surface, entirely free from forest growth, and from all objects offering impediments to a clear view in every direction. The survey party will be equipped with a few steel measuring chains, a good supply of poles and flags, and one or two highly refined and accurate instruments for measuring angles, called *theodolites*.

If the island is completely new and unknown ground to the party they will first of all explore it carefully, making what is called an 'ocular' survey—so as to gain a general idea of its main features, and of the position of its prominent points. Its approximate size will also be estimated by the length of time required to traverse it in one or two directions at a roughly known rate of travel. The next operation will be to select—probably somewhere along the flat, sandy shore—a fairly level and unencumbered surface, on which a long straight line can be measured. This line, which will form the initial base of the whole survey is called the '*base-line*.'

A suitable position for this important line having been found,

a number of flag-posts, or signal 'stations,' will be planted probably on, or near, the coast line, each placed on ground as elevated as possible, in order that it may be visible from at least two other stations. The position of these signal-stations will be selected with great care, and they will be arranged so that a series of lines running from one to the other will parcel off the whole island into several large triangular spaces, and the line which has been selected as a 'base' line will form a side of one of these triangular spaces. The position of the various signal-stations, which are to form the meeting-points of the lines enclosing the triangles, having been fixed, the party will proceed to measure the exact length of the 'base-line.'

Now the length of a 'base-line' requires to be measured with the most extreme attainable accuracy, because, if this line is wrongly measured, all the rest of the work based on it must be wrong with it; consequently a great deal of trouble is taken to ensure the accuracy of this measurement. Either the ground is levelled very carefully, or it is so arranged that the steel chain with which the measurement is about to be made, shall, when stretched very tight from point to point, be a true, straight, and level line. First of all the length of the measuring chain is checked with a 'standard' chain brought by the party to see if it exactly corresponds, and, if not, it is adjusted. The surveyors then proceed to measure carefully the length between the two flag-posts which have been planted to mark the extremities of the base-line. They are not satisfied with measuring this once, but they measure it several times over—first one way and then the other, repeatedly checking the length of the measuring chain with the 'standard' to see if it has stretched or altered at all under use. When they have obtained, a good many measurements taken backwards and forwards along the base line, it is found that, although very near each other, no two of the measurements agree quite exactly. The divergence, however, unless great, is of no consequence. All that it is necessary to do is to add all the various lengths together and then divide the sum by the number of times the measurement has been made, and thus a *mean* length is obtained, which will be sufficiently near to the true length to answer the purpose in view. To enable our readers to follow the progress

of the work, we here insert a rough sketch (Fig. 1) of what in the first instance is guessed to be the general shape of the island, and on this sketch we have marked the probable position of the flag-posts which have been planted near the coast. We have also inserted letters which indicate the angles of the various triangles that the surveyors propose to measure, and we have numbered the triangles themselves from 1 to 5. Having completed the measurement of the base-line, marked in the fig. *a-b*, a 'theodolite' or instrument for measuring angles

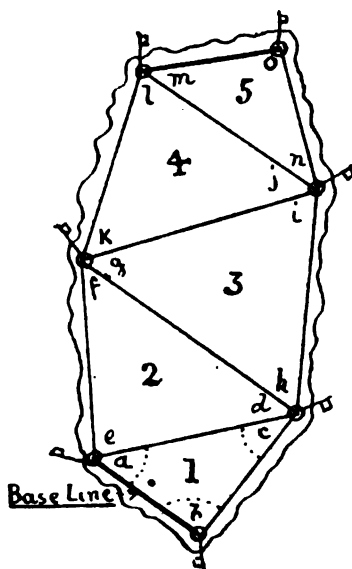


FIG. 1.

is set up at the point *a*, and the surveyor carefully measures the angle at *a*, sighting alternately the flag-posts at *b* and *c*. Having recorded this angle, the surveyor removes the instrument to the *b* end of the base-line, and in a similar way measures the angle *b*, sighting alternately the flag-posts *a* and *c*.

Of triangle No. 1, the length of one side, viz., the 'base-line,' which has been directly measured, is known, and the size of each of the angles *a* and *b*. Having this information, by a simple calculation the size of the distant angle at *c* can be discovered without actually measuring it with the theodolite, as also can

be the lengths of the two sides $a c$ and $b c$. These lengths, obtained by calculation, will, if the length of the base-line and the angles which have been measured are correct, be far more accurate than if they had been measured directly on the ground with the measuring chain. Knowing in this manner the length of the side $a c$ (which is also a side of No. 2 triangle) it can be treated as a new base-line, and after the angles at e and d have been measured, another calculation will give the size of the angle at f , and also the lengths of the sides $e f$ and $d f$. The surveyor can now treat $d f$ as another new base-line, and by its means, and by measuring the angles at h and g he can measure the third triangle. From the side $g i$ of this triangle, the length of which is obtained as before by calculation, he can measure the fourth triangle, then, proceeding in exactly the same way, he is able to measure the fifth and last triangle.

Now, in order to see if the work hitherto done is quite correct, one side of the last triangle, say $m o$, is very carefully measured with the steel chain, in precisely the same manner as the original base-line was measured. If it is found that the length $m o$ as given by calculation, and as found by direct measurement, agrees exactly or very very closely, the trigonometrical work is done, but if by calculation it works out altogether different from the measured length, then it is known that there is a great mistake in the work somewhere, and it will be necessary to do it all over again, until the mistake is discovered and corrected, and until the two measurements at last practically agree.

It will now be clear that, having the angles and the exact lengths of the sides of each of the five triangles, the surveyor can—to any scale he likes to select—draw, or what is called ‘plot’ these triangles on a sheet of paper, and it will be certain that their sides and the points where the flag-posts are erected will have their relative dimensions, and lie in their true relative positions, the one to the other. If care is now taken to mark in a permanent manner on the ground, the points occupied by the flag-posts, it will be possible at any subsequent time to complete the survey of the details of the island. The *triangles*, which have been correctly laid down on paper, will serve as a skeleton or framework for everything else required. For example,

it is desired to draw on paper the exact outline of the coast. All that it is necessary to do is to measure a sufficient number of what are called 'offsets' from the sides of the triangles nearest to the shore, thus supposing ef in Fig. 2 represents the precise length, to scale, of the side ef of No. 2 triangle, stations, situated opposite the chief points of irregularity in the shore-line are measured off on the ground along this line from the

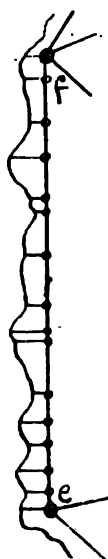


FIG. 2.

point e . From each one of these stations, and at right angles to the line ef , an 'offset' is measured to the shore. These measurements having been entered in a book, it is evident that the 'offsets' can be drawn or 'plotted' on the plan of triangulation, and by drawing a line through the outer ends of the 'offsets,' the exact outline of the coast between the points e and f will be produced. When it is desired to fill in and add to the plan the inland features of the island, the surveyor can, either by means of smaller triangles laid down inside the main ones, or by running any desired number of measured lines tied to the sides of these triangles, obtain lines, 'offsets' from which will give all the interior features with any degree of detail desired, or suitable to the scale on which it is proposed to draw the map. The important matter to notice is that every point of the detailed filling up will be in its correct place, because all will be tied and held

together in exact relative position, on and about the main lines of triangulation, which constitute, in fact, the skeleton on which the whole body of the map is moulded.

The above serves merely as an illustration of a simple framework, consisting of a single series of triangles grounded on and verified by two measured bases. The island that has been dealt with is in reality so small that a perfectly correct map of it could very likely have been obtained by a few simple direct measurements, without the necessity of any angular measurements at all.

When it is necessary, however, to provide a suitable skeleton or framework for the detailed survey of a very large continent,

island, or other surface, there are two methods usually employed, one is to spread in every direction by means of a *network* of triangles a series of fixed points, from and within which the topographical or detail surveyor can securely work ; the other, which for the most part has been employed in India, is to lay down a series of chains of triangles following, say, north and south lines, connected together by cross series of east and west chains, forming thus a sort of *gridiron* of chains of triangulation. The interior area of the triangles themselves, and also the areas of the interior spaces between the chains forming the gridiron, can then be readily surveyed in detail ; the areas to be filled in being brought down to manageable dimensions.

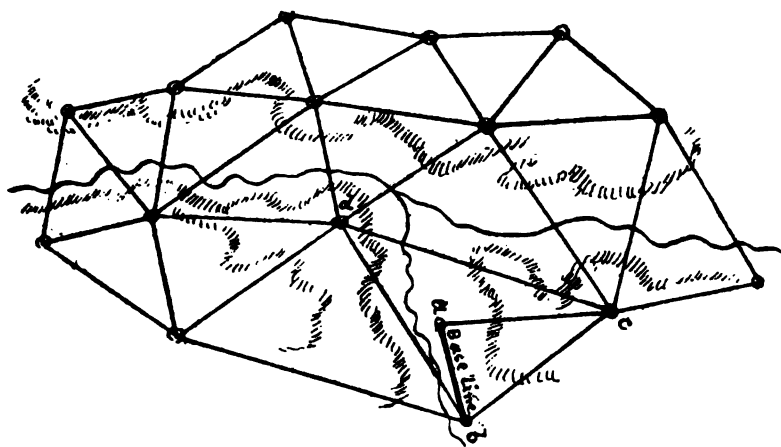


FIG. 3.—NETWORK SYSTEM.

In such a triangulation or rather ‘trigonometrical survey,’ the sides forming each of the main triangles may be as much as fifteen to thirty miles in length, so that the mere ranging and sighting of the distant points or stations will require not only the most perfect optical instruments but will often, from physical causes, present problems of extreme difficulty in practical solution. The measurement of the various base-lines of origination and verification—each probably many miles in length—will also involve the most extreme nicety of measurement.

In order to make quite clear the meaning of a *network* and of a *gridiron* system of trigonometrical survey, Fig. 3 is a repre-

sentation of a network system, and Fig. 4 of a gridiron system. In each, the little circles represent stations or observing points from which angles are measured, which, wherever possible, are fixed on the highest elevations.

Looking at Fig. 3 it will be seen that the triangles forming the network are all what is called 'well-conditioned,' that is to say, they have no very sharp or very wide angles. It is, in fact, a general rule in all trigonometrical triangulations that no angle shall be sharper than 30 degrees, or wider than a right angle or 90 degrees. The measured base-line $a b$ will be found

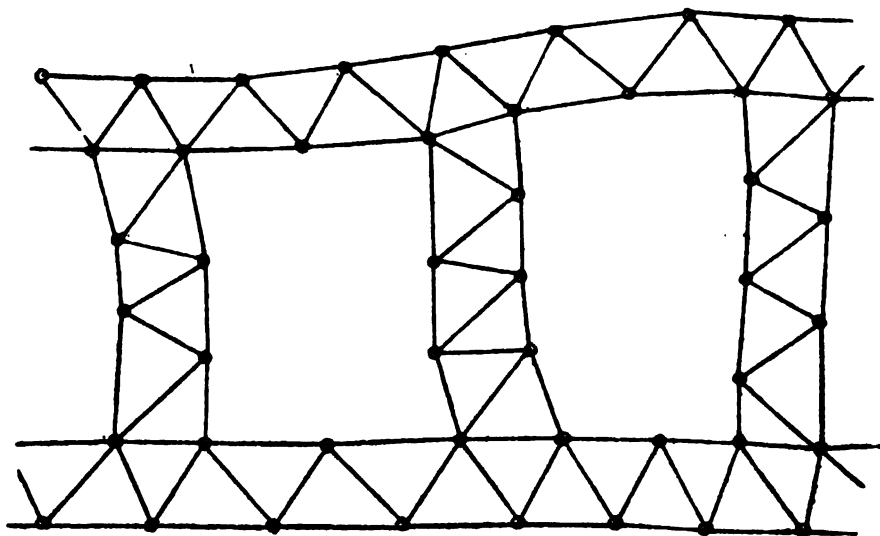


FIG. 4.—GRIDIRON SYSTEM.

marked on the lower right-hand corner of the sketch. As before explained, all trigonometrical operations in the first instance, start from some actually measured base-line, and it has been noted that the correct measurement of this base-line is a matter of the first importance, because from it the length of the sides of a whole series of triangles has to be computed, which computation will be all wrong if the base-line has not been correctly measured.

Although apparently a very easy matter, the exact measurement of a long base-line is in reality an exceedingly difficult

operation, and every expedient that ingenuity can devise has to be employed in order to obtain the necessary accuracy. It is desirable that the length of a base-line for a primary trigonometrical survey should be as great as possible, but circumstances seldom permit it to exceed more than seven or eight miles in length, because, in the first place, a fairly level and unencumbered surface has to be selected, so that each end of the base may be visible from the other end; and secondly, it is necessary that conveniently situated signal stations, suitable for laying out 'well-conditioned' triangles with the base-line, should also be clearly visible from both ends, and these conditions are only rarely to be found. Where only a short base is obtainable, there are, however, convenient ways of deriving from it, by means of a triangulation, much longer lines, say ten or twenty miles in length, from which a continuation of the triangulation can proceed. One such expedient is shown on sketch-plan, Fig. 3, of a network system. From the short base-line marked $a-b$ a triangle, a, b, c , is laid out, having its apex at the station c , and with an angle at this point not less than 30 degrees. Having calculated the length of the side $b-c$ of this triangle, another one, much larger, can be laid out from it as a base, having its apex at the station d . The length of the side $c-d$ can now be calculated, and in this line we have one considerably longer than the original base-line.

Some of the expedients employed in the measurement of base-lines will be described further on. For the present, turning to Fig. 4, we have a representation of a simple *gridiron* system of chains of triangles, such as has been adopted on the Indian Trigonometrical Survey. The country to be surveyed is traversed by a series of such chains of triangles, crossed by other chains, leaving relatively large spaces between them. This method of trigonometrical surveying is considered superior to the network system, because it is simple, contains fewer triangles, and these capable of more regular and systematic deduction, the one after the other, than is the case with a network. In practice, however, on a very large surface of country, the two systems are in reality combined, the main framework of the survey being the gridiron, whilst between the chains forming the gridiron, a secondary network of triangles, of gene-

rally smaller size than those which compose the chains, is filled in, this network being of course dependent on, and connected to, the sides of the primary triangles forming the chain. In course of time, under the operation of a detailed survey, the secondary network may be still further broken up into smaller and smaller triangles, or traversed with cross lines in every direction, each line being tied and bound into its proper relative position, as also will of necessity be the position of every geographical feature of the country, which is measured from, and fixed by means of offsets or other means, from one or other of these intermediate lines.

To recapitulate, it will now be clearly understood that trigonometrical surveying consists—First, in the selection of suitable sites for, and the accurate measurement of, base-lines for the origination and verification of either a complete network of triangles, or of long chains of triangles, across a given belt of country. Secondly, the selection of suitable intermediate points, such as prominent hill-tops, or specially selected or constructed lofty towers, for the meeting points of the lines, forming in each case ‘well-conditioned’ triangles. Thirdly, the fixing of the exact position of these intermediate points, by means of measured angles and calculated sides of triangles, starting from the measured base, and carried successively through the intermediate points, so as to form either a network or a chain of triangles. The accuracy of the intermediate computations is then verified by means of a measured base at the other extremity of the network or chain.

The trigonometrical survey of the entire country is completed either by covering the whole area to be surveyed with a network of triangles, or by carrying a sufficient number of ranges of triangles, longitudinally and laterally across the country, so as to form a sort of gridiron. The work is also further checked by means of astronomical observations for obtaining the exact latitude and longitude of numerous selected spots over the whole area. The principal triangulation is then handed over to detail surveyors, and all the interior spaces are filled up with a secondary triangulation, which may be again broken up into tertiary triangles, within which the detailed features of the country can be closely measured, and their positions accurately fixed, by means of ‘offsets,’ or in other various ways.

CHAPTER II

Early Geography of India—Major James Rennell's surveys in Bengal—Route maps—General atlas of India—Advantages of trigonometrical triangulation—William Lambton, father of Indian surveys—Proposes measurement of arc of meridian, and trigonometrical survey of southern portion of India—Objects in view—Proposals submitted to Madras Government—Lambton appointed to conduct operations—Instruments employed—Commencement of operations, 1802—Madras Observatory—Measurement of the first base-line—Correction for temperature—Triangulation carried to opposite coast—Inaccuracy of former route surveys—Origin of 'Great Arc Series'—Base at Bangalore—Injury to great 36-inch theodolite—Early opposition to survey operations—Demonstration of their utility—Recognition of Colonel Lambton's services—Great arc series carried to Beder—Captain Everest appointed chief assistant—Colonel Lambton extends arc series to Takal Khara—His illness and death—Summary of his great labours—Everest appointed his successor.

Less than 150 years ago the geography of the interior of India was very little known. At that time the only knowledge of the country was derived from the descriptions of the routes of occasional travellers into the interior, and from the rough charts of the coast lines made from time to time by English and foreign 'marine surveyors. About the year 1755 an English edition of a French map of India, compiled from such sources, was published. Shortly after this time, and up to the year 1782, Major James Rennell, an East India Company's officer, who was appointed Surveyor-General of Bengal, did much geographical work in that province. Major Rennell surveyed, by means of chain measurements, a tract 900 miles long by an average of 300 miles broad, taking observations for latitude and longitude at various points, and his map of the districts of Bengal and Bahar was published in 1781. From this time various route-maps of different parts of the country were from time to time obtained by special surveyors appointed to accompany armies in the field.

In Madras, the latitude and longitude of numerous points were astronomically fixed, the coast line was laid down for a distance of 700 miles, and upwards of 2000 miles of route measurements were made in the Carnatic during the war with Hyder Ali. From the material thus accumulated, a general atlas of India was nearly completed in 1787, but owing to the fragmentary nature of the surveys, and the numerous errors contained in them, little practically useful results were obtained. Further materials, however, slowly accumulated from numerous route surveys, and carefully computed astronomical observations, until the year 1798, when the results were sent to England for the purpose of framing a great map of India which, however, was never published, and much of the interesting and valuable data collected is said to have been lost in the destruction of old records which took place at the time of the abolition of the East India Company. These various route surveys, greatly inaccurate as they necessarily were, were at the time when the interior of India was almost unknown of great service for the use of armies on the march, but as the country was gradually brought under British administration, the want of good and accurate maps of the districts became more and more keenly felt. At the beginning of the present century the method of surveying a country by means of measured routes, and positions astronomically fixed, was more and more seen to be liable to serious errors, and it slowly began to be recognised that a trigonometrical triangulation was the only really secure basis for accurate map-making, although many experienced men brought up under the old system still believed in, and clung to, the earlier practice. Great improvements and refinements were introduced into the manufacture and accuracy of mathematical and optical instruments for astronomical and surveying purposes, and the results so far obtained in the progress of the trigonometrical survey of Great Britain, which was commenced in 1784, showed the many advantages of the trigonometrical system.

The magnificent undertaking known by the name of the 'Great Indian Trigonometrical Survey,' consisting of chains of triangles, which extend from Cape Comorin to the borders of Tibet, and from Afghanistan to Burma, was commenced about

the year 1800 by a man possessed of that indomitable ardour and perseverance of which heroes are made, a man whose name will always stand in the forefront of the great achievement he initiated, and whose death on the field of his labour, at the age of seventy, after twenty-three years of battling almost single-handed with the most formidable obstacles, in the midst of a terribly baneful climate, must always render his career memorable in the list of willing martyrs to science and to duty. William Lambton, who was an entirely self-taught man, was born in the year 1753. Very little is known of his early life except that he obtained a commission in the 33rd Regiment, and owing to his having acquired a knowledge of surveying, he was for some years employed as a land surveyor in America, where he devoted himself ardently to the study of the higher mathematics. In 1797, being then forty-four years of age, he rejoined his regiment, at that time in Calcutta, and shortly afterwards saw service in the war with Tippoo in Mysore. After the successful termination of that war, Captain Lambton brought forward a proposal for the measurement of a long arc of the meridian, that is, a long north and south line, and for a trigonometrical survey of the southern portion of India. Its object, to quote his own words, was 'to determine the exact positions of all the great objects that appeared best calculated to become permanent geographical marks, to be hereafter guides for facilitating a general survey of the peninsula.'

Lambton proposed laying out a network of triangulation from Madras across to the opposite coast, for the purpose of fixing the breadth of the peninsula on that parallel, at the same time making observations for obtaining the exact latitude and longitude of numerous important places. The accurate measurement of a long arc of the meridian, such as could be obtained in India, was a matter of the highest importance from a scientific point of view. By its means the true curvature of the earth could be obtained, and the astronomical tables used in navigation (which are affected by the shape of the globe) would be perfected, whilst the triangulation necessary for the measurement of the arc would serve as the principal axis of a system of triangulation to be extended over all India, on which a correct geographical map of the country could be built.

Captain (afterwards Colonel) Lambton's proposals were submitted to the Madras Government, and were warmly supported by the Marquis of Wellesley. The Governor of Madras was also favourably impressed by the advantages likely to accrue from the undertaking, and sanction to it was shortly afterwards accorded by the Government. Colonel Lambton, as a matter of course, was appointed to conduct the operations. Lieut. Warren of the 33rd Regiment, and Lieut. Kater, were appointed assistants. The chief instruments employed by Lambton were a 36-inch theodolite (a highly refined instrument for measuring angles with extreme accuracy), an 18-inch repeating Theodolite, both by Carey, and several smaller ones; an astronomical instrument called a 'zenith sector,' by Ramsden; two measuring chains of blistered steel, and a standard brass scale. The large theodolite was unluckily captured by the French on its way out from England, but it was afterwards chivalrously returned by the French Governor of Mauritius, with a complimentary letter to the Governor of Madras. The steel chains were 100 feet long, consisting of 40 links of $2\frac{1}{2}$ feet each, of excellent manufacture, in fact, the whole of the instruments were the most perfect that were at that time obtainable in England.

Operations commenced on the 10th April 1802, by the measurement of a base-line, something over $7\frac{1}{2}$ miles long, near St. Thomas Mount, Madras. The Madras observatory, then for some time in existence, thus became the starting-point of the Trigonometrical Survey of India. By means of a long and regular series of astronomical observations, the longitude of that observatory was more accurately known than any other point in the peninsula, and this longitude served—as it still does—as the local meridian, in place of the meridian at Greenwich, to which all the observations for longitude in the Indian surveys are ultimately referred.

In measuring his first base-line at Madras, Colonel Lambton used a chain similar to that employed by the English Ordnance Surveyors. The chain was supported in five wooden boxes, each 20 feet long, which were carried on tripods, fitted with elevating screws, the whole being adjusted to exact line by means of a telescope. At one end the chain was secured to a 'draw-post,' with provision for adjustment by means of a fine

screw-movement. Near the handle was a brass scale, with minute divisions, fixed on the head of a separate post. This scale, by means of an adjusting screw, could be moved backwards or forwards until it exactly coincided, under a magnifying glass, with a dot or mark on the chain, from which its measuring length commenced. At the other end of the chain was a similar arrangement, but the handle here instead of being fixed to a 'draw-post' had a rope passing over a pulley, to which rope a 28-lbs. weight was attached, to keep the chain tightly stretched. Thus the two ends of the measuring length of the chain could be accurately brought into position. This done, it was moved forwards, and a new length measured, and so on, until the base was finished. The temperature of the chain was determined by means of thermometers placed inside the boxes, and the rate of expansion having been fixed by previous experiments, the necessary corrections could be made. This correction in all amounted to $\cdot 00725$ inch for every degree of Fahrenheit. All measurements made with the steel chain were reduced to that of a standard chain, whose length had been fixed at a temperature of 50 degrees. The measurement of the Madras base occupied forty-two days, when observation was taken to determine the angle formed by the base with a meridional, or true north and south line.

It may be mentioned here, that although the above method of measuring a base-line was employed in several cases in the earlier stages of the survey, it was subsequently superseded by a greatly improved system, to be explained further on, and all the important base-lines measured with the steel chain, were afterwards re-measured with the improved apparatus.

After some time spent in experimental trials in the neighbourhood of Madras, Lambton and his staff carried a series of triangles inland from the Madras base, in a westerly direction, to a point situated near Bangalore (see Map of the Triangulation). Here in May 1804 a base of verification was measured. The distance was 160 miles, and the measured and calculated length of the new base was found to differ by $3\frac{1}{4}$ inches only. From the Bangalore base-line triangles were then laid out across the remaining width of the Peninsula, to the west coast near Mangalore. The complete distance across from Madras

to the Malabar coast was found to be 360 miles, or 40 miles less than had hitherto been given by the best maps. The inaccurate results obtained by the earlier methods of survey was thus demonstrated.

The base-line measured on the Mysore plateau at Bangalore, was adopted as the origin of the long meridional series of triangles which was ultimately (not, however, before the year 1837) carried up from Cape Comorin to the foot of the Himalayan mountains. This immense range of triangles, 1540 miles in length, is named the 'Great Arc Series.' At the time it was completed it was—and it is believed that it still is—the longest arc measured on the earth's surface. Starting from the Bangalore base, the 'great arc' triangulation was first gradually carried down to a point near Cape Comorin, where a base of verification was measured, then in the year 1811 Colonel Lambton commenced its northward extension from Bangalore.

During these early years of the survey the operations were constantly interrupted by the disturbed political condition of the country, which was not completely pacified until the year 1818, as well as by the jealousy and apprehensions excited in the minds of the people at the sight of the mysterious proceedings of the surveyors, with their strange and uncanny looking instruments perched successively on almost every hill-top, and their long array of flag-posts and signals which seemed to pervade the country. Whatever may have been the exact nature of the opinions or fears thus aroused, it is evident that much patience, firmness, and tact, were requisite on the part of the officers of the survey in order to avert danger, allay suspicion, and conciliate goodwill. Additional obstacles to progress were also imposed by the untrained condition and inexperience of the subordinate staff, and by the constant sickness of the field-parties exposed to a highly malarious climate. The stay of the two officers appointed as assistants, was too of but short duration. The services of Lieut. Warren were before long required elsewhere, and Lieut. Kater's failing health soon obliged him to quit the service. Thus the chief of the survey was often compelled to work nearly single-handed, and he had to turn his time and attention to many harassing details. It

is recorded that on one occasion when the great 36-inch theodolite—the mainstay of the operations—was being hoisted to the top of a lofty pagoda tower, the tackle broke, and the instrument was seriously injured; the main limb having been completely bent out of shape. Such an accident, occurring at a time when no experienced artificers accustomed to the repair of such delicate instruments were to be found in India, was a severe blow. Colonel Lambton, however, was not disheartened. He carried the broken theodolite to Bangalore, and by his personal labour, assisted by some workmen from the Artillery establishment, after six weeks' delay he succeeded in completely repairing the injuries, and the instrument was made as good as ever, continuing in use up to the year 1830.

The work on the southern portion of the 'great arc series' is far from representing the full extent of Colonel Lambton's labours at this period. By the year 1815 he had covered the greater part of the country between Madras, Bangalore, and the Godavery river with a network of triangulation, fixing the position of all the more important points extended over this area, and carrying out simultaneously an immense number of astronomical observations. He was, moreover, harassed by frequent opposition from the highest quarters, calling in question the fundamental utility of his operations, it being still maintained that the old system, based on route surveys, and astronomically fixed positions was equally accurate, and more economical. He was also kept ill-supplied with money by the financial authorities at Madras. It was only after long and tedious argument and correspondence that he at last successfully refuted his opponents, patiently demonstrating the many serious errors in the position of numerous places, as fixed astronomically on the old maps. Not only was the breadth of the Peninsula on the Madras line forty miles wrong, as previously stated, but the position of Arcot was shown to be ten miles out of place, and Hyderabad no less than eleven minutes in latitude, and thirteen minutes in longitude. It was not until the year 1818 that he at last succeeded in completely vindicating the utility, and demonstrating the extreme importance of the labours on which he was engaged, and this only after their value had been fully recognised and appreciated

by numerous scientific bodies in Europe. In 1817 he was made corresponding member of the French Institute, and in the following year was elected a Fellow of the Royal Society.

In the meantime the 'great arc series' of triangulation (all work on which was conducted with special care and accuracy) had been pushed northwards to Beder, in latitude 18° north, where a new base line was measured. Colonel Lambton, now at the age of 65, had greatly broken down in health and physical energy, and Captain Everest, afterwards his able successor, was appointed as chief assistant. Owing to the disturbed condition of the provinces of Central India at that time the 'great arc' work was temporally suspended, and Everest was employed in completing the network of triangulation to the southward, where in 1820 he was disabled by fever, and had to proceed to the Cape of Good Hope for the recovery of his health. Colonel Lambton, much broken in health as he also was, then proceeded with the 'Great Arc Series,' extending it up to Takal Khera in latitude $21^{\circ} 6'$. More and more prostrate by disease and infirmities of age whilst vainly attempting to measure a base-line at Takal Khera, he exposed himself so unduly to the severe tasks imposed upon him by the sickness and prostration of nearly all his party that he completely broke down. Soon afterwards setting out from Hyderabad to Nagpore—still in prosecution of his work—he died on the road at Hingunghat, now a large cotton centre in the Central Provinces, on the 20th January 1823. A modest tomb, consisting of a pillar surrounded by a walled enclosure, was afterwards erected over his remains by the Resident at Nagpore, on the bare ridge not far from the spot where the water-works reservoir now stands.

Thus died in harness, at the age of 70 years, the worn-out 'Father of the Indian Survey'—like many of his humble followers, a faithful martyr of devotion to the public service. His last great work comprised a triangulation aggregating 165,342 square miles of the Peninsula of India, at a total cost of £83,537, or an average and moderate outlay of about 10s. per square mile. About the year 1820 Colonel Lambton in a report on the survey operations writes, 'In the twenty years devoted to this work I have scarcely experienced a heavy hour,

such is the case when the human mind is absorbed in pursuits that call its powers into action. A man so engaged, his time passes on insensibly, and if his efforts are successful his reward is great, and a retrospect of his labours will afford him endless gratification. If such should be my lot I shall close my career with heartfelt satisfaction, and look back with increasing delight on the years I have passed in India ;' and again in his last report he says, 'It would indeed be gratifying to me if I could but entertain a distant hope that a work which I began should at some future day be extended over British India. I sincerely hope that after I relinquish the work somebody will be found possessing zeal, constitution, and attainments, wherewith to prosecute it.'

This hope was amply realised in the person of Captain, afterwards Colonel, Everest, who was shortly afterwards appointed his successor.

CHAPTER III

Continuation of Great Arc Series to Sironj—Ill-health of Superintendent—Absence for five years—Calcutta Longitudinal Series—Useful work of Everest in England—Colonel Colby's compensation bars—Description of apparatus—Return of Colonel Everest to India, 1830—Measurement of Base of verification at Calcutta—Northward extension of Great Arc Series—Erection of permanent towers—Site for northern base of Arc Series—Connection of base with Sironj—Re-measurements and revisions—Results—Observatories—Completion of Great Arc Series—Bombay Longitudinal Series—Retirement of Colonel Everest—His substitution of a Gridiron for Network System—North and South ranges of chains one degree apart—Modification—Calcutta Meridional Series—North-Eastern or Himalayan Series—Deadly tracts of the Terai—Loss of life and health—Base of verification at Sonakoda—Himalayan Peaks—Mount Everest—East Coast Series—Difficulties—South Kankan Series—North-Western Quadrilateral—Prolongation of Calcutta Longitudinal Series to Karachi.

CAPTAIN EVEREST whilst on sick leave at the Cape of Good Hope, had opportunities of studying the Abbé de la Caille's arc measurement, and he contributed a valuable paper on the subject to the Astronomical Society. On his return to India he was engaged at the time of Colonel Lambton's death, in laying out a series of primary triangles, intended to extend from the Beder base-line to Bombay. In consequence of the death of his chief, he succeeded to the office of Superintendent of the Survey, having been for five years chief assistant. Captain Everest at once transferred his attention to the continuation of the 'great arc series.' After many difficulties consequent on defective staff, sickness, and the nature of the country, he carried on the triangulation from Takal Khera to latitude 24° North, where, in the year 1824, a base-line was measured with the old chain at Sironj (situated about seventy miles south of Bhopal), near which place a lengthy series of astronomical observations was also undertaken.

The health of the new superintendent, however, again broke

down, and he was obliged to go to England in 1825 to recruit, remaining absent from India for about five years. He still, however, retained his appointment, there being no person then competent to succeed him in so important a post. It was not, however, necessary that field work should be suspended, there being by this time many able and experienced assistants on the survey establishment. A party was therefore organised to carry on during Captain Everest's absence, and in accordance with his written instructions, a long chain of triangles, to extend from the Sironj base-line to Calcutta, a distance of nearly 700 miles, over a wild and unhealthy tract of hilly country, the survey embracing an area of over 33,000 square miles. This chain of east and west triangulation was named the 'Calcutta longitudinal series,' and it was carried on in the face of severe obstacles and difficulties, at an average rate of about 112 miles per year, so that when Captain Everest returned to India in 1830, the greater part of the distance had been covered. It was not, however, until the year 1832 that the series was finally closed on to a measured base at Calcutta.

Captain Everest, during his long stay in England, had usefully employed his time in investigating the latest improvements in the manufacture of all classes of instruments and apparatus used in survey operations, and in studying the English Ordnance Survey system. By the liberality of the Honourable Court of Directors of the East India Company, he was able, before his return to India, to provide himself with a full and complete equipment of the most improved and perfect apparatus existent at that time. One of the most important of these improvements was a new device for the measurement of base-lines, which had been already employed on the Ordnance Survey in England, and which was the invention of Colonel Colby of the Irish Survey.

The principal source of error entailed by the use of the old steel chain method of measurement, was the practical impossibility of arriving at the true correction for alterations in the length of the chain due to changes of temperature whilst in use. Colonel Colby's invention obviated this difficulty by making the measure itself self-correcting for temperature. Bars, each 10 feet long, were used instead of chains, each bar being com-

posite,—that is, made up of two strips, one of iron and one of brass, laid one upon the other, and firmly joined together in the middle, so that movements of expansion and contraction would take place evenly at the two extremities.

At a temperature of 62° , the two component metals are of the same length, but owing to the greater expansion of brass as compared with iron, under the influence of heat, at all other temperatures the extreme length of one strip exceeds that of its fellow. Accordingly at the two ends of each brass and iron strip there are projecting pivots, adjusted to a flat movable tongue or lever, which tongue becomes inclined inwards or outwards in proportion as the length of the strips vary. It will thus be seen that there are points on the movable tongues at either end—outside the pivot—which will be the central points around which the movement takes place, and which will be always equidistant from each other. These equidistant points are each marked with a dot; the distance apart of the dots being fixed at exactly 10 feet. The bars are mounted on brass rollers, and are enclosed in long wooden coffers, or boxes, from the ends of which the tongues only project.

Provided with six sets of Colby's compensation bars, and a full supply of every description of improved instrument and apparatus, which the most skilful artificers of the day could produce, Colonel Everest reached India in 1830, having in the meantime been appointed by the Court of Directors 'Surveyor-General of India' in addition to his duties as Superintendent of the Trigonometrical Survey.

On his arrival he determined to measure the base of verification for the 'Calcutta longitudinal series,' with the new measuring bars. A line $6\frac{1}{2}$ miles in length was laid out along the road from Government House, Calcutta, to Barrackpore, at the ends of which two towers, each 75 feet high, were constructed. This base, the first measured in India with the improved apparatus, was measured at the end of the year 1831 and beginning of the year 1832. About the middle of the same year the triangulation of the 'Calcutta longitudinal series,' which had thus occupied over six years, was closed in upon it.

Owing to the defective state of the instruments employed, and other causes, the work on this series was not considered to

be of the first order, and subsequently much of it was again gone over. For a period of about seven years work on the 'great arc series' had thus been entirely suspended, but from this time it was resumed and carried on unremittingly, until this great chain of triangulation, extending from Cape Comorin to the Himalayas, and forming the main axis of the Trigonometrical Survey of India, was finally completed.

Up to the Sironj base the surveyors had worked over a general hilly or undulating country abounding in elevations, affording excellent sites for observing stations, but for a great portion of the distance northward of the Sironj base the work had to be carried over extensive low-lying plains, thickly interspersed with groves of lofty trees, often interposing dense and impenetrable obstacles to the view, whilst the clouds of dust so common during the dry season in the Gangetic valley, rendered the instrumental work exceptionally difficult. Much of the work had to be done at intervals during the unhealthy rainy season, so as to have the advantage of a clearer atmosphere, but this occasioned much loss of health and life to the survey parties. In order to gain the necessary elevation above the plains numerous permanent towers had to be constructed, and great preliminary labour was entailed, not only in the building, but in fixing the position of these towers. So great was their distance apart, that special and complicated signalling arrangements, both for day and for night signalling, had to be devised and elaborated. The towers, of which there were seventeen in all, were 50 feet high, with walls 5 feet thick at the base and 2 feet at the top: they were provided with a stage and awning for the observer, kept detached from the central stone platform on which the instrument rested, so as to avoid vibration.

In the meantime a site was required for the northern base and terminal point of the 'great arc series.' The position finally chosen was in latitude $29^{\circ} 30'$, in the midst of the beautiful Dehra Doon Valley, between the lower Sewalik range of hills and the Himalayas, at a part of it situated about 2000 feet above the level of the sea. The base was most carefully measured with the Colby apparatus during the cold season of 1834-35, its length being 7.42 miles. It was then transferred by means of triangulation to certain peaks of the Sewalik range,

visible both from the measured line and from the valley of the Ganges.

By the early part of the year 1837 the Dehra Doon base-line was connected with the triangles brought up from Sironj ; but Colonel Everest did not consider the results altogether satisfactory. The Sironj base had been measured in 1824 by the old steel chain method, and it was now determined to re-measure it with the compensation bars. This was done during the cold season of the year 1837-38, and its length was found to be too short by nearly 3 feet. In 1838 a party was sent to revise all the angles southward of Sironj as far as Beder, a distance of 260 miles, with the new and improved instruments brought out from England by Colonel Everest. This work was completed by the year 1839. On the first connection of the old Sironj and the new Dehra Doon bases, the difference of the measured and computed lengths amounted to nearly $3\frac{1}{2}$ feet. In the earlier days of the survey this would have been considered a sufficiently satisfactory agreement, seeing that the length of the base is nearly $7\frac{1}{2}$ miles, and the distance between the two bases upwards of 400 miles. After the re-measurement, however, of the Sironj base with the same apparatus as used at Dehra Doon, the difference between the length of the latter base, as measured, and as computed through the triangulation brought up from Sironj, amounted to 7·2 *inches* only, a degree of accuracy showing the great exactness of the instruments now employed, and the skill with which the work had been carried on.

In 1841 the old base-line, nearly 8 miles in length at Beder, was also re-measured, and the difference in length as now found, and as found by computation from the Sironj base, was 4·296 inches. Two observatories were established, one at Kaliana, near the Sewalik range of hills, and the other at Kalianpur, near Sironj, both on the same meridian. The difference of latitude between these observatories was exactly fixed by the—as nearly as possible—simultaneous observation of 36 stars, half of them to the northward and the other half to the southward of the zenith of both stations. In a similar manner the exact latitude of a point on the same meridian near the Beder base-line was fixed.

Thus, in the year 1841, nearly forty years after it was com-

menced, were brought to conclusion the operations on the great central meridional arc of the Indian survey, an arc of the earth's surface 1540 miles long, and comprising an area of triangulation of nearly 57,000 square miles (including the revision of the section from Beder to Sironj). At this date the length between Cape Comorin and the Beder base line was founded on Colonel Lambton's early work, done with instrumental appliances far less perfect than that with which the more northern portion of the 'great arc series' had been executed. Some twenty-five years later, the old bases at Bangalore, and at Cape Comorin—or rather other bases on ground selected near them—were measured with the Colby apparatus, and the whole of Colonel Lambton's southern portion of the arc series underwent careful revision.

In the year 1841 the longitudinal series, starting from the Beder base towards Bombay, which had been commenced in 1822 by Colonel Everest, before Colonel Lambton's death, and which had been interrupted, was also completed. The chain extends a distance of 315 miles to Bombay, having an area of triangulation of 15,198 square miles.

We do not propose to follow in detail—or in order of time—the execution of the various meridional and longitudinal ranges of triangles laid down by the Indian Trigonometrical Survey. We will confine ourselves to the main framework only, which will be briefly indicated. Colonel Everest, in consequence of severe illness, was compelled to retire from his arduous duties in 1843, and five years before his death, which occurred in 1866, he received the order of knighthood. In laying down his original programme for the future operations of the Trigonometrical Survey, he abandoned the old network system employed by Colonel Lambton in Southern India, and substituted the 'gridiron' system. He proposed to lay down a number of 'meridional arcs,' or north and south chains of triangles, at close intervals, to be connected by comparatively few cross or longitudinal chains, thus forming sections somewhat resembling a gridiron in shape. It had been originally intended that the north and south ranges of triangulation should be placed at about 1 degree apart, and in that portion of the survey which is called the 'North-east quadrilateral,' or that portion lying

between the 'Calcutta longitudinal series' and the Himalayas, north and south chains about this distance apart have in fact been laid down (see Map of the Triangulation); but in the other main divisions of the survey it has been found unnecessary for topographical and detail purposes to range them so closely together.

Shortly after Colonel Everest's departure from India, the 'Calcutta meridional series,' starting from the base measured at Calcutta in 1832, was carried northwards for a length of 260 miles, over a flat and marshy country, necessitating the building of towers for every observing station, to Sonakoda, near the foot of the Darjeeling mountains. This series, comprising an area of 4136 square miles, forms the eastern boundary of the 'North-east quadrilateral,' and it was completed in the year 1848. The North-eastern or 'Himalayan' series, forming the northern boundary of the same quadrilateral, extends from Dehra Doon to the Sonakoda base, along the foot of the hills, over a distance of 690 miles.

The work on it was executed by different parties, at various times, and its execution was attended with greater dangers and difficulties than had been experienced on any other part of the survey. The operations had to be carried on over one of the most deadly tracts of swamp and jungle in the world, or that forming the renowned 'Terai,' lying along the foot of the Himalayan range. Of the five officers who were engaged upon it, two died from fever, and two were forced to retire utterly broken down in constitution, and it is stated that in one season the lives of no less than forty native employées were sacrificed.

In the year 1847-48 a base-line was measured at Sonakoda for the verification, both of the 'Calcutta meridional' and of the 'North-eastern Himalayan' series, the base serving also as a point of departure for the future prolongation of the work in the direction of Assam. It was measured with the Colby apparatus, and was also proved by a minor triangulation laid off from its side, with satisfactory results.

The 'North-eastern Himalayan series' connects the northern ends, and verifies the series of meridional chains, nearly one degree apart, which at different times were carried up from the 'Calcutta longitudinal series,' and it also completes the

outer framework of Colonel Everest's North-eastern gridiron, or quadrilateral.

From this series a number of observations to determine the distance and altitude of most of the great snow-clad peaks of the Himalayas, including some of the loftiest mountains in the world, were undertaken. Amongst these was one since named 'Mount Everest,' after the late chief of the survey, 29,002 feet above the sea.

In the year 1845 the long 'East coast series,' starting from the Calcutta base, and skirting the coast as far as Madras, was commenced. Progress on it was very slow, and the work was frequently interrupted, especially in the low-lying and difficult tracts between Calcutta and Balasore. Here during the cold season fogs are frequent, and in the spring and hot season the district is the playground of furious cyclones and hurricanes, often causing the most frightful devastation. In one season the tent equipage of the survey party was completely annihilated. The country, for the most part covered with dense vegetation, and low marsh lands, cut up by deep sea creeks, opposed constant obstacles to the progress of the survey. In addition to these physical difficulties, the extreme unhealthiness of the tract was such, that every season the whole party was more or less decimated, broken up, and compelled to suspend operations. The 'South Konkan series,' commencing at Bombay and extending southwards along the West coast, had been taken up after the completion of the 'Bombay longitudinal series,' and was carried down to the neighbourhood of Gôa, in latitude 16°. In 1847-48, two important series were commenced, which were to form the northern and southern sides of the 'great North-west quadrilateral.' One of these was to extend from the Dehra Doon base along the foot of the hills to Peshawur, the other was a prolongation in a westerly direction of the 'Calcutta longitudinal series' from Sironj to Karachi, to be called the 'Western longitudinal series,' making one great cross line of triangulation from Calcutta to Karachi, and intersecting at right angles the 'great meridional arc' series at Sironj.

CHAPTER IV

Review of progress by Superintendent of Survey—Area and Cost—Duties of officers, and rate of working—Trigonometrical triangulation the permanent basis for present and future surveys—North-Western Quadrilateral—North-Western Himalayan series—Western longitudinal series—The 'Thur,' or desert of Guzerat—Terminal bases at Attock and Karachi—Indus Valley series—Base at Vizagapatam—Accuracy of survey operations—Extension of East Coast Series—Joining in at Madras—Interior connecting series of chains—Completion of main system of triangulation—Topographical and detailed surveys—Number and position of measured bases—Subsidiary operations—Trigonometrical levelling—Levelling with spirit level and staves—Indus valley line of levels—Extreme care and accuracy—Levelling extended to Calcutta—Various connections with coast—Tidal gauges—Size and figure of the earth—Early Greek measurements—Mohammedan attempts—French arc-measurements—Pendulum operations—Manner of registering number of vibrations—Conclusion.

THE superintendent of the survey reviewing its progress from the commencement in 1802 by Colonel Lambton, up to the year 1848 says, 'The grand total area triangulated amounts to 477,044 square miles, and the grand total cost to Rs.34,12,787 or say £312,389, showing an average cost of Rs.7. 2. 5. per square mile, or about 13s. 1d., which cannot but be considered remarkably moderate, especially when the nature of the country and the climate, as well as the absence of all the usual resources to be found in Europe, are taken into account. The hardships and exposure of surveyors working in the field for the greater part of the year in such a climate as India are either little known or little appreciated.' . . . 'The duties of the Trigonometrical Survey are often unremitting day and night, because the best observations are obtained during the nocturnal hours, when the dust raised by the hot wind subsides, and the atmosphere becomes clear and calm. With regard to the rate of progress, much depends on the efficiency of the officers, and on the accidents of the climate. In a hilly country the average advance made per season by each party is about 120 miles in length by 30 in

breadth, or say 3600 square miles. In a flat country the average is 80 miles in length by 12 in breadth, or about 1000 square miles.' And summing up his review he says, 'The triangulation supplies a permanent and accurate basis for the present as well as for the future internal surveys, for it must be borne in mind that as the resources of the country become developed under the fostering protection of British rule, the topographical aspect of many districts must in a moderate number of years be completely changed. Tracts now covered with jungle will be reclaimed. Canals will be dug, marshes drained, and roads established. New towns and villages will arise, fresh groves be planted, and rivers will change their course. That these views are not chimerical may be attested by experience, for places where the tiger, the bear, and the boar were formerly hunted are now covered with fields yielding a plentiful harvest to the cultivator. The greatest difference is also perceptible in the extension of towns and villages, showing the increase of productive wealth which is taking place on all sides. This alteration cannot but produce in the course of time considerable changes in the topographical features of the country, for which reason revised surveys will be required, and these, like the present ones, will be based on the operations of the great trigonometrical system of India, which are intended to form a lasting monument for future generations, and an imperishable record of the landmarks of the present time.'

The programme to be carried out on the North-western side of the 'great arc' was the formation of a great framework for a gridiron to be called the 'North-west quadrilateral' with measured bases at each of its four corners. Just as the 'North-east' quadrilateral has its four measured bases, viz., at Sironj, Dehra Doon, Sonakoda, and Calcutta, so that on the North-West would be dependent on four measured bases of origin and verification at Sironj, Dehra Doon, Attock, and Karachi. The four sides of the new quadrilateral are bounded: On the east by the portion of the 'great arc series' lying between Sironj and Dehra Doon; on the south by the 'Western longitudinal series;' on the north by the 'North-western Himalayan series;' and on the west by a long chain carried up the valley of the Indus from Karachi to Attock.

The 'North-western Himalayan series' from Dehra Doon to Attock was completed in the year 1853. Its length is 416 miles and it comprises 33,000 square miles of very hilly country. It had been commenced in 1847, but its progress was interrupted by disturbed political conditions. The 'Western longitudinal series' extending from the Sironj base to Karachi, was commenced in 1848, and the triangulation reached Karachi at the end of the year 1852, after five seasons of extremely arduous labour. The length of this side of the great quadrilateral is 668 miles, covering an area of 20,323 square miles. A portion of the survey crosses the 'Thur' or desert country north of Guzerat, and its execution entailed much skilful arrangement and forethought for the due provision of supplies and water to the working parties, numbering about 200 persons.

As soon as these two great series were approaching completion it was necessary to measure the terminal bases at Karachi and Attock. A suitable site for the latter was chosen in the 'Chuch' Doab, near Attock, on the east side of the Indus. The valley of Peshawur had at first been proposed as the most appropriate position for this base, but the idea had to be abandoned owing to the disturbed state of the valley at that time, in consequence of the frequent incursions of lawless tribes along the frontier. Attock thus became the upper corner of the North-west quadrilateral and a branch triangulation was subsequently carried to the frontier at Peshawur.

After the measurement of the Attock base the apparatus was sent down to Karachi, and the base-line at that place was carefully measured. The remaining side of the great North-west quadrilateral was to be formed by a long range of triangles extending along the Indus valley from Karachi to Attock. This work was started from both ends of the line, but before it was completed the Sepoy mutiny of 1857 broke out, and work on it was suspended until 1858. It was finally completed in the cold season of the year 1860-61.

In 1862 a base-line $6\frac{1}{2}$ miles long was measured at Vizagapatam, a point on the 'East Coast series,' nearly in the same latitude as Bombay. This base was to serve for the verification of that part of the east coast triangulation lying between Calcutta and Vizagapatam, which had now been completed, and

also for the prolongation from the Beder base of the 'Bombay longitudinal series,' thus completing a range of triangles extending across the Peninsula from coast to coast. At the Vizagapatam base the difference in length, as measured with the compensation bars, and as computed through the triangulation brought down from Calcutta, 480 miles away, was a quarter of an inch only. This great accuracy indicates to what an extreme state of precision all the operations of the Survey had now been brought.

In 1864 the extension of the 'East Coast series' from Vizagapatam to Madras was completed. Thus after an interval of sixty-two years the triangulation which had been started by Colonel Lambton from a base-line at Madras was again brought back to that point, having in the meantime made the long circuit *via* Bangalore, Sironj, Calcutta, and the East Coast. During the course of execution of the main framework of the triangulation now sketched, nearly all the interior connecting series of meridional and longitudinal chains forming the principal gridirons, were at the same time being carried on, and at the period to which we have now arrived the larger portion of the main triangulation was accomplished, although it was not until about the year 1883 that the whole system of chains as shown on the accompanying map was complete. Since that period the principal operations have extended eastwards into Burma, and westwards to the borders of Baluchistan and Afghanistan.

The long arms of the all-embracing triangle have also penetrated on every side into the otherwise impenetrable heart of the great mountain ranges which separate Hindustan from the rest of Asia, and have measured the distances apart of their various chains, and the heights of their lofty inaccessible peaks. During the progress of the Great Trigonometrical Survey of India, of which we have given the very briefest possible outline, the greater part of the topographical and detailed surveys of the interior—on account of which the triangulation was specially undertaken—have *pari passu* been carried on. The many thousands of aerial triangles which we have depicted reaching from hill-top to hill-top, or from tower to tower, stretching in systematic chains across the country from south

to north, and from east to west—making those gigantic ‘grid-irons’ of which we have been speaking—form the permanent framework, or skeleton of the real survey. On this framework every detail and every physical feature of the interior topography of the country is—and will under all subsequent changes continue to be—supported, and by it are tied together on our maps in their true relative positions.

The whole trigonometrical system of triangulation in India now rests on ten measured base-lines, all of which have been measured by the bars, self-compensating for temperature. These bases in order are as follows: On the ‘great arc,’ Cape Comorin, Bangalore, Beder, Sironj, and Dehra Doon. At the eastern extremity of the North-East quadrilateral, Calcutta and Sonakoda. At the western extremity of the North-West quadrilateral, Attock and Karachi, with Vizagapatam on the East coast series. For purposes of symmetry an additional base at Bombay would appear to be wanted, but for the practical purposes of the topographical survey it has not been deemed necessary. Another base-line at Mergui, in Tenasserim, has lately been measured to serve as a base of verification for the Burma coast series, and for a point of fresh departure in the trigonometrical survey of that province.

Before concluding this rapid sketch, it only remains to briefly indicate two of the many subsidiary operations connected with the great survey. It was especially necessary that the exact height of the various base-lines above the level of the sea should be determined. Now there is a method of measuring heights by means of measured vertical angles which is called ‘trigonometrical levelling,’ but this method, although capable of a high degree of accuracy, is nevertheless inferior to that more general system of carrying forward a line of levels and determining heights, which is executed by means of a spirit level and staves.

In Upper India, where the distances from the sea are very great, it became a matter of much doubt whether the heights as hitherto determined by means of trigonometrical levelling, checked only by barometrical observations, were sufficiently accurate. It was determined therefore to undertake and bring up from the coast a regular series of spirit levels as the only

reliable check to the trigonometrical levelling on which the heights of the various base-lines, and also of the peaks of the Himalayan range, were still dependent. The first line of spirit-levelling was carried up the Indus valley, starting from the tidal gauge at Karachi to the Attock base, and to the Sironj and Dehra Doon base-lines, in order to furnish a precise datum or fixed height above the sea, for subsequent mountain operations, where spirit-levelling would be out of the question, and also to ascertain the exact elevation above the level of the sea of numerous points in Sindh, the Punjab, and North-West Provinces, for the use of the survey, and for the service of the canal and other engineering departments.

The great distance to be levelled, and the absence of any certain check at the end of the line, necessitated extraordinary refinements and minute care in conducting this line of levels. In order that every possible source of error might be eliminated or minimised, it was arranged that three sets of observers should level along the same line of pegs following each other in close order, each using a separate instrument and staves, by this means any important error was at once detected, and to eliminate what is called the 'personal error'—or that error due to personal peculiarities, such as eyesight, in the different observers, an alternating system of observations was instituted, so as to counterbalance as far as possible this, together with certain instrumental errors. On arriving at the Attock base, a distance of over 700 miles from the sea, the difference between the height of a point on that base as given by vertical angles, and as now found by spirit-levelling was 3 feet 2 inches. At Dehra Doon base the difference was 5 feet 1 inch, and at Sironj 2 feet 1 inch. This line of spirit-levelling was afterwards extended along the valley of the Ganges to the sea at Calcutta, thus completing one of the longest lines of continuous levelling up to that time executed, the distance along the line levelled from Karachi to Calcutta being 2200 miles. Subsequently other long lines of spirit-levelling connecting numerous important points of the Trigonometrical Survey with the sea at various parts of the coast have been carried out, and much still remains to be undertaken.

Simultaneously at a number of selected points on the coast,

tidal gauges have been established, and observations regularly recorded to ascertain the true mean sea-level, and furnish a fixed datum, or height of departure, to which all the measured heights over the whole country can be reduced and referred.

On the completion of the measurement of the 'great arc series' extending from Cape Comorin to Dehra Doon, a basis existed for ascertaining the curvature of the earth on that arc by means of astronomical computation. Various attempts to discover the true size and figure of the earth have from time to time been made, commencing from a very early period in the known history of mankind. Although probably not the first attempt of this kind, Eratosthenes, custodian of the great Alexandrian library, attacked the problem about 250 years before the Christian era, between Syene and Alexandria. Some two centuries later Posidonius, an Athenian and Rhodian philosopher, made another attempt between Alexandria and Rhodes, by observing that the bright star Canopus just grazed the horizon at the latter place, whilst at Alexandria it rose $7\frac{1}{2}$ degrees. In each of the above cases the distance between the two points of the earth's surface chosen was estimated, not measured.

The Mohammedan Khalif Al Mamun (A.D. 813-832) having become convinced of the globular form of the earth, gave orders to the astronomers of his time to measure a degree of a great circle on it. On the shores of the Red Sea, in the great plain of Shinar and by the aid of an astrolabe, the height of the pole above the horizon was determined at two stations on the same meridian, exactly one degree apart. The distance between the two stations was measured and found to be 200,000 Hashemite cubits. The general result of these various observations gave for the earth's diameter about 8000 miles, a determination not very far from the truth.

In the year 1527, or just five years after Magellan had for the first time circumnavigated the globe, the first attempt made in Christendom to ascertain the size of the earth, was by Fernel, a French physician, who, observing the elevation of the pole at Paris, went northwards until he came to a place where its height was exactly one degree more. He then measured the intervening distance by registering the number of revolutions

of a wheel, and came to the conclusion that the circumference of the earth was 24,480 Italian miles.

Numerous measures were subsequently made in other countries. One of great accuracy was determined by Picard in France, celebrated as having finally confirmed Newton's theory of universal gravitation. Picard connected two distant points by means of a triangulation, and thus ascertained the length of an arc of the meridian intercepted between them. He then compared the measurement with the difference of the latitudes found by astronomical observations. The two points chosen were situated close to Paris and Amiens, and the zenith distances of δ Cassiopeia determined the latitudes of the two places. Some years later, Picard's observations were extended by the French Academy, and in 1718 measurements were carried out from Dunkirk on the north, to the southern coast of France.

The true figure of the earth, whether it was a perfect globe, or whether it protruded or was flattened at the poles, was not, however, as yet ascertained. In order to determine this point, expeditions were sent by the French Government to measure degrees of the meridian, at the equator and at a point situated as far north as possible. These measurements made in Peru, and in Swedish Lapland, confirmed the oblate, or flattened form of the earth. Among the more recent measurements made in different parts of the world, is the one nearly $12\frac{1}{2}$ degrees long, from Dunkirk to the island of Formentera near Minorca, and the great Indian meridional arc, of which we have been speaking. The modern more accurate observations made to ascertain the true size and figure of the earth have resulted as follows: Equatorial diameter, 7925 English miles. Polar diameter 7899 miles. Difference twenty-six miles. In India, however, as elsewhere, it became desirable that the results should be checked and verified by a further and independent series of observations made by means of pendulum vibrations.

Owing to the flattening of the earth at the poles, the force of gravity on the earth's surface is not everywhere the same; but increases somewhat in proportion to the latitude, from the Equator—where it is least—to the poles, where it is at a maximum. Consequently a pendulum swinging freely, having a certain number of vibrations per minute at the Equator, will have

a quicker rate of vibration at the poles, and at every intermediate point between the Equator and the poles a slightly accelerated rate. By observing, therefore, the exact number of vibrations made, say in twenty-four hours, by a pendulum of fixed length, at various selected points along the great arc, the true figure of the earth along that line could be ascertained.

In the practical carrying out of these observations, however, many refinements became necessary, to eliminate various sources of error. Even to fix the exact rate of vibration of the pendulum in any given time required much elaborate arrangement. The method adopted was the following. The observing pendulum was set up in close proximity to a slightly shorter one attached to an astronomical clock, the clock pendulum being shorter, vibrates at a slightly quicker rate, and gradually gains on the other, until a maximum divergence has been reached. At the end of another interval the two pendulums again approach each other until they exactly coincide. At this instant of time the observing pendulum will have made two vibrations less than the clock, in the interval which can be read off the clock face. The exact rate of the clock being known, the precise number of vibrations made by the observing pendulum in twenty-four hours can be readily calculated. In order to get rid of all disturbing currents of air, the pendulums had to be swung in a vacuum.

The ascertainment of the true figure and density of the earth is by no means a matter of mere curiosity; on the contrary, numerous problems of the highest scientific and practical importance are dependent on its correct definition.

The extraordinary value, accuracy, and precision which characterises the operations of the Great Indian Trigonometrical Survey, together with the numerous other scientific labours carried out in connection with it during the present century, under the direction of the British Government in India, has been sufficiently attested by the highest authorities of Europe, whilst the skill and energy with which the work has been accomplished can only be fully appreciated by those who are specially acquainted with the extremely adverse conditions under which it has been carried on.

The present brief and mere outline sketch of these vast

operations conveys but a most fragmentary and inadequate picture of the enormous amount of labour, whether in the field or in the office, which the Great Trigonometrical Survey of India has imposed. To recount the exceptional difficulties and obstacles, physical, political, and climatic, which have been encountered and successfully overcome during the progress of this great work, would alone require a volume. Such a record would exhibit one of the highest triumphs of British energy anywhere displayed. It would depict the arduous toil with which, in furtherance of its main object, the labour was carried on over some of the widest and most deadly tracts of swamp, forest, or desert, perhaps anywhere to be found, and it would paint a deplorable loss of human life. In the course of its long progress we should see the almost impassable and most stupendous mountain barrier in the world conquered and laid bare to its innermost recesses. We should see the signal-stations of the survey planted triumphantly on lofty snow-clad peaks never before trodden by the foot of man, and covering enormous hilly tracts of primeval jungle, unoccupied by, and almost inaccessible to, human beings. Finally, we should witness the patient and skilful exactness with which all the vast stores of data, and information, so laboriously collected, is collated, and the immense chains of triangles are computed and slowly pieced together in the computing and drawing offices of the survey, until there results the perfection of that great skeleton framework, on which is moulded in minute and accurate detail the topographical features of considerably over a million square miles of the earth's surface.

Note.—The data for this very condensed account of the Great Indian Trigonometrical Survey, have been largely derived from the memoranda on the Indian Surveys by Clements Markham (1878) and C. and D. Black (1892)—and other official papers and reports.

ROADS IN INDIA

CHAPTER I

HISTORICAL—NATIVE WORKS—PRINCIPLES OF CONSTRUCTION

Roads in Europe—Diversity of character of Indian roads—Devious routes of natural trade tracks—Roads under the Moguls—Old bridges—Bridge over the Gumti at Jaunpore—Northern Road from Lahore by Shir Shah—‘Pepul putta ka Seran,’ Jagganath to Delhi—Ancient road bridge and aqueduct in Mysore—Old native road in Assam—Caravanserais—Backward state of roads in early days of English rule—Lord Elphinstone proposes roads for Madras—Inauguration of reform under Lord William Bentinck—Observations on laying out and constructing roads—First-class roads—Hill roads—Laying out—Deviations and moderate curvature—Earthworks—Borrow pits—Openings for culverts and small bridges—Waterway and bridges—Selection and consolidation of road metal—Varieties of material, and modes of application—Binding material—Ramming and rolling road metal—Trees on road-sides—Rest-houses and staging bungalows.



ROADS in the modern sense, that is to say, embanked lines of way, well drained, with easy inclinations and hard smooth surfaces, allowing the use of wheeled traffic with a minimum of resistance, and carried by means of raised bridges over the water-courses of a country, were practically unknown in India, until a comparatively very recent period. In Europe public roads may be classed under two heads, viz., main leading or ‘turnpike’ roads, and cross-country roads. There is seldom any difference between these two classes, except that the main roads have a greater surface width, and easier gradients than the secondary class: both are metalled and bridged throughout. In India, how-

ever, there is a far greater diversity of character in the public highways. Like the main or 'turnpike' road of England, the first-class Indian road is embanked, is of ample width, well-graded, drained, and everywhere metalled and bridged. The second-class road is also embanked, of the same, or of a smaller width of road-bed, is drained, metalled on the surface, but not yet, or only partially bridged. Or again, a second-class road may be embanked out of reach of floods, and drained, but neither metalled nor bridged, often having, however, permanent causeways, temporary bridges, or other facilities for assisting traction across the beds of the water-courses during the dry season of the year. These second-class varieties of roads may be either virtually first-class highways in a state of transition, or may be intended to remain permanently as designed and made. Still lower in the scale are the surface tracks of more than one kind, usually called 'fair-weather roads.' In the better class of fair-weather road the course is systematically laid out over a selected line of country. For a width of from 30 to 50 feet the surface is cleared of jungle-growth or other obstructions, ditches on either side are cut to serve as drains, and the earth from these ditches is thrown into the centre to level up the worst hollows and inequalities of the ground, and to assist the water to run off into the side drains; or in very low ground a slight continuous embankment may be thrown up. The banks of the larger and more troublesome streams are cut down to an easy slope, so that carts may pass over the bed of the river, either directly, if the bed is firm, or by the aid of some temporary or even permanent causeway laid over the worst portions. During eight or nine months of the year, or even longer in certain districts, these inexpensive fair-weather roads are of great service. Other fair-weather tracks are formed by merely clearing the surface of jungle-growth, and easing the approaches to the beds of the intervening streams, without drains or earthworks of any kind. Other tracks are almost unaided by any labour whatsoever, the traffic, very much as a natural stream of water might do, wearing for itself a passage along the easiest and least resisting line of country.

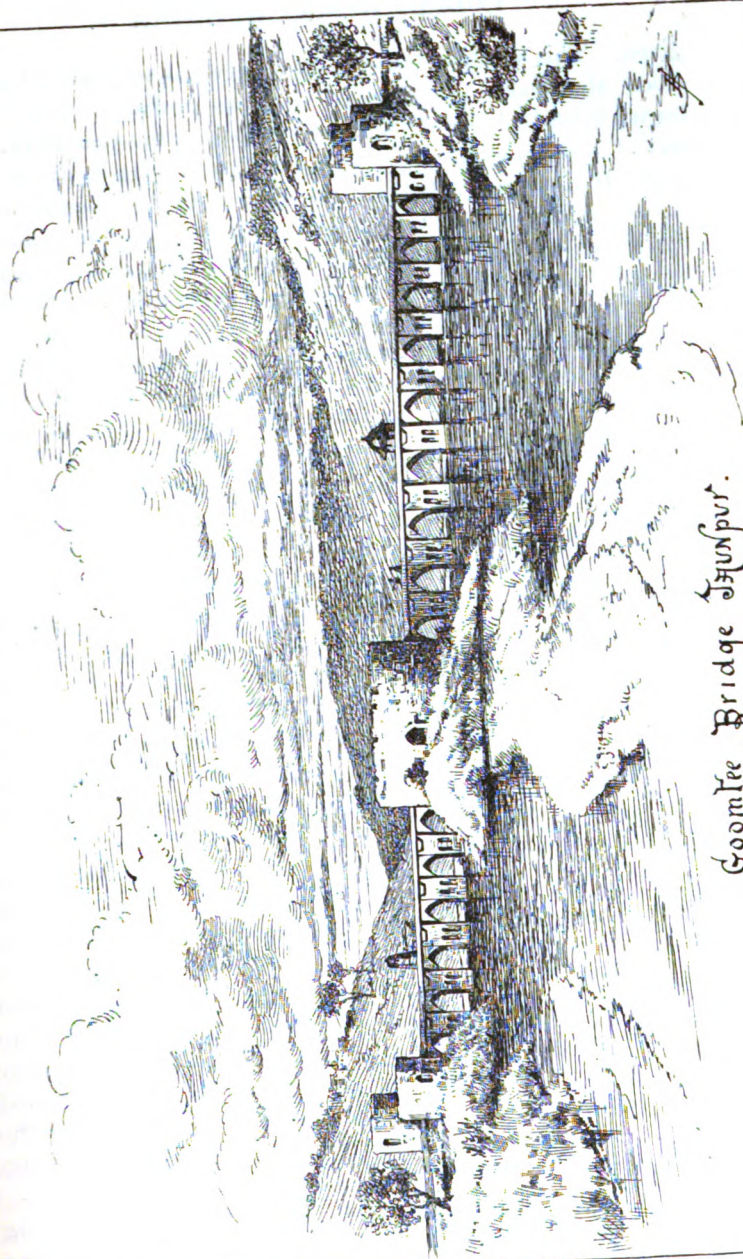
During the dry season, when, in the plains of northern India, or on the elevated plateaux of the Deccan, the surface soil is

baked and hardened under a fierce tropical sun, wheeled traffic is rendered possible along deviating and tortuous lines of route, often covering very wide stretches of country, with no expenditure of money or skill, beyond the occasional easing down of some trifling natural obstacle, such as the bank of an intervening stream too steep to admit of unaided passage, or the felling and removal of a few shrubs or trees. Such surface trade tracks—often of great width and deeply fissured with heavy ruts, scarcely visible, however, through the thick coating of fine impalpable dust—used for the transit during the dry season of merchandise carried on the backs of pack animals, or in rude carts drawn by yokes of bullocks, served probably for untold centuries all the requirements of the internal carrying trade of the country, and even still forms a not inconsiderable portion of the country's highways. In many of the more undulating and hilly districts in the central portions of India, the extraordinary devious course taken by some of these well-worn trade-tracks, often evidences in a very striking way, the complete apathy of the earlier population, and their neglect of all considerations of convenience and economy, as well as their want of ordinary attention to the physical configuration of the country. Not seldom, it may be remarked that a few hours' labour would remove some trifling obstacle in the direct line of route, and obviate an enormous actual deviation. At other times it will be observed that in order to cross a small stream at some point where the naturally shelving banks afford an easy descent, a track will be found to deviate a dozen miles, which the artificial easing of the nearer banks in the direct line would, by a few hours' work, have obviated, and this where the natural ford is equal to the one chosen, or even more favourable. The practical and energetic European, however, soon ceases to wonder at these things—recognising that he is in a new world, where time is of no value, and where it is every one's duty literally to follow closely in the footsteps of his immediate predecessor.

The general course followed by these natural trade-tracks, existing within small limits of deviation probably for ages—especially in those parts of the country outside the great plain districts of Upper India—were considered by many unreflecting persons to point out, as if under an infallible law of natural

selection, the best possible lines of route for permanent road construction. Nothing, however, could be more fallacious than such an idea—an idea which has, nevertheless, been the cause of more or less costly mistakes. In India, what may be called the natural flow of wheeled traffic unassisted by art, follows, as a matter of course, the—to it—easiest line of country, but it is only the easiest unassisted line. A very little examination of the country usually serves to show that the removal of a few comparatively small obstacles will often to a prodigious extent shorten and cheapen a natural track between two points distant a great many miles from each other. In the earlier days of English road-making in India, when as a matter of necessity the work had to be largely projected and executed by unskilled agency—even such an obvious consideration as the above was sometimes overlooked.

It is very doubtful whether the Mogul Emperors devoted much money or consideration to the question of permanent roads. Very little evidence of such exists at the present day, and, in any case, it is certain that on no single line of traffic was communication open except during the dry season. Many of the minor streams near the larger cities of Upper India were indeed bridged by the Moguls. Some of these bridges have no doubt been carried away, and all trace of their former existence has been long lost. Such as remain are singular structures, not, however, unlike many of the older bridges in Europe. They consist of what at first appears to be a massive barrier or dam of masonry or brickwork, perforated with numerous small pointed-arched openings, often of very irregular size, and affording an open area for the passage of the water, greatly less than the area of obstruction presented by the piers. The whole bridge is usually founded on small wells supporting a continuous masonry platform, and it is to the latter circumstance that those which remain standing have so long withstood the violent floods to which they have so often been exposed. No doubt in many instances these bridges were left isolated, and were dangerous or impossible to approach during the flood seasons, and the bridges themselves have been preserved by the extensive washing away of their approach banks. An interesting and picturesque example of these Mohammedan structures is the old bridge over the Goomti at Jaunpore, of which an illustration is



Goomtee Bridge Banpur.

given. This really extraordinary bridge has successfully withstood the floods of centuries, and has probably often been buried beneath the waters. Even so late as the year 1871, ten feet of water passed over the roadway, carrying away all the shops that then existed on the piers. In the Panjab from Lahore northwards, the general direction of a road made by Shir Shah in 1540 can still be traced by the rows of ancient trees and brick pillars at intervals of two miles. The road appears to have followed the natural level of the ground, and was neither metalled nor drained. It was, however, partially bridged. Some of the bridges still remain, and others no doubt have perished, leaving no trace. Remains of ancient made roads are to be found in Bengal, which show that the former rulers of the country were not altogether unmindful of their advantages. One called the 'Pepul putta ka Seran,' lined with Pepul trees on each side, extended a thousand miles from Jagannath to Delhi. This road was from 60 to 70 feet broad. It was embanked over low ground, but was unmetalled. In several places it was bridged, the piers being 12 to 14 feet thick, and the arches of the usual narrow pointed form. In Mysore some remains of bridges of still greater antiquity have been noted. One such bridge was constructed over the south branch of the river Kaveri near Seringapatam, probably at a period dating before the usual construction of archwork. A portion of the bridge serves as an aqueduct to convey water from the river to the town. The structure is of the rudest kind. 'Square pillars of granite are cut from the rock, of a sufficient height to rise above the water at highest floods. These are placed upright in rows, as long as the width of the bridge, and distant about 10 feet from each other. They are secured at the bottom by being let into the solid rock, and their tops being cut level, a long stone is laid upon each row. Above these stones others are placed contiguous to each other, and stretching from row to row in the direction of the length of the bridge. The celebrated bridge over the Euphrates at Babylon was constructed on similar principles.¹

Major Briggs, Superintendent of Works in Assam, reporting on the proposed Assam trunk road in 1863, gives an interesting

¹ Mill's *History of British India*.

account of some old native road works in that province. He says, 'These ancient rulers of Assam fully appreciated the incalculable advantages to the country of intercommunication by land, and restraint upon the incursions of the water. All their roads, "Allees," as they call them, were constructed with this double object, as highways above the line of flood, and as "bunds" (*i.e.* embankments) to control the inundations of their rivers. From above the spot where the Dihong and Dibong join the Brahmaputra, down to the farthest confines of the Kamrup district, relics of their efforts remain, which for bold engineering skill and wonderful contempt of difficulties, deserve to rank with the works of the old Romans. Their lines of road were generally so well chosen as to direction, that if we can only afford to make our roadway as massive as their bold projects require, many portions of their work may be adopted. To unite their efforts with ours, though years roll between us, and to complete, repair, and bring into use, what internecine wars and foreign invasions prevented them from doing, has throughout a long and arduous survey been my constant endeavour.' And again, 'At the same time, in many of the great plains at present subject to partial inundation, the road embankment might be capable of controlling the inundations of the Brahmaputra, and so serve the double purpose of roadway and "bund." This was successfully done by the old rajahs of Assam. When Rajah Rudru Singh, upwards of a hundred years ago, commenced the present "Bor Allee" (great road), also at places called the "Dhodur Allee" (complete road), he designed it to oppose an impenetrable barrier to the floods of the great river, as well as to afford the most direct line of communication between important points of the country. It was never completed, but the portion between Jaipur and Jankana, near Jorpath, about seventy miles, remains to show the stupendous nature of the work. From the height of the embankment it is visible two miles off. The width at top is 35 to 40 feet. Its course is generally perfectly straight, and where there is a bend, the curve is formed with mathematical precision. The trenches are dug with equal regularity and never approach nearer than 100 feet to the road centre. So thoroughly has it reformed the water system of the country, that in one place the whole drain-

age of thirty miles passes through four openings of about 100 feet each, and the sides of these openings have not been eroded by the passage of the waters for more than a century; the estimated area of waterway on a line parallel to this part and farther inland was 718 feet, according to a former survey made; only one of these openings was bridged, as, according to the present tradition, the Bengali architect succeeded too well in pleasing the Rajah, who, fearful of so accomplished a person returning to Bengal, and offering aid to the British Government, caused him to be strangled. The Jorpati people were most solicitous that the line of the "Bor Allee" should be adapted for the trunk road, and predicted the greatest benefit to the country. They thought the adoption of any other line unworthy of so great a Government, when their own Rajahs had successfully constructed a portion of the great road.'

Perhaps the best evidence of attention to a matter of public road convenience to be met with under native rule, is to be found in the Caravansaries. These erections, often of great size, consist of large square or rectangular enclosures, having usually two massive arched gateways or entrances. Along the inside of the enclosure walls are ranged a series of slightly raised chambers or recesses, each large enough to accommodate a man and his horse. The centre of the enclosure is for cattle, and generally contains a public well and drinking trough. The entrances were closed at night and kept guarded. These shelters afforded free protection to travellers and their merchandise. Many are still in use, and are maintained by the English Government.

It is not easy to account for the extremely backward state of road communication for many years succeeding the establishment of English rule over a large portion of India.

About the year 1818, spasmodic efforts appear to have been made to improve the native tracks, and the surplus ferry funds were assigned for this purpose, convict labour being mostly employed. Even so late as the year 1830 it is recorded that 'beyond 20 miles from Calcutta the roads communicating with the principal stations of the Upper Provinces were in no better state than in the time of the Moguls,' and up to at least ten years later, the Government despatches were still carried on men's backs to Agra and Delhi and the North-West Provinces,

at the rate of 3 or 4 miles an hour. The extraordinary neglect with which the subject of improved road communication was treated by the early government of the East India Company, cannot be altogether ascribed to want of funds, as no doubt the money could have been found if the need had been recognised as pressing. The exceedingly low cost of the carriage of produce by the Ganges and other rivers, and over the natural beaten tracks of the country, no doubt prevented attention being strongly directed to the necessity of made roads. It is said that when Lord Elphinstone was appointed Governor of Madras, he proposed the construction on a comprehensive scale of new roads in that Presidency. The idea appeared so ridiculous to men in authority at that time, that a certain member of the council wrote home to England, 'The silly young nobleman actually talks of making roads.' There seems to have been a sort of impression that made roads were a superfluous luxury in India. On one occasion the Government being pressed probably by some enthusiast, sent out circulars, inviting the various district collectors to send in a statement of what district roads they considered necessary to develop the resources of the country. There is a story current that, in reply to this circular, an ingenious collector reported that 'no roads were required' in his district, 'because the people there did not use carts, but carried everything in panniers on the backs of bullocks.' In course of time, however, it came to be more generally recognised that main lines of metalled and bridged public roads—offering facilities for the transport on wheels of mails and military baggage—were among the first necessities of the State, and that an improved condition of the commercial roads of the country, to lower the cost of produce, was an essential antecedent to all progress. It is to Lord William Bentinck (1828-1835) that the first inauguration of reform in this matter of public road construction is to be attributed, and it was during his administration that the first important steps were taken for the construction of a permanent high road, for military and commercial purposes, to connect Calcutta with the distant stations in the Upper Provinces.¹

¹ Vide 'Public Works in the Bengal Presidency,' vol. xvii. *Proc. Inst. of Civil Engineers*.

Before, however, referring to that early example of Indian road construction known as the 'Grand Trunk Road,' now extending 1500 miles from Calcutta to Peshawar, it will be convenient to make a few observations on some of the more simple elements and principles of road engineering in India, for the benefit of the unprofessional reader.

The selection of a suitable line for a first-class road, even in a moderately level country, is a matter requiring some professional aptitude and skill, and in a mountainous or hilly country a very high degree of engineering proficiency, combined with a keen and practised talent for rapidly detecting the framework of mountainous masses, and the conformation of the valley systems to be dealt with, so as to avoid losing the advantages of elevation, regularly gained. A badly laid out hill road may impose the lifting of the whole weight of traffic to a height far beyond the total altitude to be actually surmounted, whilst a good line will continue its course at an almost uniform and easy slope, losing scarcely anything by descent. The laying out of a line of first-class road over a tolerably level plain district is a comparatively simple matter, but even here, the choice of country within certain practical limits of deviation requires intelligent co-ordination of means to ends. It will not suffice to take a ruler, and, on the map, draw a straight line from one point to another. In the first place, the cost of 'metalling,' that is, placing hard material for the wearing surface of the road, will cost maybe six to eight times as much as the cost of earthworks, and after the road is made, the 'metal' has to be periodically renewed as worn down by the traffic; hence the neighbourhood of quarries, where stone metal can be obtained, or the facilities for obtaining other kinds of metal used in road making—such as that concretion of carbonate of lime in hard nodules called in India *kunka*, or gravel, or even hard burnt broken brick and sand, have to enter into calculation, so that it may be decided how far it will pay to sacrifice the absolutely shortest line for the sake of cheapening the carriage of the most expensive items of construction and maintenance. Again, to avoid exceptionally expensive bridgework, it will be often economical to keep the road on the ridges of a country, involving some deviation, or merely favourable points for crossing

the larger streams, causing a less expenditure in bridge foundations, and may warrant a more or less degree of departure from the shortest line. Even where no money saving is to be gained by leaving that perfectly straight line, which is of course the least distance between any two points, it is better to deviate a little. There is perhaps nothing in the world more monotonous or fatiguing than a perfectly straight and level road, always stretching away to distant points on either horizon. Moderate curvature adds but the merest trifle to the total length, and anything more than two or three miles of perfectly straight line ought to be avoided.

The road being laid out, and levels taken at some 300 or 400 feet apart, on stout pegs driven into the ground along the centre line, the heights and quantities of the earthworks required can be estimated as soon as the width of the road has been fixed, and bamboos or stakes are driven so that their tops, or cross pieces fastened on them, shall mark the future road surface; a trifle of extra height being allowed for the subsequent settlement of the earthwork. The earth to form the embankment, usually only two or three feet high in a plain country, but of course varying in height where inequalities of surface level exist, is obtained from 'borrow' pits dug along the sides of the road and parallel to its course. These borrow pits do not form a continuous excavation, because almost every country has some slope, and if they were continuous water would run along them, forming streams which would wear away their sides. The pits are; therefore, not longer than about 100 feet each, having spaces of untouched ground of about fifty or sixty feet—or even more if the soil is very loose—between them. Their sides are sloped, and they are made wide enough to admit of the necessary quantity of earth being got out of them, without the necessity of digging more than a few feet in depth. It is usual to keep them thus shallow so that they may be used for obtaining earth for the future repair of the banks, but here and there some are made deep enough to retain a certain amount of water, which is always required in renewing or mending the surface of the metal. The near edge of the pits are always placed at some distance from the bottom of the embankment slopes.

Generally at the lowest points of the ground section, along the line of the road, it is necessary to leave openings for culverts or small bridges, to allow the cross drainage of the country to pass from one side of the road to the other. Money can often be saved by cutting drains from some of these depressions, so as to divert any water collected, and lead it to still lower depressions, so as to collect the cross drainage as far as possible into a fewer number of separate culverts, although these may individually require to be a trifle larger. To make these small bridges for cross drainage just large enough but yet not too large and expensive, is often the most important of the minor problems to be solved. In some cases the separate drainage basins, or collecting areas, on the up-stream side of the road bank are easy to determine, so that the maximum rainfall of the district being known, the total amount of water to be provided for can be readily ascertained. In the case of large streams or rivers, however, especially if liable to receive the surplus or 'spill' water from other still larger courses, the proper amount of waterway to allow becomes a more intricate problem, and in most cases it will be better to err a little on the safe side than to run any great risk. If the bed of the river to be bridged is very hard and not liable to be washed or scoured out by the water, so as to undermine and injure foundations, or if the bridge is built with a solid masonry platform between the piers and abutments, protected along the up and down-stream edges by walls carried well down into the river bed, so that the force of the current will not be able to wash it up, the water can be safely allowed to rise to a greater height by keeping the bridge shorter in length than might be otherwise necessary. In this particular there will of course be every degree of difference or difficulty, accordingly as small channels or great and wide rivers are dealt with.

Another exceedingly important matter in connection with road-making is the selection and consolidation of the hard material which is to form the wearing surface of the road. It is always usual to wait until the earth forming the banks has become thoroughly hardened and compacted together under the influence of the rainfall, before placing the expensive road-metal upon it, otherwise a great deal more will be required,

which, although in the end not detrimental to the road, will render it much more costly. It is also generally economical and necessary to interpose between the earthwork of the banks, and the expensive hard road-metal, some intermediate substance, such as one or other of the various forms of decomposed material called *moorum*, gravel, broken rubble or rough stone—or even broken brickbats—ordinary river sand mixed with many kinds of soil, especially that known as ‘black cotton,’ will also harden the surface of banks to a surprising degree. The varieties of substances used for metalling the surface of roads in India are very great. One of the commonest, in the districts where it is abundant, is hard nodular *kunka*. It makes an excellent, although in dry weather a very dusty road, besides requiring a good deal of petty repair under exposure to heavy traffic. Block *kunka*, besides being expensive to break unless quite fresh from the quarry, is inferior, and is seldom employed. All the softer materials, such as broken laterite, and most varieties of globular trap, or the hardest kinds of broken bricks, etc., are ill-adapted to form a durable road surface, but have often to be employed where better are not procurable. As a general rule, the softer the material, the larger is the average size of the pieces into which it is broken, so as to give a greater section of resistance to fracture under the grinding action of the cart-wheels, the rough bottoming is also made thicker, and the road is formed with a greater rise in the centre. *Moorum* metalling, which is largely used in the Bombay Presidency, is spread at least twelve inches thick, on a good bottom. It makes an excellent dry-weather road, but will not well stand a heavy traffic in the wet season. Globular trap, very common in Malwa, is too friable to make a good road metal. Under traffic the fragments, however angular they may have been when first broken, are apt to wear down at the edges, leaving an unconsolidated mass of rounded stones very difficult to bind together. All the harder granitic and basaltic rocks furnish, when broken into road-metal, the best and most lasting surfaces; they are, however, the most expensive in first cost. When good *moorum* is also plentiful, perhaps the most economical process is to use this material alone as road-metal for some time, until the crust of the

road becomes thoroughly firm and reliable. Thin layers, about three inches thick, of hard stone road-metal can then be gradually applied.

In order to bind the hard stone fragments together some fine sand or *moorum*, in quantity about one fifth the volume of the metal, is required. In using broken basalt, however, much less of this binding material is employed; it takes consequently a far longer time to consolidate into a compact surface than other materials; but when once consolidated it forms one of the most resisting of road surfaces. If too much binding material is used with basalt, or indeed with any other very hard metal, it causes the road to become rough and unpleasant, the softer material, wearing and being blown from the surface by the wind, is apt to leave the upper parts of the less wearable stone fragments projecting. The choice of material for road-metal in India is most commonly limited in each locality to some one or two substances which it is possible to obtain at a reasonable cost. Whatever may be employed, whether hard stone, *kunka*, or *moorum*, it is necessary that it should be artificially compressed into a firm compact crust, so as to be unmovable by the wheels of vehicles. This is usually done by beating it down with heavy rammers by hand labour, or by the frequent hauling over it of heavy rollers. The latter process is, for the harder kinds of metal, by far the best, where really heavy rollers are obtainable. Steam-road rollers of fifteen or twenty tons weight are also frequently and economically used for consolidating road surfaces where a large quantity of such work is required to be done.

On the better classes of Indian roads, lines of trees planted so as to afford a grateful shade to travellers is an almost invariable rule, and groves of trees at about day-journey intervals are frequently added. Near these groves wells are dug to supply both man and beast with a plentiful supply of water, without which, in so dry and thirsty a land, travelling would be virtually impossible. On such roads, also, accommodation and shelter for the upper class of travellers is in all cases provided. 'Rest houses' or 'staging bungalows' are erected at intervals of twelve or fifteen miles along the roads. These provide accommodation for two or more families; containing distinct sets of apartments

plainly furnished. A keeper, who acts also as cook, and supplies provisions under a fixed tariff, together with a small staff of menial servants, is maintained, and a small fee—for the benefit of local or district funds—is charged to travellers for the temporary use of the ‘rest-houses.’

CHAPTER II

Neglect of Public roads until comparatively late date—Military fair-weather Roads—Road up the Bhoze Ghat early in the century—The Grand Trunk Road—Alignment—Early commencement under Warren Hastings—Real commencement under Lord William Bentinck—General description of Grand Trunk Road—Bridges—Lelajaum Bridge—Paucity of information—Paved Causeways—Sone Causeway—Probable cost of Grand Trunk Road—Difficulties of early engineering work in India—Insufficient waterways—Initial importance of Grand Trunk Road—Other early road operations—Agra to Bombay—Great Deccan Road—Extension of Hill Roads—Coast road through Orissa—General outline of important roads—Indus river at Attock—Proposals for a tunnel—Modified project—Construction of Attock Tunnel—Abandonment of work—Central India Roads—Roads in the Berars—Roads in the Central Provinces—Northern, Eastern, and Sangor Roads—Early importance of Northern road—Important Bridges—Roads in Bombay and Madras.

It has been pointed out that very little was done by the English Government in the matter of public roads for India until a comparatively late date. Fair-weather roads were constructed by, and for the use of, armies on the march, but these were neglected almost as soon as they had fulfilled their immediate purpose, and those absolutely necessary for the control of newly acquired territories were only kept open by constant reconstruction. These military road-tracks were no doubt of service to the commercial traffic of the country, and this especially so in some of the more mountainous districts in the lower peninsula, where work of a much more permanent and substantial character had of necessity to be undertaken from time to time for military purposes, such as that road passable by artillery, made under the orders of the Duke of Wellington in the early part of the century, up the Bhoze Ghat between Bombay and Poona. It was not, however, until the years 1840 to 1845 that any large and systematic general construction of

permanent commercial and military roads throughout the country was undertaken.

The earliest example of an important main road constructed in India was a considerable length of that well-known highway 'The Grand Trunk Road.' This remarkable work when completed was no doubt for many years unsurpassed by any single public road then in existence. Owing to various causes work on it was not brought to a final conclusion until long after its first inception and commencement, but a very large portion of it was executed before the year 1848. The Grand Trunk Road now stretches in a practically unbroken line from Calcutta to Peshawur, to within a short ride of the mouth of the Khyber Pass in Afghanistan, a total distance of 1500 miles. Starting from Calcutta the road is taken in an almost direct line to the southern bend of the Ganges near Benares and Mirzapore, passing through the Kymore line of hills forming the last spur of the Vindhyan range of mountains stretching across India. From Mirzapore the road follows the valley of the Ganges to Allahabad and Cawnpore, thence striking somewhat to the west it follows the eastern bank of the Jumna to opposite Agra and Delhi, with which towns it was united by temporary pontoon or boat bridges. Northwards of Delhi it passes *via* Karnal, Ludhdiana, Lahore, and Jhilm, crossing the Indus at Attock a few miles before reaching Peshawur.

It is stated that under the government of Warren Hastings, so far back as the years 1772 to 1785, a commencement of this magnificent early work—on that portion of its length lying between Calcutta and Benares—was made by a Captain Charles Rankin, but to what extent, or whether the work executed was anywhere or everywhere on the precise alignment of the present trunk road, does not appear. It is most likely, however, that the very early work referred to would have been the construction of what would now be called a fairweather road of superior class. However this may be, the inauguration of the first important steps towards the realisation of the splendid project of a great permanent trunk road from Calcutta to Delhi and the North-West frontier—afterwards successfully carried to completion—appears to have taken place under the government of Lord William Bentinck 1830 to 1835. Twenty years

later, or in the year 1855, the road was completed to Karnal, some seventy-five miles north of Delhi, or for nearly 1000 miles from Calcutta, and its prolongation to Lahore was then in progress. The extension of the road from Lahore to Peshawur, although a vigorous commencement had been made not long after the annexation of the Panjab, was delayed for many years owing to want of funds.

The Grand Trunk Road has been constructed throughout as an embanked, thoroughly well-drained and well-metalled highway of the first class. It is raised in every part well above the height of known floods or inundations. The top width of the earthwork was in the first instance made 30 feet, but was soon afterwards increased to 40 feet, with side slopes of 4 to 1. The central portion was originally everywhere metalled to a width of 16 feet, with either broken stone or *kunka*, laid 8 inches thick, and rolled or beaten down to a thickness of 6 inches. Rows of good timber trees were planted for the greater part of its enormous length, along the foot of the embankment slopes at intervals of 50 or 60 feet. Halting-places, or encamping-grounds, were also arranged at suitable intervals for the convenience of merchants and goods, and at every ordinary stage for troops on the march, enclosures for shops, and open encamping grounds, marked off and kept clear from cultivation, were established. 'Rest-houses' for the better class of travellers were also provided at distances apart of ten or fifteen miles along the road.

Except in the case of the widest rivers, of the first order of magnitude, the road was permanently bridged throughout. Subsequently, after the construction of the great line of railway—first from Calcutta to Delhi, and then on to Peshawur—provision was made for carrying the road over these largest rivers by means of the great railway bridges then constructed. The bridge structures on the lower portion of the trunk road were to a great extent constructed of stone, the piers being founded on cylindrical wells, or on perforated blocks of brickwork sunk into the sandy beds of the rivers in the manner peculiar to India. A great number of these bridges were of very considerable size—such as the one over the Lelajaum river, consisting of twenty-six arches of fifty feet, costing the

moderate sum of about £10,000. Little detailed information, however, appears to be now available as to these early works. Occasionally, in the case of the large rivers, where bridges, either temporary or permanent, could not be constructed except at inordinate expense, paved causeways across the bed were resorted to. This expedient is often of considerable value in India, where the greater number of the watercourses are dry, or nearly so, for the larger part of the year, and where in many parts of the country they contain practically no water of any consideration for nine or ten months out of the twelve. In such cases the banks of the stream are cut down to an easy slope, and the whole sandy width of the river-bed is traversed by a paving—often of stone set in mortar, resting on a foundation made sufficiently secure to withstand the rush of water during the seasons of flood.

The first large river encountered by the Grand Trunk Road, before reaching Mirzapore, was the Sone, and it was carried over the unusually wide sandy bed of that watercourse by a causeway of the above description, no less than 11,450 feet, or over two miles in length. The paved roadway, 16 feet in width, was formed of stone slabs, 9 feet and 7 feet long, about a foot and a half broad, and 1 foot thick. A foundation was provided by first driving two parallel rows of common jungle-wood piles to a depth of about 15 feet, for the purpose of supporting bamboo frames and mats to temporarily hold up the sides of the sand excavation that was to be made between the two rows of piles. The sand being excavated and a trench dug of the requisite depth and width, a layer of gunny-bags filled with concrete made of river shingle and lime, was set closely packed together over the whole bottom of the trench. On these bags a layer 2 feet 6 inches thick of rubble stone was laid, set in similar concrete, on which the long paving stones forming the causeway were placed crossways in alternate long and short lengths so as to break joint. The joints of the stones were then grouted and pointed with good hydraulic mortar, and the surface of the causeway was finally levelled but left rough enough to afford a secure foothold for draft animals.

It is not possible to state with any accuracy the total cost of the Grand Trunk Road, constructed at intervals over a con-

siderable number of years, and a large proportion of the earlier work being done by convicts, or by famine relief labour. The probable cost of the initial work would hardly be less than £500 a mile, exclusive of the large bridges, or between seven and eight hundred thousand pounds. A sum of £489,100 is recorded to have been spent on it up to the year 1848, at which time the cost of maintaining the road, so far as completed, was £35,000, and for many years subsequently the total cost of maintenance was not less than about £50 a mile. Before the introduction of railways the traffic carried by the trunk road was very large, and it was calculated that the whole thickness of metalling, throughout its entire extent, was renewed every six years.¹

At the early date when the greater portion of this splendid public work was constructed, English engineers working in India were to a great degree unfamiliar with the peculiarities and flood phenomena of the great Indian rivers, and, moreover, carried on their operations under exceptional difficulties as regards skilled labour of every description. As might be expected, in several instances bridges were constructed with a waterway insufficient to pass without undue obstruction the sudden and violent floods to which they were subjected, and consequent failures occurred. In 1850, during the construction of the Lelajaum bridge above mentioned, a heavy flood carried away five of the arches which had been completed. In another case, owing to insufficient waterway, an entire bridge was wholly destroyed. Delays in construction were also frequent, whether caused by paucity of funds or from one or other of the innumerable difficulties encountered in the manufacture and provision of building materials, and their transport over a virtually roadless country, and the absence for many years of any other than the rudest labour. The early successful achievement of this magnificent 1500 miles of permanent road, and its real magnitude, when considered in connection with the peculiarly difficult conditions under which the main portion of it was carried out, has been to a great extent thrust into the background by the subsequent press of railway construction. Its

¹ Vide 'Public Works in the Bengal Presidency,' vol. xvii. *Proc. Inst. Civil Engineers*.

importance as a commercial and military line of communication has also necessarily dwindled beside the splendid iron road which is now placed almost alongside of it for the larger portion of its length, but it remains none the less a truly remarkable and representative monument of early British energy in India, and a work which, for boldness of conception and execution under exceptional conditions, has hardly ever been surpassed.

Other very early road operations that may be mentioned are the following: In the five years succeeding the year 1839 upwards of 400 miles of embanked and partially bridged roads were constructed in the Bareilly district of the North-West Provinces, and seventy-seven bridges of masonry or timber had then been built. In 1840 work was commenced on a great trunk line of road designed to extend from Agra to Bombay—the total length of which is 735 miles. An annual expenditure of £10,000 was at that time apportioned to this work. Before many years, a postal service along the road was established, and, by offering premiums to the postmasters, an average speed of ten miles an hour was obtained between the chief breaks of continuity—the work being performed by light mail-carts. This fine metalled and bridged line of communication now extends from Agra, *viâ* Gwalior, Indore and Mhow, Dhulia, Nasik, and the Thul Ghat, to Bombay. It is mentioned also that up to the year 1851 no less than 638 miles of embanked and partly bridged roads had been constructed in the small district of Azimgurh in the North-West Provinces.

An important trunk line called the 'Great Deccan Road' emanating from the line of the Grand Trunk Road at Mirzapore on the Ganges, to extend *viâ* Rewah to Jubblepore, and connect with Nagpur and Bombay, was also an early work, and in 1856 the bridging and metalling of this great highway, now extending across the whole continent of India, was commenced. By about the year 1870 nearly all the larger undertakings connected with the earlier through trunk routes had been completed, including many of the fine engineering works leading to the Himalayan hill stations, or to communicate with the Tibetan trade routes beyond them; to the coffee districts of Wynaad, and to the Nilgiri hills in the southern peninsula, as well as the long south-western coast road from

Calcutta, through Orissa, *via* Midnapore, Belasore, Cuttack, and Gangam in the Madras Presidency, together with a very large total mileage of secondary roads connecting the main thoroughfares with the railway centres which were then springing rapidly into existence.

Some few of the more important main-lines of first-class roads which have now been opened out may be enumerated, but it would serve no purpose, and be needlessly tedious to attempt any general trace even of these. The reader will gather a better idea of the extent and ramification of the first and second-class roads of India by consulting the annexed map. Many of the roads to be mentioned are now old established highways, such as the Calcutta-Darjeeling road, which, metalled and bridged throughout, over a very difficult and inundated country, and crossing numerous watercourses and several large rivers by iron bridges resting on screw-piles, is carried well into the Northern mountainous district, opening up an important connection with the external trade routes on that side of India. In the low-lying districts of Eastern Bengal an excellent system of water carriage, by the numerous intersecting channels, prevents the necessity of any considerable extension of ordinary roads.

The old and prosperous districts of the North-West Provinces are covered with a very extensive network of roads of every class. From Gwalior, on the Agra road, and from Cawnpore, main trunk lines extend to Jhansi, Laltipur, and on to Saugor in the Central Provinces. From Bareilly, after traversing nearly seventy miles of plain, a mountain-road is carried to the hill sanatoria of Naini Tal, Ranikhet and Almora, and in the elevated district of Gharwal various lines of hill road extend to the Niti pass, forming a valuable line of communication for traders from Tibet.

In the Punjab and upper parts of Scinde a very considerable network of excellent roads also exist, among others the important road from Umballa to Simla, and the Hindustan Tibet hill road extended beyond for over 150 miles up the Sutlej Valley. The Kangra Valley road, and that from Rawalpindi to Murree, and from the same place to Malora and Kohat; the frontier roads—Peshawur to Kohat, Thal, Katabagh, and

Isakhel; from Jhilum and Gujrat to Miani, Shahpur, Jhanj, and Chichawatni, situated on the railway above Mooltan; from Mooltan to Bahawalpur, and Dera Ghazi Khan, and numerous others.

Soon after the Sepoy Mutiny of 1857 serious attention was directed to the military necessity of reducing the difficulty and danger of crossing the river Indus, on the line of the grand trunk road in the neighbourhood of Attock, near the north-west frontier of India. The town and fort of Attock is situated on the left or eastern bank of the Indus, just below the junction of the Cabul river, at a point where the usually wide channel of the first is contracted to 1000 or 1200 feet in its passage through a range of hills which crosses its course. This contraction causes the river to rise in ordinary high floods to the great height of about 50 feet above the average cold season level, the velocity of the current being then increased to upwards of 12 miles an hour. The river, moreover, is subject to extraordinary floods at uncertain intervals, caused by the temporary damming up of one or other of its Himalayan branches by ice or landslips. In the years 1841 and 1858 it is recorded that the summer floods rose 100 and 70 feet respectively, above the ordinary cold weather level, and from the nature of their origin, and the formation of the valley at Attock, there appears to be nothing to prevent the occurrence of still higher floods at any time. The important crossing of the Indus in the neighbourhood of Attock, on the line of the grand trunk road, was for many years effected by means of ferry-boats during the summer, or flood-season, and by a temporary boat-bridge during the winter; the ferry crossing was always difficult and often dangerous, and the communication was at all times liable to sudden and prolonged interruption. Numerous proposals and trial efforts were made from time to time for improving this state of matters—such as a permanent boat bridge, a flying bridge worked by cables and the force of the current, a steam ferry, and a suspension or other bridge placed at a high level above the reach of floods. The great difficulties to be encountered in dealing with such a torrent as the Indus at Attock, subject to so great an ordinary flood rise, and liable, moreover, to extraordinary floods of uncertain

limits, led at length to a well-considered proposal in the year 1859, to turn the more important of these difficulties by the substitution of an under passage or tunnel beneath the river. Careful studies entered into showed that the banks and bed of the Indus at Attock were composed of slate rock, moderately easy to work, and apparently free from fissures likely to seriously endanger, or enhance the cost of the work. A scheme was therefore elaborated in full detail for a brick-lined tunnel 1215 feet long, 24 feet wide, and 20 feet high, to extend underneath the river, with a roadway 82 feet below low-water level. It was proposed that the level of this under passage should be reached by descending tunnelled approaches on either side of the river, each on a grade of 1 in 20; the entrances being placed at 100 feet above the level of winter flow—that is, at 182 feet above the floor of the actual river tunnel. The total length of the complete gallery, including the approach grades, would have been 7215 feet, or over $1\frac{1}{2}$ miles. The tunnel was to be ventilated by air shafts placed 600 feet apart (except at the river section, where the interval would be longer) in the shape of hollow cut-water towers, having their summits placed above the reach of floods, and the gallery was to be lighted throughout with oil-gas manufactured on the spot. Duplicate pumping engines were to be provided for keeping the tunnel clear of water, and provision was also made for its rapid flooding by means of a syphon at any time under military necessity. The estimated cost of this project was £104,408.

The scheme so far found favour with the authorities that a sum of £1000 was sanctioned for the purpose of carrying out an experimental trial drift, and in March 1860 the sinking of the necessary shafts on either bank of the river was commenced, by military labour. The leakage of water, however, was found to be heavier than anticipated, and subsequently further sums, amounting in all to £6000, were granted, until, in the summer of the year 1862, it having been found that the cost of the work greatly exceeded the rates of the first rough estimate framed, the Government decided upon a suspension of operations, at a time when only 258 feet remained to complete the junction of the drift-gallery across the river-section.

The drift underneath the river—about 6 feet by 3 feet in

section—and the vertical shafts on either bank were, however, afterwards completed, but the execution of the complete tunnel project was at the time postponed. The work actually carried out was as follows. On the east bank of the river a shaft, 168 feet deep, with 8 feet extra for drainage, was sunk through the hard rock. On the west side a similar shaft—situated 1505 feet 6 inches from the first—was sunk 93 feet deep, with 8 feet extra for drainage. The position of the west shaft being near the river edge, and much below summer water-level, a hollow pier of masonry was built up to keep out the floods. From near the bottom of the shafts two galleries were pierced northwards for a distance of 25 feet, each 6 feet high and 3 feet wide, to meet the main drift of the same dimensions, which was carried under the river, and on the east side of the river at the level of the grand trunk road, a gallery was driven to meet the vertical shaft. Owing to fissures in the rock, and the influx of water, both shafts were lined with brick masonry. The drift-gallery beneath the torrent of the Indus was made with a slope or inclination of 1 in 300 towards the east, or Attock side, in order to drain off the water. The work throughout was performed by a small detachment of the 24th Punjab Infantry, aided and directed by six European miners; the object of the drift heading being to test the nature of the rock, and the feasibility and probable cost of carrying out a complete tunnel scheme.

After some discussion it was decided on various grounds to abandon the tunnel project; it being held that an overhead bridge would be a more suitable crossing, and less costly to maintain. The miners were, therefore, withdrawn, and the heading was allowed to fill with water. In the year 1870—when Lord Mayo, then Governor-General, came to Attock,—the drift-gallery was pumped out for his inspection, and it was found to be quite uninjured. The proposal to complete the work was reconsidered, but it was again rejected in favour of the combined road and railway bridge, which now crosses the Indus at Attock, a remarkably fine work, which will be subsequently fully described. The tunnelling work carried out in 1860-64, was executed with few appliances, and under great financial restrictions, but was sufficient to demonstrate the per-

fect feasibility of constructing a permanent tunnel under the Indus at a reasonable cost. The military importance of a second line of communication removed at least from the danger of any possible injury by extraordinary floods, would appear to indicate the desirableness of completing the Attock tunnel, but the relative value and advantage of the work as compared with other means of passage, either at Attock or elsewhere on the Indus, is one for decision by scientific military experts. The successful piercing of the drift gallery under the river has been here mentioned as a bold and interesting operation, carried out upwards of thirty years ago, by a small and energetic body of pioneers, under very disadvantageous conditions.

In Central India occur the roads *viâ* Jeypore, Tonk, and Deoli, Ajmere, Neemuch, Rutlam, and Mhow. The line communicating with the North-West Provinces, leading from the grand trunk road at Aligarh, *viâ* Muttra, Bhurtpore, Jeypore, Ajmere, Sihari, Mount Aboo, and Deesa. In the Berars is an excellent system of first-class roads intersecting the rich cotton districts, such as the lines Malkapur, Buldwana, and Mehkar, Nandura, Molala, Khamgaon, and Jalna (leading into the Bombay Presidency *viâ* Aurangabad, and Ahmednagar to Poona). Akola to Bassim and Umardhed, Murtazapur to Karunga and Bassim, Budnera *viâ* Amroati to Morsi and Ellichpore.

In the comparatively late acquired Central Provinces, it is recorded that in the year 1862 there were barely twenty miles of first-class road fully opened out. During the following twelve or fifteen years, besides a very large aggregate mileage of roads of the secondary class, three excellently constructed first-class lines of communication were carried out, viz. the Northern, Eastern, and Saugor roads, together with those from Jubbulpore to Mandla, and from Warora to Chanda. The northern line extends from Nagpur *viâ* Seoni to Jubbulpore, a distance of 185 miles. The eastern road is carried from Nagpur, *viâ* Bhandara and Nandgaon, to Raipur, the chief town of the Chattisgarh district; and to Sambulpur. The road is metalled throughout, and permanently bridged, except over the very largest rivers. The Saugor roads form an important connecting link between Bandalkhand and Western India, these

extend from Jubbulpore, *viâ* Damoh, to Saugor and Hatta, and from Saugor to the valley of the Nerbudda, near Nursingpore. The short line of northern road from Nagpur, *viâ* Seoni to Jubbulpore, is stated, as regards engineering and alignment, to be one of the best in the interior of India. The road has for many years ceased to be of more than local value, but for a considerable time—before the difficult section of railway traversing the Nerbudda valley from Khandwa to Jubbulpore was completed,—this particular length of road formed a very important link in the chain of communication between Upper India and Bombay, inasmuch as it connected the termini of the then open railways situated at Nagpur and Jubbulpore respectively. The road, which is everywhere bridged and metalled, surmounts a portion of the Satpura range of hills by a well laid out and constructed length of mountain-road, with an even line of gradients of 1 in 30. The Seoni plateau is 1500 feet above the level of Nagpur, and until this line of communication was made, [all produce from the high lands could only be brought to the larger markets, or to the railway at Nagpur, by means of pack animals. The road also crosses two important rivers, viz., the Kanhan, and the upper portion of the Weingunga; the first by a handsome stone bridge, which is probably the largest bridge for road purposes constructed in India, and, as such, has been selected for more detailed illustration in the following chapter. The bridge over the Weingunga is a fine brick structure, consisting of twelve arches of 50 feet span, placed at a considerable elevation above the river.

The numerous important through lines of first-class roads in the Bombay and Madras Presidencies are now for the most part old-established highways, and later construction, here as elsewhere, has largely consisted of district roads and railway feeders. By the year 1870, 1800 miles of roads, of which upwards of 500 miles were metalled and bridged, are stated to have been constructed in Mysore alone, opening up numerous lines of communication for cart traffic, from the elevated plateaux, down to the principal places on the Western coast.

CHAPTER III

Types of bridges on Indian roads—Early iron suspension bridge near Saugor—Early iron bridge over the Gumti at Lucknow—Particulars of history—Masonry bridges—Examples—The Palamcotta bridge over the Tambrapurni in Tinnevely—Bridge over the Sohan, Lahore, and Peshawur road—The Kanhan bridge at Kamthi—Description of the Kanhan bridge—Unsuccessful attempt to bridge the river—Construction of the second bridge—Foundations—The Cofferdams—Piers and abutments—Details of timber centerings—Archwork—Method of striking the centres—Particulars and cost of bridge—Paucity of statistical data relating to Indian roads—Probable annual amount expended on roads in India—Conclusion.

It is evident that over the immense mileage of metalled and bridged roads, intersecting in every direction the great continent of India, and traversing such wide tracts of country, covered for the most part with large watercourses and more or less frequent great rivers, an enormous aggregate number of bridges spanning these streams will occur. Moreover there will necessarily exist a general similarity in the type and particulars of such structures. For ordinary road purposes Indian rivers and watercourses of all sizes are commonly crossed by masonry arched bridges of brick or stone, with piers and abutments founded either directly on the hard substratum found at their sites, or on cylindrical wells, or blocks of masonry sunk to a sufficient depth into their sandy beds. Occasionally, although rarely, the superstructure, and even the piers of road bridges may be constructed of iron, or timber—the latter material, however, for climatic reasons, being ill adapted for permanent erections in India. In the few notices or illustrations of Indian road constructions which follow, the particular works mentioned are chosen either on account of special interest as early examples of road engineering, or on account of their more than

average size ; from either category the number of works noted might have been enormously increased.

A road work, interesting only from the early date of its construction, and from the circumstance that the whole structure was made up in India, and erected without the aid of skilled workmen, is that of an iron suspension bridge, constructed upwards of fifty years ago, to carry a road over the river Beosi near Saugor in the Central Provinces. The bridge is 200 feet in clear span between the points of suspension, and the abutments, which are built on solid rock found near the surface, are 42 feet high to the roadway. The chain piers carried on the abutments are 33 feet high above the road ; the arched passage ways through them being 9 feet wide and 15 feet high. The bridge platform is 200 feet long, 12 feet wide, and weighs, with suspension chains, about fifty-three tons. The iron rod suspension chains are twelve in number, arranged in pairs,—three pairs on either side, one above the other, at a distance of 2 feet apart, they pass over twelve iron rollers a foot in diameter (each weighing about half a hundred weight), placed on the suspension piers, and are firmly anchored into masses of masonry 16 feet below the surface of the road. The twelve main chains are made up of solid round bars $1\frac{1}{2}$ inches in diameter with enlarged eyeholes, and from 15 to $15\frac{1}{2}$ feet long. They are bolted together in pairs, and are so disposed that vertical rods of square iron may fall from the joints of each chain alternately in parallel lines 5 feet apart, to support the road platform.

The road platform is raised, or 'cambered' nine inches in the middle, is formed of two lines of flat iron bars, 4 inches by $\frac{3}{4}$ inch, set on edge, and suspended on each side of the bridge from the vertical rods ; carrying cross joists and longitudinal planking 3 inches thick, covered by an upper layer of cross planking $2\frac{1}{2}$ inches thick. The planks were imbedded in a composition of resin boiled in linseed oil mixed with ashes. A cornice or moulding of wood is secured along, and protects the outside edges of the planking, and a trussed hand-rail of pillars and diagonal braces of iron, surmounted by a stout wooden top-rail, runs from end to end of the platform on both sides. The quantity of material employed in this small suspension bridge

is 14½ tons of ironwork, 36 tons of wood, and 91,388 cubic feet (or 3385 cubic yards) of masonry. The cost of the finished structure is not given.

The details of the work throughout display considerable ingenuity and neatness in the fittings and attachments, and in the precautions taken to allow free movement in all parts of the ironwork without injury to the masonry; the ironwork is all hand-wrought, and the pin or bolt-holes are all accurately bored by hand to exact fit. The ready resource and patient labour that must have been exercised in carrying out such a piece of work in the far interior of the country so far back as the year 1840 or 1841, by the aid only of native workmen and appliances, is sufficient warrant for the inclusion of this suspension bridge in any mention of early bridge structures in India.

Another very early example of an iron road bridge is the singular but pleasing structure built over the Gumti at Lucknow. This bridge consists of three cast-iron ribbed arches, supported on piers and abutments of brick masonry, carrying a roadway 30 feet wide at a height of 35 feet above low water in the river. The centre arch has a span of 90 feet, with a rise of 7 feet, and the two land arches are each 80 feet span, rising 6 feet in the centre, giving a graceful curvature to the outline of the bridge. The piers and abutments are built on wells sunk into the river-bed. The structure crosses the Gumti almost immediately opposite the site of the old Residency of Lucknow, memorable for its gallant and successful defence when besieged during the Mutiny of 1857. The history of the Gumti iron bridge is in some respects curious. The structure is said to have been designed by Rennie, the great engineer, architect, and builder of London Bridge. The ironwork was received in Lucknow in the year 1798, during the reign of Nawab Saadut Ali Khan, King of Oude, only about twenty years after the erection of the first iron bridge in England, and it is supposed that General Martin, the talented and eccentric French officer, then living in Lucknow, suggested the idea of the bridge to the Nawab. It is probable that the unfamiliar character of the work caused the project to be laid aside, for the ironwork remained unused in Lucknow for more than forty years, when it was at last erected, and the present bridge completed in the

years 1841 to 1844, at a cost of about £18,000, without including the sum paid for the ironwork, which is not known.

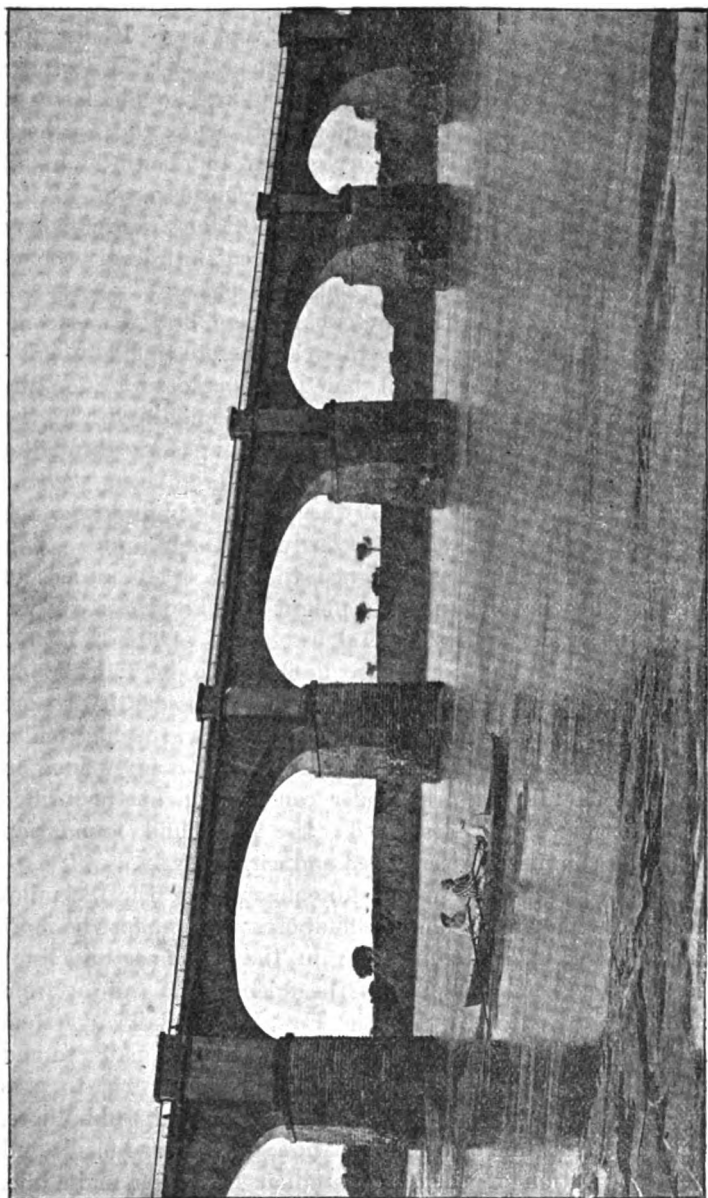
An early masonry road bridge of some interest is that constructed over the Tambrapurni river, in Tinnevely, in the year 1843, known as the Palamcotta bridge. This is a handsome structure; its architectural elevation having been copied (on a reduced scale) from the Waterloo Bridge over the Thames in London. The bridge consists of eleven elliptical arches, each of 60 feet span and 17 feet rise in the centre, springing from ten piers averaging about 10 feet in height above low water, and the same in width, with two abutments 15 feet thick at springing level. The breadth of the arch-work on the under side is 27 feet, carrying a level road across the river 24 feet wide and 800 feet long. On each face of the bridge two Doric columns stand on the projecting cutwaters of the piers, occupying the space between the arches, and supporting a bold entablature with balconies. An open balustrade on each side extends along the entire length of the work. The piers for the most part were founded on hard rock *kunka*, situated at a small depth below the river-bed, but three consecutive piers were built on rows of small wells, sunk to a depth of 10 or 12 feet only, where a firm bed of clay was met with. Along this portion of the work, up and down stream lines of wells were also sunk to serve as curtain walls, and to retain a pavement or flooring to protect the foundations. The interior of all the wells was built in solid, and the spaces between them were filled in with rubble stone in cement up to low-water level. On this foundation the three footing courses of the piers were laid in stone, with cut-stone face work cramped with iron. Above the footing courses the bridge is constructed of neat brickwork partly stuccoed.

On the Lahore and Peshawur road, a plain substantial bridge of combined stone and brick masonry crosses the Sohan river, a stream draining an area of nearly 600 square miles; the depth of water during high floods being 15 feet, with a mean velocity of current of 9 or 10 feet a second. The discharge of the river in floods is calculated at about 91,000 cubic feet a second, and at the site of the bridge the river is over 1000 feet wide. This example will serve as a typical illustration of the larger class of

road bridges constructed in India, which are to be met with more or less frequently. The Sohan bridge consists of fifteen brick arches each of 63 feet span, carrying a cut-stone cornice, and a level roadway 26 feet in width. The arches are supported on piers and abutments of coursed rubble masonry, 35 feet high from lowest foundation to the springing of the arches. The bridge was built in three sections of five spans each, the abutment piers and end abutments being 12 feet, and the intermediate piers 9 feet in thickness. The foundation footing courses, which rest in firm red clay, are laid at a depth of 17 feet below the river-bed, and are protected by a continuous flooring of stone blocks, and up and down stream curtain walls, carried down to the same level as the foundation masonry of the piers. The clear waterway of the bridge is 945 running feet, the cost of the structure having been about £4300.

Probably the largest of the very numerous ordinary road bridges constructed in India is that over the Kanhan river on the northern line of road from Nagpur to Jubbulpore in the Central Provinces. This bridge—which was constructed between the years 1866 and 1873—adjoins the military station at Kamthi, situated about ten miles north of Nagpur. The Kanhan is a river of considerable magnitude, tributary to the Weingunga. The accompanying illustration, which represents a third of the total length of the road-bridge constructed over it, will convey an idea of the main features of the structure.

The Kanhan bridge, with the exception of the ornamental balustrade or parapet, which is of cast-iron, is constructed throughout of sandstone masonry; the stone for which was obtained from quarries situated along the north bank of the river, within a few miles of the site of the work. The bridge is constructed on a severely plain, but at the same time handsome design, and conveys an idea of solidity combined with lightness and boldness of outline. It is about 1300 feet long over all, and consists of twelve flattened arches of 80 feet span, springing at nearly the highest flood-level of the river, or at a height of 39 feet above the mean summer water-flow, each arch having a rise in the centre of 16 feet only, or one-fifth of the span. The total available waterway of the bridge is 38,400 superficial feet clear of any contraction, and as the maximum



ROAD BRIDGE OVER THE KANHAN RIVER AT KANTHI.

flood discharge of the point of crossing is calculated at about 458,000 cubic feet per second, a current velocity of 12 feet per second is required to pass the highest floods. The bed of the river consists of pure sand overlying Gneiss rock. The latter is found almost on the surface immediately below the northern bank, but dips gradually and irregularly to about 30 to 32 feet below the lowest water-level on the southern side of the river. The piers and abutments of the bridge are everywhere carried down to the solid rock, which was cut into level benches to receive the lowest foundation courses of masonry.

The construction of the present Kanhan bridge was commenced in the year 1866. Several years before this date, however, an unsuccessful attempt had been made to bridge the river, at an ill-chosen spot, situated about a mile higher up the stream, where the channel was contracted in passing through a gorge, just below the confluence of three large rivers, viz. the Pench, Koilar, and Kanhan, and where, during high floods, the velocity of the current was necessarily extremely rapid. This first proposed bridge was designed to have twelve arches of 59 feet span each, springing at a height only 28 feet above the bed of the river, giving a total water-way of about 17,000 superficial feet. The piers were designed to be founded on wells, sunk into the sandy river bed, where the depth of sand overlying the rock below was insufficient for this particular method of foundation. During the course of a high flood in the year 1864, all the works under construction at this bridge were undermined and destroyed; the piers and foundation wells being completely overturned and carried away.

At this time, and for many subsequent years, the 185 miles of road between Nagpur and Jubbulpore, was perhaps the most important link of communication in India, connecting, as it then did, the terminal points of the open line of railway from Bombay on the one side, with the East Indian Railway system on the other. For many years all passengers and mails, to and from Bombay, Calcutta, and the Upper Provinces, had to pass between the two railway termini at Nagpur and Jubbulpore, by means of this line of communication, until that difficult and expensive portion of the Great Indian Peninsula main line, traversing the Nerbudda valley between Khandwa and Jubbulpore,

pore, was completed. The removal of the obstruction to traffic caused by the Kanhan river, during the four or five months of the rainy season, was, therefore, a matter of such considerable moment, that after the destruction of the works on the first bridge, it was almost immediately determined to commence the construction of the present one, on a new and much superior site, and with a greatly enlarged waterway. A short description of this fine work, together with some of the more interesting details of its construction, will afford a suitable example of the largest class of road bridges in India.

To obtain a secure foundation for the piers and abutments of the bridge, which would be exposed to the full force of that great depth and velocity of current which we have already indicated, it was obviously necessary to commence building operations on the solid rock, which had been proved by borings to exist at varying depths, from a few feet on the north side, to upwards of 30 feet below the level of the lowest summer flow on the south side of the river. Between this water-level and the very irregular surface of the rock beneath, the space was occupied by pure clean sand. In order to lay bare the surface of the rock at the site of each pier or abutment foundation, it was necessary to excavate and remove this overlying sand, and whilst doing so to exclude the entry of water, which would inevitably wash fresh sand into the excavation. This could only be done by employing what are technically called *cofferdams*. A cofferdam, according to the depth or head of water to be excluded, is formed of a single, or a double row of pointed piles, driven closely together round the site of a foundation, so as to enclose it. When the piles are driven down to the necessary depth and the cofferdam is completed, the water is pumped from the interior area by means of steam-pumps, and the solid material within can then be excavated to any depth desired, within the limit of depth of the cofferdam itself.

In all ordinary cases of the employment of these enclosing dams, whether single or double, the piles are driven into some retentive bed of clay or other material, sufficiently firm to serve as a foundation for the intended structure, and to some distance below the level of the actual commencement of the foundation courses. It is obvious, however, that when the

foundation material to be built upon is solid rock, into which the piles cannot be driven, a problem of a very different nature is presented. In such a case the excavation inside the cofferdam has to be carried down to, or even below, the level on which the pointed piles themselves rest, so that, when the outside head of water is considerable, and the surface of the underlying natural rock is exceedingly uneven and irregular, it becomes a most difficult matter to exclude the water and sand, and prevent it rushing in between the bottom of the cofferdam and the surface of the rock. During the interval necessary for the work of levelling the rock surface and building up the masonry to a height sufficient to enable the lower part of the dam to be securely stopped from the inside, the rise of water can only be kept down by an extraordinary application of pumping-power sufficient to cope with the inrush, which, in spite of all expedients that may be employed, such as the sinking of bags of clay or cement around the feet of the piles, must always be exceedingly heavy.

If the pressure or head of water to be excluded is small, a single cofferdam can be made sufficiently water-tight; but beyond a certain depth it is necessary to employ a *double* dam, that is, two lines of piling, one inside the other, with an interval usually about 6 or 8 feet between them. In this case the space between the two rows of piles is first excavated as far down as possible by the aid of pumping-power, and bags of clay are then carefully packed and piled within it. These bags by their own weight, and by the weight of other bags continually added from above, gradually sink in proportion as the sand below them is forced into the interior of the now excavated dam by the underflow of the water, until eventually they reach the rock surface, and serve materially to reduce the rate of inflow through and underneath the piling, thus enabling the pumps more easily to cope with the volume of water, until at last the whole interior area of the cofferdam is laid dry, and the workmen are enabled to level the surface of the rock, in readiness to receive the first foundation masonry.

It was by the above means that the foundations of the greater number of the piers, and the large and deeply-founded southern abutment of the Kanhan bridge was laid on the rock

bottom of the river-bed. In this work, including wet and dry excavation, about 3 millions of cubic feet, or 130,000 cubic yards of material, weighing upwards of 187,000 tons were excavated, of which more than half a million of cubic feet was excavated below water-level at the site of one foundation alone, viz., in reaching the rock under the southern abutment of the bridge, where the size of the double cofferdam employed was 180 feet long and 60 feet broad. The double cofferdams at the sites of the deepest piers were 80 feet long and 43 feet broad, the depth of the rock below sand and water-level being from 15 to about 27 feet. Nearly 20,000 cubic feet of timber and 18 tons of manufactured ironwork were utilised in the construction of these foundation cofferdams.

The piers and abutments of the bridge are built of rock-faced ashlar, hearted with rubble masonry of a substantial character. The piers are 10 feet in thickness at the top, increasing downwards, according to a batter or inclination of 1 in 24. The twelve spans of the bridge are divided into three bays, or series of four spans each, by abutment piers of heavier dimensions, it having been intended in the first instance to construct the arches in sets of four. Subsequent arrangements, however, by means of which the timber centerings, or supports on which the arches were built, were enabled to be left standing during the flood seasons, permitted the arches to be constructed independently of the abutment piers. Four sets of timber centres for the temporary support of the arches during construction were, however, employed. These were constructed chiefly of foot square timber, disposed according to a very firm and rigid design. During the turning of the archwork, each centre had to support a maximum dead weight of 570 tons, and owing to the very flat form of the arches it was absolutely necessary that the sinkage or settlement of the temporary timber work under this great weight should be as small as possible. That the design fully answered the requirements of the case is evidenced by the circumstance that the maximum subsidence of the centres under the 570 tons of dead weight imposed upon them was hardly more than 2 inches.

In the case of every span where it was necessary that the centering should remain standing during the rainy or flood

season, the central supports of the timber work were carried, either directly or through the intervention of dwarf piers, on the rock-bottom of the river, and were protected by a heavy mass of rough stone thrown round them. Several of the bridge centres, during the construction of the arch-work, were exposed to the severe action of floods of nearly maximum volume, with perfect safety and success. The width of the centres on their upper surface was 25 feet, and their height from lowest water-level to the crown of the arches was 55 feet. Including foundations, the maximum height of the centering reached about 75 feet. In the construction of the temporary timber work, including renewals during its use, 37,500 cubic feet of timber, and more than 50 tons of manufactured iron-work in the shape of straps and bolts, were employed; the total weight of wood and iron in each centre being about 300 tons. The temporary centering of the arches cost £17,800, or at the rate of nearly £1500 per span of the bridge.

As soon as the erection of the first timber centres was complete the construction of the archwork commenced. The arches of the Kanhan bridge are 80 feet in clear span, 24 feet wide, and have a rise in the centre of 16 feet. They are of oval outline, composed of seven blended curves ; the tangent to the first curve being vertical. From the haunch stones resting on the piers to the keystones in the centre, the archwork is built of radiating stones, each of the full depth of the arching. These stones vary from $6\frac{1}{2}$ to $4\frac{1}{4}$ feet long, and are of proportionate breadth and thickness. Their weight varies from $2\frac{1}{2}$ to $\frac{1}{2}$ a ton each, and the average number in each arch is about 1000, or 12,000 in the whole bridge. The total weight of a single completed arch is 735 tons, and the calculated pressure at the keystones in the centre is 22,000 lbs. per square foot, or 152 lbs. on every square inch. When the support afforded by the centres was removed, the average sinking or settlement of the whole twelve arches was under $1\frac{1}{2}$ inches, the maximum being under $2\frac{1}{2}$ inches. This exceedingly small settlement was due to the extreme thinness of the mortar joints between the arch voussoirs, and to the perfectly even and level bed to which each arch course was worked before the next was laid on it.

On the successive completion of every arch, the 'striking' of

the centres—that is to say, their removal from contact with the arch masonry, so that the latter might be left self-supporting, was effected in the following manner. The centering was divided into two portions, from about the line of the springing level of the arches. The upper or arch-shaped portion consisted of six vertical ribs, firmly braced together, and covered at the top with ‘lagging’ or planking to receive the arch-stones. Between this upper portion of the centering and the lower division sixty iron cylinders, disposed in six rows of ten each, were interposed. Each iron cylinder was 15 inches high and 12 inches in diameter, and was filled with fine dry sand. The whole upper division of the timber work, weighing from 90 to 100 tons, was supported on this sand, through the intervention of sixty wooden plugs, each 11 inches in diameter, which entered the cylinders. Near the bottom of the latter two holes about an inch in diameter were bored, and were kept firmly closed by wooden pegs or plugs, but when it was desired to lower the upper portion of the centering and detach it from the archwork, the 120 plugs closing the holes in the sixty iron sand cylinders were simultaneously withdrawn, permitting the dry sand to slowly escape, and the whole mass of timber work forming the upper portion of the centering to descend in a regular and even manner for a vertical distance of one foot, or until well clear of the arch masonry. By this method of lowering the heavy timbering all concussion and jar to the archwork was avoided, and the operation of striking the centres was performed with the most perfect ease and success.

The upper line of the Kanhan bridge is crowned with a massive and boldly projecting cornice of ashlar stone, carrying a cast-iron balustrade or parapet, the width of the level metalled roadway over the bridge being 20 feet. The total quantity of sandstone masonry in the whole structure is 975,640 cubic feet, or 36,135 cubic yards, of which 158,640 cubic feet, or 5876 cubic yards, is composed of archwork. The bridge was opened for public traffic in September 1873, the total cost to the local Government of the Central Provinces, exclusive of the road approaches, amounting to £109,550, or about £84 per foot run of bridge.

A short time after its completion the Kanhan bridge was

temporarily used to carry—in combination with the road traffic—a narrow-gauge railway, which was constructed to connect Nagpur with the rich grain-producing districts of Chattisgarh. On the recent conversion of this line of railway into one of a broad gauge, and its extension to join the East Indian Railway near Calcutta, an independent railway bridge of iron girders was constructed over the Kanhan river, not far from the site of the older work, which then reverted to its original character and use as a road-bridge.

Very little statistical data or information appears to be available in connection with road construction generally in India. In the ten years from 1848 to 1858 it is recorded that some 30,000 miles of roads of various classes were constructed, of which 5000 miles were of the first-class metalled and bridged type. During the following fifteen years road-making—more particularly in the Central Provinces and in the Punjab—was energetically carried on, but the rapid growth of the railway system from this time gradually diminished the importance of new trunk lines, except in the hill regions of the Himalayas and other outlying portions of the country beyond the probable immediate reach of railways. To such places important new roads were, and still are being constructed. Local district and railway-feeder roads—especially in times of scarcity or famine—have, however, continued to be made in all the chief provinces; their construction having in the year 1871 been handed over to local boards or committees, duly provided with the revenues or grants considered necessary for the purpose. A sufficient extension of railway feeder-roads, capable of being kept open during the entire year, still remains, however, a very urgent need in many districts.

No accurate estimate can be formed of the total length, even of the main metalled and bridged roads now existing in India, but it is stated that during the thirty years previous to 1889 the amount expended from general and local funds on ordinary roads and bridges throughout the country does not fall short of Rs. 1,500,000¹—or a million and a half sterling—a year, and all important centres of population in the chief provinces—especially of Upper India—have now long been connected by lines of permanent highway.

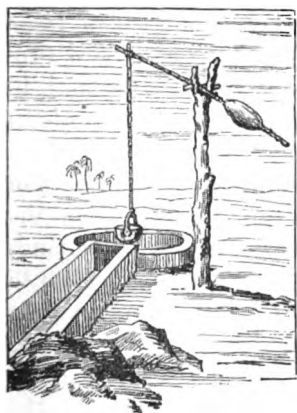
¹ *Indian Administration during the past thirty years.*—Parl. Paper, 1889.

IRRIGATION WORKS IN INDIA

CHAPTER I

NATIVE WORKS

Early introduction of irrigation into India—Rainfall conditions—Bengal—North-West Provinces—Punjab—Scinde—Bombay and Madras—Modes of obtaining water for irrigation—Varieties of canals—Native works—Ancient inundation canals—Native state of Bahawalpur—Uncertain and irregular system of irrigation—Madras irrigation—Storage tanks—Channel irrigation by means of ‘anicutts’ or weirs—Kaveri Delta irrigation—The ‘grand anicut’—Native weirs—Mode of construction—‘Bhandaras’ in Khandesh—Tanks in Mysore and the Carnatic—Examples of large tanks—Ponairy tank—Viranum tank—Chembrembaukam old and new reservoir—The Cummun tank—Lokain embankment—The Nuggar ancient tank in Mysore—The Kaveri Pauk tank—Description of the Madduk Masur tank.



THE value of artificial irrigation and its employment for increasing the fertility of the soil, was in very ancient times well known and practised in India. Its early introduction is no doubt of Hindu origin, and its greater or less prevalence in any district was, as it still is, mainly dependent on the deficiency or abundance of the rainfall, and the supply of water carried by the water-courses and rivers of the country. In the extreme eastern districts of the Province of Bengal the annual rainfall is so abundant and regular in quantity, that artificial means of irrigation are needless, and failure of the crops is practically unknown. In Behar and Orissa the rainfall is ordinarily large and even excessive, but less certain ; disastrous

failure occurring at long intervals, such as occurred in the latter district in the year 1866.

Over a great portion of the Lower Province the high annual rainfall, added to that precipitated on the slopes of the Himalayan range to the north, occasionally floods the rivers with such great volumes of water as to inundate the country and damage the crops by excess of moisture. Artificial irrigation is here more commonly resorted to for the cultivation only of the cold weather crops.

In the higher Provinces to the north-west, however, the rain clouds coming up from the sea, before meeting the northern range of mountains, have first to pass over immense tracts of highly-heated land, and have already discharged a large portion of their contents. Hence arises that almost constant scarcity of water for purposes of cultivation, which renders artificial irrigation in this region of such inestimable importance.

Still farther to the westwards, over the greater part of the Punjab Province, south of Lahore, the amount of annual rainfall rapidly diminishes, many districts being practically rainless. In this region, without the aid of water drawn from the great perennial rivers or from wells, agriculture becomes virtually impossible. Over a large tract of the central districts of India the conditions are much the same as in the North-West Provinces, the average annual rainfall being between 30 and 40 inches, increasing gradually in quantity to the eastwards of Nagpur.

Along the line of the Western Ghats, from the Gulf of Cambay to Cape Comorin, the rain-laden clouds from the south-west principally discharge themselves on the high lands immediately adjoining the coast, giving a fall averaging 100 to 150 inches; but, as a consequence, farther inland, over a long central belt of country extending from Khandesh to the extreme southern point of the peninsula—comprising nearly all the central portions of Bombay, Hyderabad, and Madras—the annual rainfall is scanty and inconstant. In the southern portions especially of this tract, owing to the fall of the country, the water is carried off by the rivers with great rapidity, hence arises that immense development of artificial tank and other irrigation, under both the ancient and modern rulers of the

country, for which the extreme southern part of India is so celebrated.

There are three special methods of obtaining a supply of water for irrigation purposes, viz., by means of wells, storage tanks, and canals derived from the rivers of the country—any or all of which may be combined. Canal methods may be divided into several classes. First, there are simple ‘inundation’ canals, consisting of water-channels, artificial or semi-artificial, unprovided with any means of regulating and controlling the supply at the head—which lead water away from the rivers, and are filled only when the latter are in flood, being incapable of drawing off water at other times. Secondly, there are canals which may be called ‘periodic.’ These are derived from rivers having a changeable and uncertain supply. In order to prevent the water running to waste, some kind of temporary or permanent dam is constructed across the river bed, to intercept, store up, and divert the water into the canal, either during the rainy season only, or more constantly, as the supply in the river admits. Lastly, there are those which are called constant or ‘perennial’ canals. These draw their supply from rivers which at all times of the year run with a sufficient volume to supply the canals, without previous storage, and are supplied with dams or weirs, and necessary works at the head for raising and regulating the supply of water as required.

Wells, artificial storage tanks, and inundation canals have for ages been largely employed by the natives of the country, also to a certain extent ‘periodic’ canals; but it is only during the period of British rule, with small exception, that the great class of ‘perennial’ canals have been constructed.

Over the greater part of the Indus basin, the cradle of the first civilised races in Hindustan, and especially in those almost rainless portions, where cultivation, without the fertilising influence of water would have been impossible, evidences of ancient ‘inundation canals’ for irrigation are to be met with in great quantity. These artificial cuts were sometimes of large dimensions, in some cases they were no doubt originally old abandoned river-channels kept open by continual clearance. As their name implies, they could only be of service during the period when the rivers were in flood.

In the early part of the year, under the influence of the growing heat of the sun the water stored up in the form of snow on the Himalayan mountains is gradually released. Increasing volumes descend the Indus and other snow-fed streams, and the canals are filled; the water reaching its maximum body during the fierce temperature of the summer months, when for the purposes of man it is most required; but during the winter months of the year, the level of the water in the river remains at too low a level to enter the elevated channels. These inundation canals, together with wells, were the only means of irrigation available in very ancient times in the Punjab and Scinde.

A very large number of early inundation canals are to be met with in the almost rainless regions of the Indus basin, especially in the great alluvial plain below the junction of the five Punjab rivers. In size they vary from 10 to 300 feet in width, from 3 to 10 feet in depth, and are of all lengths up to sixty or seventy miles. As already stated there are no head works to control the supply of water, and irrigation from them is carried on by means of branch cuts leading from the main canal, which feed the minor distributing channels. The excavations are carried at such an angle from the parent stream as to gain as great a fall as the nature of the country admits. Owing to the constant encroachment or recession on either hand of the Indus, these canals are most difficult to keep open from season to season. The Indus brings down an enormous quantity of material held in suspension in its waters, which being deposited along its course causes a gradual raising of its bed. The banks also are constantly being eroded, thus there is a continued action tending to fill up the channels derived from it, necessitating heavy periodical labour to keep them clear. The greatest deposit takes place in the portion nearest to the river, where it often reaches 5, to even 10 feet in depth; and in order to preserve the original level, stone posts are set up to mark the limits of clearance required.

Owing to the elevated position of the bed of the Indus, the highest land is at the river banks, and the inundation canals are cut through this relatively high margin in order to carry water to the lower levels removed from the stream. An

interesting example of these ancient canals is that called the 'Bigari,' on the right bank of the Indus, below Sukkar. 'In 1844 it was described by Lieutenant Maclagan as having a total length of forty-eight miles, with a fall of 38 feet. The head was on a side channel at a distance of nearly seven miles from the Indus. For the first twenty-three miles it passed through a country covered with jungle, but presenting frequent traces of former cultivation. It was then becoming yearly smaller from the defective system of clearing. At the head it was 24 feet wide, with a depth of 9 feet. This canal in 1854 was enlarged, and its capacity nearly doubled, by the British Government. One of its main branches or offshoots was also cleared, numerous villages sprang up along its course, and the town of Jacobabad was founded in the midst of a barren, treeless waste, the tail being extended to the Kelat boundary, near Khyra Garhi.'¹

Another large and ancient inundation canal, originally following a natural branch of the Indus, is that known as the 'Fuleli'—from Hyderabad, in Scinde, to a point on the Indus sixteen miles below. The junction of the natural channel at the latter point was closed by a dam in the time of the Amirs, and the water was utilised to feed the Gaja Guni and other canals to the southwards. A large number of the very numerous ancient inundation canals and their branches in this part of the Indus valley have during comparatively recent years been improved and rendered exceedingly valuable for the wants of this arid region.

In the higher portions of the Indus valley above Multan, and in the valley of the Sutlej, inundation canals were formerly numerous, and the rich country of Muzaffargarh between the Chenab and the Indus, was one sheet of cultivation. In a former age such canals were conducted from all the five rivers of the Punjab, and traces of them are perceptible, with ruins of cities and villages on their banks. In the central parts of the 'Bari Doab,' above the Multan district, the face of the country is covered with traces of former life and prosperity, due to inundation canals derived from the old 'Beas, which, before it

¹ *Statement exhibiting the Moral and Material Progress and condition of India during the year 1872-73.*—Parliamentary Paper.

was diverted into the Sutlej in 1790, had an independent course to the Chenab.'

The chief canals of the upper Sutlej system are the Kanwah and the Sohag. The Sohag canal leaves the Sutlej a little below the mouth of the Kanwah, and irrigates the country between that canal and the river. It is seventy-three miles long, and has been much improved under British rule, the channel having been straightened, and masonry outlets constructed. A continuation of the Sohag is connected with the old Beas by a cross channel called 'Nawabbin,' a name derived from the Nawab of Multan in the last century, who carried the water into the Beas, and thence into the Multan district, for the purpose of providing a navigable passage for his wife, who was travelling down country in a boat.¹ The Afghan rulers left by Aurungzib were to a great extent, the authors of this system of irrigation.

In the native state of Bahawalpur a great number of inundation canals formerly existed, fed from numerous branches of the Ghaggar—the ancient 'Saraswati'—which formerly flowed through the country to the Indus. After the bed of the Ghaggar dried up, and the desert sands had encroached over large districts which had once been fertile and populous, many of the old branches of the Ghaggar continued for a long time to be partially supplied with water by cuts made from the Sutlej to their nearest points, but gradually, year by year, more and more land fell out of cultivation, until nearly the whole of the upper north-east portion of the State became practically a desert. Since the year 1867, under the fostering care and energy of the English political agents in power during the minority of the Nawab of Bahawalpur, a large amount of prosperity has been restored to these regions. Numerous inundation canals of considerable size and length have been constructed, together with some few perennial canals, drawing off the Sutlej water from below the winter level. Many of the older water lines have also been reopened, and the blessings of extended irrigation have once more been diffused over the land.

'The important system of inundation canals from the Punjab

¹ *Statement, etc., ut supra.*

rivers, upon which the very existence of the inhabitants of a vast area in the rainless region depends, was administered in former times by the people themselves. The whole of this class of canals within British territory has now long been placed under the regular management of the Irrigation Department. Until a comparatively recent period there was no direct canal revenue from this class of canals, the returns appearing only in land revenue.¹

It is obvious that inundation canals, under any circumstances, afford a very irregular and uncertain system of irrigation, being entirely dependent on the fixed volume, regular periodicity, and duration of the river floods. To convert this system of canals into one of a certain and permanent character, whether in Scinde or in the Punjab, presents no difficulty beyond that of expense, but this consideration has exceptional force owing to the comparatively sparse population and poverty of the districts where the system is chiefly met with.

In the southern districts of the Madras Presidency, where the rainfall is small and exceedingly precarious, and river supplies are more difficult to obtain, an enormous number of artificial tanks or reservoirs for the storage of water, some of great antiquity, are to be found. These tanks, often of prodigious size, and displaying in their construction a very high degree of engineering skill, were, and still are, so contrived as to collect during the rainy season, and store up large bodies of water for use during the season of drought. The storage of water in reservoirs for irrigation purposes, although reaching an unusual development in Madras, was in early times as it is at present, common over the greater part of India. In the neighbourhood of almost every large town, reservoirs or tanks for bathing, washing, and drinking purposes, are very numerous. These tanks are usually fed by the surface drainage of the immediate ground. Some of them are of very considerable size, and are enclosed by massive masonry walls, having flights of steps at intervals for the convenience of bathers. Large trees, affording a grateful shade, overhang the banks, and picturesque temples or shrines cast their reflections in the water. Many of these tanks are of great beauty, as that of Saugor in the Central

¹ Parliamentary Paper, *vide* note, page 8.

Provinces, or the Holy tank in the centre of the large commercial town of Amritsar, in the Punjab. The latter, with its golden temple in the centre, connected with the shore by a marble footway, and the quiet seclusion of its surrounding marginal platform, forms one of the most striking and beauteous objects in India.¹

The main feature of the ancient irrigation system in the Madras Presidency was, to a great extent, as it still is, the employment of large or small tanks for the storage of water, but channel irrigation was at the same time extensively practised. The smaller streams of Southern India are frequently mere torrents, carrying off the water with great rapidity, so that they become dry after a few hours. In order to utilise the water for irrigation purposes, it was intercepted by *anicuts* or weirs, built across the streams. It is only the larger and more important rivers that can supply means of irrigation on a large scale directly from their channels, and probably all these rivers were to some extent laid under contribution in former times. The most interesting example is perhaps the Kaveri Delta irrigation in the district of Tanjore, which, designed and constructed by native engineers, contained the germ of the great Delta schemes subsequently carried out by the British Government. Near the head of the Kaveri Delta, 'the ancient native work, called the "grand *anicut*," was a solid mass of rough stone, 1080 feet long and 40 feet broad, stretching across the bed of the Kaveri in a serpentine form at the lower extremity of Seringham island. It was built upwards of 1600 years ago.'² The improvement of the Kaveri system of irrigation was the earliest irrigation work undertaken by the English Government in this part of India.

'Tinnevely, the southernmost district of Madras, is watered by the Tambrapurni river by means of *anicuts* placed at intervals across the stream, whence channels are led, either directly for irrigation, or to supply tanks—the number of which in this district is exceedingly large. The *anicuts* are earth-embankments with masonry sluices: they are very

¹ *Vide* 'Public Works in the Bengal Presidency,' vol. xviii. *Proc. Inst. Civil Engineers*.

² Parliamentary Paper, *vide* note, p. 8.

ancient native works.¹ In the middle reaches of many of the larger rivers there are to be found ancient *anicuts* or weirs of stone, generally admirably situated, but of rude and imperfect construction: many are ruined, and others require extensive annual repairs to keep them serviceable. Advantage was usually taken of a reef of rocks running across the river, the low places being filled in with rubble, or random stone, faced on both sides with large blocks laid dry, and occasionally fastened together with cramps. There is in most cases much leakage through the body of these native weirs, but it can hardly be due to this circumstance, that although they are not provided with sluices for creating a scour, the river-beds on the upper side of them do not appear, except in a few cases, to have been materially raised.²

The sites of many of the old *anicuts* thrown across the rivers in this part of the country have often been so judiciously chosen by the native engineers, that very little expense has been incurred in constructing them. One across the Tumbuddra river in the Belari district, at a point where it is divided into two streams by an island, is an interesting instance. Between the island and the river banks there are a number of smaller islands, or clusters of granite rock. These have all been utilised in constructing the long *anicut*, which itself consists simply of boulders and blocks of granite thrown promiscuously together to fill up the spaces between the natural portions. The irrigation channel taken off above this weir is 25 feet wide and 3 feet deep, with a fall of 1 foot per mile.³ Nine such *anicuts* on the Tumbuddra were constructed by the Rajahs of Bijayangar in 1521 and subsequent years, and irrigation channels of a total length of eighty-nine miles were led into the valley.

In construction the native weirs are of a simple character, but nevertheless very effective for their purpose. The up-stream side is often formed by a slightly 'battered,' that is, inclined wall, carefully built of large-sized stones, with extra long ones, or 'headers,' inserted at frequent intervals. The stones of the top row next the water are sometimes notched together, or

¹ Parliamentary Paper, *vide* note, p. 8.

² Vide *Minutes of Proceedings, Institution of Civil Engineers*, vol. xxxiii. session 1871-72.

³ *Ibid.* vol. xxvii. session 1867-68.

bound with iron cramps. A long apron, or slope, formed of rough stones thrown promiscuously, extends on the downstream side, and along the foot of the slope two or three rows of very large and heavy stones are carefully laid, to prevent the escape of the rough stone forming the apron. In some cases the upper surface of the latter is set with stones regularly laid by hand, so as to give it a smooth surface. The *anicuts* are invariably founded on a rocky bottom; the construction of permanent weirs across sandy-bedded rivers having probably been beyond the skill of the old native artificers.

In the Bombay Presidency the British Government have inherited from ancient times a series of weirs on almost every perennial stream in Western Khandesh. These old weirs, or *bhandaras*, are found from near the source of the rivers as far down as suitable land for irrigation exists—or as far as it is possible to construct them at a reasonable cost. Originally the weirs, from the existence of curious square holes cut in the rock near the sites of many of the existing works, appear to have been wooden structures, or temporary dams of earth strengthened by wooden posts. Wood, however, became scarce, and now the dams are either of solid masonry or occasionally of earth and sand. The number of *bhandaras* in working order in Khandesh and Nasik is now about 200, but there are also many ruined and abandoned ones.

The channels which lead the water off from the *bhandaras* to the irrigated fields, usually skirt along the river bank, with little or no protection against the river floods, until they reach the higher land. The alignment of the channels show little regard for cross-drainage or levels. As a rule physical obstacles are avoided by following a contour line; small streams are crossed on a level, while the bed-falls of the channels are often very insufficient. The ground at the commencement is often very broken, and originally the channels ran for long distances up the hollows, or intercepted streams, crossing the latter on a small bank which would be carried away by every freshet, then down again to get round the hillocks, in and out in a most tortuous course, at times clinging to the precipitous cliffs of the river until more favourable ground was reached; and in some places it is extraordinary to note with what patience very

considerable difficulties have been overcome. The original channels have in course of time been improved by the construction of aqueducts and weirs at the crossings of the small streams, protecting walls have been built and diversions cut to straighten the alignment. The total area irrigated by these old works is nearly 24,000 acres.¹

The amount of irrigation formerly and still carried on over large districts in Southern India by means of artificial tank storage is extraordinary. 'Mysore and the Carnatic are covered with thousands of tanks. In the fourteen districts of Madras there are said to be some 48,000, all of native origin, with 30,000 miles of embankments and 300,000 separate masonry works. The tanks are formed in various ways, according to the accidents of the ground. Embankments are thrown across the gorges of valleys, high enough to retain a volume of water proportioned to the irrigable acres situated below. Descending terraces of land are occupied by a succession of reservoirs, the higher feeding the lower from its surplus supply. Long slopes have portions embanked on 3 sides, and the included space forms a storage area for such volume of water as local wants call for.'²

It is not known at what period many of the more important of these works were constructed, although the names given to them occasionally afford a clew. Some of the larger tanks are of very great antiquity, and others have undoubtedly existed for centuries. Many are also of enormous size. In a report made in 1853 by Colonel Baird Smith, of the Bengal Engineers, it is stated that the 'Ponairy Tank' in Trichinopoli had an embankment 30 miles in length, and a probable area of 60 to 80 square miles. A reservoir—occurring in the neighbouring island of Ceylon—is mentioned by Sir H. Wood in a paper presented to the Royal Asiatic Society, having an embankment 11 miles in length; and another in which the water of a valley is retained over an area of 15 square miles in the rainy season, and not less than three in the driest period.

The Viranum Tank, still in operation after a fabulous duration, has embankments 12 miles in length, about 20 feet high, and

¹ Bombay Irrigation Revenue Report, 1890-91.

² Parliamentary Paper, *vide* note, p. 8.

an area of 25 square miles, storing about 100 million cubic yards of water. It is supplied by a canal taken from the river Kalerun. The great Chembrambaukam tank, 14 miles from Madras, has an embankment more than three miles long. Before its enlargement by the British Government in 1867, at a cost of over £40,000, it held from 56 to 78 millions of cubic yards of water, and had an area of 4648 acres, or $7\frac{1}{2}$ square miles. Its present capacity is 108 millions of cubic yards, with an area of 5729 acres, or nearly nine square miles. It irrigates from 9 to 10,000 acres of chiefly rice cultivation, and its safety is secured by six overflows or waste weirs, having a total length of 676 feet.

In the district of Guntoor, the Cummun tank embankment closes a gorge which is little more than 300 feet long; whilst the area of the reservoir itself measures about eight square miles. The embankment is more than 100 feet high, made entirely of earth, with slopes of 2 to 1, the inner slope being carefully laid over with large stones. On the river Lokain, an embankment no less than 117 feet high closes a gorge which is but a little over 200 feet in length, the base of the earthen embankment measures 400 feet. The Nuggar, ancient tank in Mysore, has an embankment 1000 feet long, about 85 feet high, and 600 feet broad at its base. The margin of the tank measures 40 miles round. The 'Kaveri Pauk Tank' in North Arcot is also of very great size and antiquity. It is fed from the Pallair river: has embankments nearly four miles long, revetted along its entire length with stone, and irrigates about 7700 acres.

The following interesting description of one of these large ancient native tanks, which will afford a clear idea of their construction, is taken from a paper read before the Institution of Civil Engineers in 1872, by Mr. G. Gordon, M.I.C.E. :—

'A good specimen of the tanks is one which the author was deputed to examine a few years ago, with a view to its restoration. A short description of it will afford an idea both of the construction of ancient works and the untrustworthy nature of the data which old works seem to afford for the construction of new works.' The tank is named the Madduk Masur Tank. 'This great work is believed to have been constructed under

the Annagoondy dynasty, about four centuries ago. It was formed by an embankment resting on the sides of a narrow gorge through which the river Choady passed, supplemented by two *bunds* or dams, on saddles in the range of hills; that on the east being 1350 yards, and that on the west 670 yards from the main *bund*. The length of the main *bund* is 550 yards on the top. The inside slope of $2\frac{1}{2}$ to 1—in some parts 3 to 1—was revetted with large stone up to a cubic yard in bulk. It is from 945 to 1100 feet broad at the base, and is now from 91 to 108 feet high. There was a sluice under the dam at the east end, about the level of the ground.

‘The dam is composed of a strong red earth, with a considerable admixture of gravel taken from the sides of the hills on which it rests. The east supplemental *bund* has its base 74 feet above the sluice in the main *bund*, and had also a sluice under it at the ground-level. The west supplemental *bund*—the breaching of which destroyed the tank, seems to have been of similar construction to the others, and its base was perhaps 50 or 60 feet above the bed of the tank. There is no trace of any waste weir, and it is probable that the want of this was the cause of the ruin of the tank. On the main *bund* there are what appear to be traces of the water having topped it, and having cut into the rear slope in two deep gullies. The west *bund* had probably a sluice in it which weakened it, as cut stones were found in the river some way down.

‘After this *bund* was breached, the water cut into the ground on which it stood to the depth of 100 feet, and would have completely emptied the tank but for a reef of rock some distance from the dam on the inner side, which now causes a waterfall 25 to 30 feet in height, and retains about 10 feet of water in the tank. On this reef a weir has been built.

‘From the heights of the dams and the levels of the sluices, it is probable that the depth of the tank was 90 to 95 feet; and at that level its area would have been 40 square miles, and its contents about 1400 million cubic yards of water. The drainage basin is about 500 square miles, and three-fourths of it lies within the jungly district containing the spurs of the Western Ghats. It is found from observation of the discharge of the river that a good average monsoon supply would not

exceed 668 million cubic yards, or 16 inches running off. It is not probable that the average annual rainfall, so near the Western Ghats, has diminished so much, although it may to some extent, from land having been cleared of jungle. The difference between the present supply and what it must be supposed to have been, when the tank filled and was breached (even supposing that to have occurred in an exceptional year), is probably owing in part to the construction of small tanks on some of the feeders. The tank as proposed to be restored would have contained 644 million cubic yards. As regards capacity, this is the largest reservoir in Southern India of which the author can find any record.'

CHAPTER II

Native works continued—Details of Madras tanks—Chain system of storage reservoirs—Construction of native embankments—Absence or insufficient size of waste-weirs—Description of native *calingulas* or waste-weirs—Manner of drawing water from the reservoirs—Little skill displayed—Function of the larger tanks—Remains of old reservoirs—Diminution of average rainfall—River feeders—Subsequent regulation of river feeders and waste-weirs by English engineers—Ancient canals in Upper India—Feroze Shah's canal from the Jumna—Decree by the Emperor Akbar ordering restoration—Construction of Delhi branch by Ali Murdan Khan—Canal on left bank of the Jumna—Present Eastern and Western Jumna canals constructed on general lines of these old works—The 'Husli' canal in the Bari Doab—Canal from the Sutlej to Sirhind—Remains of old canal near Meerut—Traces of embanked canals in the valley of Peshawur—Conclusion of native irrigation-works.

THE general principles of construction adopted by the early tank engineers of the Madras Presidency may be gathered from the many thousands of examples left by them. The reservoirs themselves are of all sizes, and may be divided into several classes. In some cases the opportunity is taken—as in the cases already quoted—to close by a dam, or embankment, of considerable height, some narrow gorge, where a river leaves a range of hills, and so convert the valley above into a deep artificial lake. Many of these kinds of tanks have been breached either from neglect, the insufficient or entire absence of any provision for escape of surplus water in years of maximum rainfall, or in consequence of the water finding its way through the embankments, generally along the outside of the discharge outlets, which are invariably carried through the banks. In other cases, long and comparatively low embankments are carried for miles over one or more streams in the flat country, thus forming above them shallow tanks, often of very great superficial area. Others again are of a smaller kind, formed against the natural slope of the country by means of embank-

ments thrown up on three sides. Tanks of the last two kinds are so numerous in some districts, particularly in Mysore, as to give the idea that as much land is occupied by them as is left to be irrigated, and probably the reality is not very far from this.

In Mysore, as well as in many parts of the Madras Presidency, an ingenious chain system of storage reservoirs, of entirely native origin, has been developed, involving much skilful laying-out and contrivance. This system is one admirably adapted for the special conditions of the localities where it is found, viz., an exceedingly scanty and precarious rainfall, and the consequent necessity of securing and saving every particle of it.

A chain system of reservoirs is laid out as follows. A hill torrent having a sufficiently lengthy course is chosen, especially one having several lateral feeders. Beginning almost at the source, both of the main stream and of the several feeders, a series of embankments at lower and lower levels, is thrown up across the valley, each embankment being provided with an overflow or waste-weir. As soon as the highest reservoir is full, the overflow passes by the weir-channel into the next reservoir below, and this being filled, the overflow again passes into the third reservoir, and so on through the whole series, often extending over many miles of country. It is obvious that this system requires a very careful adjustment of the size of the waste-weirs, so that they may be able to carry off the largest excess of water that may enter the reservoirs in years of maximum rainfall, as otherwise the whole series of embankments might be successively overtopped and breached. Although very considerable adaptive skill has been shown by native engineers in the construction of this class of storage reservoirs, there have also been many failures, owing to miscalculation in the size assigned to the several overflow-weirs, and many of the systems still in operation have been from time to time remodelled by English engineers.

The embankments of Madras reservoirs are usually constructed entirely of earth, dug from the bed of the intended work, of large and often excessive dimensions. No clay wall in the centre, or what is technically called a 'puddle-wall,' is

employed. The earth is thrown up in thin layers from baskets, the crowd of workpeople, men, women, and children, walking over each layer, both in going with their loads and in returning. By this means a very solid and well compacted embankment is formed. Generally speaking, except in the comparatively few larger examples, the height of the embankments of the Madras tanks does not exceed 15 to 20 feet. Most of them have an inner slope of one or two to one, coated with a stone-facing set by hand, 18 inches or 2 feet in thickness, where stone is abundant. In the absence of stone the inner slope is turfed only, or protected by an arrangement of reeds formed into steps, the object in each case being to prevent the earth of the embankment being injured by the wash of the waves in high winds.

In some cases there is on the side next to the reservoir a massive masonry wall, either quite vertical or slightly inclined. These walls are built of square-shaped dressed stone on the face, closely jointed and backed with rougher masonry or coarse concrete. At intervals, bastions or projections occur, serving to strengthen the walls and to break up its otherwise monotonous outline. Frequently between the bastions broad flights of steps of cut stone lead down to the water, enabling the natives of the place to bathe or wash their clothes. One of the most fruitful sources of failure in the old native tanks is the entire absence, or insufficient size, of the waste-weirs, or *calingulas* (a Tamil word meaning in this connection 'waste-weirs'). In order to prevent danger to the embankment during excessive floods, storage tanks or reservoirs are, or should, always be provided with a waste-weir, or weirs, of sufficient width to allow the escape of all surplus water after the tank has filled. Such weirs are generally of masonry, built in the land near one end of the embankment. It is made so much lower than the land itself, and the top of the embankment, that any superabundant water will discharge itself over it.

In the old native practice, all the skill displayed in careful selection of site, and ingenuity in the construction of the work, was very often rendered of no avail, owing to want of attention to or want of sufficient knowledge of these important adjuncts, and there are numerous examples of fine tanks breached and made useless from no other apparent cause than the want of

sufficient length of outlet for surplus waters. These *calingulas* often consist of a rough wall of masonry at one end of the embankment, returned against the pitching or casing of stone on the face of the slope. At right angles to this wall another is built to a height somewhat below the level of highest water which it is proposed to store in the reservoir, and is carried level until it meets the rising ground. On the outside a rough stone 'apron' or slope is thrown. Along the top of the *calingula* wall upright stones are erected, generally about 3 or 4 feet apart, and 3 or 4 feet high. When the rainfall is moderate, or towards the end of the rainy season, the spaces between the stone posts are filled in with earth, straw, and rubbish, or a close wall of turf is built up in front of them so as to retain more water in the tank. When extra heavy rain occurs this obstruction is removed, or the rising water washes it away and so escapes. In some cases the surplus water is passed through orifices left at a low level in the waste-weir wall itself, which orifices can be opened or closed by planks, or rough shutters.

Water is invariably drawn from the tanks through long culverts of brick or stone passing through the embankments. These culverts are sometimes arched, but are more generally covered with flat slabs of stone. They are usually placed about level with the bottom of the tank. The inner end, or head, of the culvert projects somewhat beyond the toe of the slope, and is closed at the extremity, but through the upper side a series of holes, seldom so much as 6 inches in diameter, are cut. Conical plugs of wood are made to fit into these holes, which can be inserted or withdrawn by means of long bamboo handles—often, as may be imagined, an exceedingly troublesome operation. In some cases long upright stones are erected a few feet apart, having cross stones at intervals, with holes of proper diameter cut in them and placed so as to come vertically over the sluice orifices. Through these holes the long bamboo handles are passed, serving to guide them whilst inserting or removing the plugs fixed at their lower ends. In the larger tanks, closed cisterns having projecting steps are often built at the inner end of the culvert passages, having plug-holes at different levels, and various arrangements for reducing the accumulation of mud at

the entrance to the passages. At the outer extremity of the culvert the water is generally discharged into a masonry cistern with raised sides, the walls of which are pierced with holes at different levels through which the water passes to branch channels, and is carried to the fields at various elevations.

From want of accurate knowledge, the area of the discharge orifices is frequently either much too small or too large for the requirements of the irrigation, and but little skill is shown in adapting the size of the openings to the head of water and area of the lands to be cultivated. The larger class of storage-tanks irrigate directly only a limited area of land ; their work is to store up a large body of flood-water which would otherwise run to waste, and let it down the river channel below the embankment as required. From the river, over long distances, the water is drawn off by irrigation canals leading to secondary distributing channels, or into other storage-tanks. The smaller class of tanks usually irrigate a given area directly, beginning close under the tank itself. In some cases, as already mentioned, the water is intercepted by a succession of tanks at lower and lower levels, each of which catches the surplus drainage from the fields above it, so that little is ultimately lost.

Besides the enormous number of tanks of all kinds actually in use, the southern country is covered with the remains of old reservoirs, which from one cause or another have been abandoned. In some cases the embankments are intact, but no water is allowed to collect, the original bottom of the old tank having been so fertilised by the silt deposited that it has become more profitable to utilise the area for cultivation, than to employ the reduced volume of water that would now be impounded to irrigate the lands below. There appears to be little doubt that the average rainfall in many districts is at present less than it was in former times, so that in some cases the old tanks would never fill, or the supply would be so reduced as to prevent any large area being irrigated. Along the foot of the Eastern Ghâts numerous instances are met with where both the beds of the former tanks, and the formerly irrigated land below them, have both reverted to jungle.¹

¹ Vide *Minutes of Proceedings, Inst. of Civil Engineers*, vol. xxxiii. session 1872-73.

In the old native practice large tanks, in addition to the rainfall on their own catchments, were fed wherever practicable by a channel cut from some neighbouring river. The channels were seldom provided with any permanent arrangements at the head for controlling the entry of water; consequently, if some extraordinary fall of rain occurred, either the tanks filled very rapidly, or if they happened to be already full, the waste-weirs were quite incapable of carrying off the sudden and violent influx of water, and so the reservoir embankments would be topped and breached. One of the chief works first carried out by English engineers in Madras was the regulation of the volume of water allowed to enter the tanks through river-feeders, by placing suitable controlling works at their heads, and carrying out the necessary alterations in the dimensions of the waste-weirs, so as to enable them to perform the heaviest duty likely to be imposed upon them. During the last thirty years considerable improvements and enlargements of many of the ancient tanks in the southern portion of India have been effected under the British Government.

Under the rule of the Mohammedan sultans and emperors, especially in the Delhi districts, attention was from time to time directed to the construction of canals, either for irrigation or for the purpose of supplying the wants of large cities and the fountains and baths of the imperial palaces. Elphinstone remarks that the reign of the Sultan Feroze Shah was 'distinguished by the enlightened spirit of his regulations, and the utility and extent of his public works.' Those that still remain afford evidence of the magnitude of some of his undertakings. The most considerable of his irrigation works was a canal that was opened about the middle of the fourteenth century B.C. 'Between the years 1351 and 1388, Emperor Feroze Shah (Tughlak) drew a canal from the Jumna to water his favourite hunting-ground at Hissar, but there are no signs of works of irrigation along the line of his canal, which fell into disuse at his death. The present Hansi branch of the western Jumna canal follows the line of Feroze Shah's engineer, and the pastoral villages at Hissar are entirely dependent on it for the means of watering their cattle. At Hissar a travelled courtier of Feroze Shah erected a building to give his master an idea of a ship

(*Juhaz*). It is now (or was) used as a store-house for the canal, for which purpose its ample "hold" renders it very suitable.' 'For one hundred years no water had flowed to Hissar, when in 1568 the Emperor Akbar issued a decree ordering the canal of Feroze to be restored.'¹

In the *Journal of the Asiatic Society* for March 1846, No. clxxi., Lieutenant Yule published the 'Canal Act' of the Emperor Akbar, with some notes and remarks on the history of the western Jumna canals. A copy of the *Sanad* of Akbar Shah Badshah, dated Shamal, A.H. 978 (A.D. 1568), is there given, and it is believed to be authentic. After mentioning the earlier work of Feroze Shah in 1351, Akbar says, 'Now that I have given the district (*sarkar*) of Hissar to the great, the fortunate, the obedient, the pearl of the sea of my kingdom, the star of my government, the praised of the inhabitants of the sea and land, the apple of my kingdom's eye, my son Sultan Mahomed Selim Bahadur (may God grant him long life and greatness), my wisdom wishes that the hopes, like the fields of those thirsty people, may, by the showers of liberality and kindness, be made green and flourishing, and that the canal may in my time be renewed, and that by conducting other waters into it, it may endure for ages. For God has said, from water all things were made. I consequently ordain that this jungle, in which subsistence is obtained with thirst, may be converted into a place of comfort free from all evil.'

The *Sanad* records how Akbar ordered the canal to be 'excavated deeper and wider than formerly,' and that 'on both sides of the canal down to Hissar trees of every description, both for shade and blossom, be planted, so as to make it like the canal under the tree in Paradise,' and adds, 'every *purganah* will be satisfied with the number of cuts made by Mirab (the superintendent of the canal), and take no more. . . . He has power to punish as he sees fit every one who takes water out of season.'

About the year 1626 Ali Murdan Khan—a noble of the court of Shah Jehan, acting as his engineer—constructed a branch from this older line of canal to Delhi, first by way of Gohana, and afterwards, on that failing, by the present channel

¹ Parliamentary Paper, *vide* note, p. 8.

passing near Paniput and Soneput. The low ground near the city of Delhi, through which the surplus water of the Nuzuffgur swamp escapes to the Jumna, was crossed by a massive aqueduct of masonry. On arrival at the foot of the rocky hills which skirt two sides of the city the canal flanks them for a short distance, and then passes through them by a bold rock excavation sixty feet deep at the crest, a work that must have entailed immense labour. It then enters the city near the Cabul Gate. An outlet from the right bank within the city supplies a small masonry channel which flows through the centre of the 'Chandni Chowk'—or silver street—partly open and partly covered in. The main canal passes through several streets and arrives at the Negumbod aqueduct, throwing off many minor streams, and carrying a plentiful supply of water to the palace baths and gardens. Thence the surplus water, after working some flour-mills, passes into the Jumna. The Negumbod aqueduct is a fine mass of masonry, carrying the canal above the level of the house-tops.¹ For 150 years this canal continued to be efficient, but in 1753 the Delhi branch ceased to flow. Ali Murdan Khan also constructed a canal on the left bank of the Jumna. It passed for part of its course exactly on the ridge between the rivers Jumna and Hindun, and thus afforded facilities for irrigation both to the eastwards and to the westwards of its course. The bed of this canal having been formed on the natural slope of the country its fall was excessive, amounting to 372 feet in a distance of 130 miles. This, together with the difficulty of maintaining a passage across the mountain torrents near the head, caused it to be abandoned soon after its construction in 1628. Both the present eastern and western Jumna canals have been constructed along the general lines of these old native works.

Under the Emperor Shah Jehan a small permanent canal was also constructed in 1633, in the Bari Doab. 'It was called the Husli canal, and was designed not for irrigation, but to supply fountains at the royal gardens of Lahore. When the Sikhs acquired the sovereignty they led a branch to Amritsar, to supply the sacred tank at that town. The canal followed

¹ Vide 'Public Works in the Bengal Presidency,' vol. xvii. *Proceedings Inst. of Civil Engineers*.

the natural line of drainage by a tortuous course of 110 miles, and passed through low ground, which least required irrigation.¹

During the first surveys made over the districts lying between the Jumna and Sutlej rivers—now watered by the Sirhind canals—Captain (afterwards General Sir W. E.) Baker mentions an old native canal supposed to have been excavated by the Souba of Sirhind early in the century. This canal was drawn from the Sutlej a few miles above the town of Rupar, and was led from thence into the lower ground near the ancient city of Sirhind after a course of forty-one miles. Shortly after its construction it appears to have been abandoned, having probably been rendered useless by a change in the course of the river at its head, and no subsequent attempt seems to have been made to remodel it.

Speaking of the districts now watered by the Ganges canal, Sir Proby Cautley² makes mention of an old canal constructed by one Mahomed Aboo Khan, belonging to a period anterior to that of British rule in the country. This canal, the remains of which still exist in the neighbourhood of Meerut, 'consisted of a cut made from the West Kali Nadi, near the village of Rampoor, to the head of a small tributary to the East Kali Nadi, called the Khodara Nulla, which rises near the village of Deorala. The length of this cut did not exceed twelve and a half miles, and its dimensions, judging from the existing hollow, could not have exceeded fifteen feet in width. The water, after reaching Deorala, must have passed down the Khodara Nulla to the town of Meerut, in the neighbourhood of which are many groves and gardens, and it is supposed that it was for the purpose of supplying water to these that the canal was originally projected. . . . The canal was merely excavated to a few feet in depth, and the water was supplied from a lake formed by throwing an embankment across the bed of the West Kali Nadi. The flooding of the valley by this retention must have done extraordinary damage to the properties within its limits; the amount of money and labour expended on an embankment of proportions sufficient to gain the engineers'

¹ Parliamentary Paper, *vide* note, p. 8.

² *The Ganges Canal*, Sir Proby Cautley.

object, must have been very great; and the necessity for an annual reconstruction of a work which was inevitably destroyed during the rain-floods, and the certainty that water could only have reached the mouth of the canal during the dry months of the year, are facts which reasonably lead us to conclude that no great benefit was ever derived by the cultivators on the high lands in its vicinity.'

In the valley of Peshawur traces and remains of an embanked canal drawn from the Swat River, of a probably early date, have been found, but whether the channel was ever used for irrigation there is no record. The hill-torrents may possibly have carried away its principal features, and no doubt this has often been the case with many old native works, traces of which are found in many parts of the Punjab and North-west Provinces.

The number and extent of the irrigation works of nearly all classes carried out over the length and breadth of India by native engineers, in many cases long anterior to the rise of British rule in the country, it will thus be seen, is very great. English engineers have to a large extent adopted and improved the systems they found already in operation, with the exception of the great Delta schemes of irrigation on the east coast, and the magnificent Doab perennial canals in the north, which are new classes of works of entirely English origination, the conception and execution of which, dependent on a higher degree of scientific attainments, were no doubt beyond the ability of the earlier native engineers.

CHAPTER III

Leading features of modern canal construction—Classes of canals—Irrigation and navigation: often combined in India—Main body of canal—Source of supply—‘Doab’ canals—Widths, depths, and slopes—Works at head of permanent canals—Dams and weirs—Scouring sluices—Protection works—Aqueducts and passage of rivers—Service bridges—Over-falls, locks, escape-weirs and drainage—Observations on proposed sketch of modern canal-systems in India—Unfamiliar character of irrigation works to the general public—Punjab irrigation—Western Jumna canals—Bari Doab Canal—Sirhind canals—Swât River Canal—Chenab Canal—Inundation canals—Sindh—Minor inundation canals—General results of Punjab irrigation.

BEFORE proceeding to place before the reader an outline sketch of the modern irrigation works of India, carried out by the direct or indirect agency of the British Government within the present century, a few words on the main leading features of canal construction, and the particular classes of engineering works with which canal engineers have to deal, are necessary in order that the unprofessional reader may be enabled intelligently to follow the necessarily very condensed account of such works in the following pages.

There are, then, two primary classes of canals, viz., canals for irrigation and for navigation. Obviously it is necessary that the former class should be made so as to flow with a regular current, and that they should be fed by some continuous source of water to make up for that consumed in irrigation. They should also be so located as to traverse as high ground as possible, in order that the water drawn from them may command and irrigate a large area of land, either on one, or better still, on both sides of them. On the other hand, navigation canals are, as a rule, better located at a low level, with hardly any current, so that boats may journey with equal facility either up or down

—unless, indeed, it happens from special circumstances that all, or nearly all, of the traffic is in the direction of the current only. It is, however, often necessary or desirable to combine irrigation and navigation in one and the same canal, in which case the current is kept as low as may be consistent with the wants of the irrigation. Combined irrigation and navigation canals have been very largely constructed in India, chiefly for economical reasons.

The main body of a canal consists of an artificial water channel excavated wholly in the soil, or carried by means of entire or partial embankment, at the required level, above the surface of the district traversed. The source of supply is usually some great river having a continuous and ample flow of water. Nearly all the great rivers of India, owing to the heavy deposit of silt from their waters, run on beds elevated somewhat above the level of the immediately adjoining strip of country on either side of them. In upper India this strip of lowland, which forms the valley of the river, and marks the general limits of the flood-deviations from side to side, is called the 'Khadir.' The higher table-land lying between two more or less parallel river valleys along the whole extent of their course, is called the 'Doab' or interfluvial tract—from *do* (two), and *ab* (water) — *i.e.* between two waters.

It is clear that an irrigation canal, to be of any extended use, should be carried along the highest ridge of the 'Doab' tract, and that a short cut from the nearest part of the river would only lead the water into a more or less deep cutting, from which it would have to be lifted out by pumps or otherwise. Hence to *command* the Doab—that is, to be above it, and to control it, the canal must obviously be drawn off at some convenient point on the river, situated high up on its channel, at an elevation sufficiently great to admit of the water being led down by means of the canal, and at a reasonable expense, to the desired level of the Doab table-land.

The relative widths, depths, and bed-slopes given to canals will vary, within limits, according to special circumstances, but will primarily depend on the quantity of water to be carried, the nature of the soil, and the necessity or otherwise of providing for navigation. If the bed-slope given is too great, the

bottom and sides of the canal may be torn up, or greatly worn; all foundations of bridges or other works along the canal will be endangered, and navigation against the current will be impossible, or difficult. If the slope is very little, a larger canal will be required to carry the intended quantity of water; there will also be danger of a rapid deposit of silt and growth of aquatic plants which may choke up the channel, whilst the expense of many additional works, such as overfalls or locks, will have to be incurred. It is necessary, therefore, that a nice adjustment be made in each case, according to a continually varying set of circumstances and conditions; the ultimate success or failure of the canals, both constructionally and commercially, being entirely dependent on the care taken in these particulars.

The heaviest works in connection with canals are usually at or near their heads, and at those places where the rivers of the country, which cross the intended line of canal, have to be disposed of. The works at the head of permanent canals most commonly consist of masonry dams or weirs across the supply-river for holding up the water in a pond or pool above them, and a 'regulator' or set of movable sluices across the mouth of the canal, which is drawn off from the pool, by means of which water can be admitted into the canal or shut out.

Dams, when they are made solid, are generally called 'weirs.' True dams are provided with a regular series of piers and openings in their central portions, the latter capable of being wholly or partially closed. Solid weirs require to be provided with sluices fitted at a low level to keep up a scour, and prevent the accumulation of deposit in front of the canal regulators situated above them. For properly effecting this purpose they are usually built in that part of the weir nearest to the canal head. In long weirs one or more lines of scouring sluices are sometimes provided in the middle portions of the weirs.

Extensive works to prevent the extremities of a weir or dam from being turned by the river when in flood, such as massive and lengthy revetment-walls, wing-walls, and embankments, are very frequently required, especially where the river banks are low, as well as protection embankments and training works to prevent the adjoining lands being flooded, and to keep the river in a fixed course.

After the canal has left its supply river, the next difficulties encountered are generally in connection with the natural water-courses of the country which intersect its alignment. Sometimes the canal is carried over these water-courses—or it may be wide rivers—by means of more or less long and elevated aqueducts; some of which may be of very great size. Sometimes it is passed under the rivers by a syphon aqueduct. At other times the river itself is carried by a bridge or ‘super-passage’ over, or is syphoned under the canal; or if this cannot be done, the river is made to cross the canal on a level, the two waters being allowed to mingle together. In this case special works are provided to control the movement of the combined water, and direct it as required.

In Upper India the first portion of most of the larger canals, derived from the Himalayan rivers near the point of their exit from the hills, have to cross—whilst traversing the low ‘Khadir’ or valley land—in one or other of the above ways, many rapid, and when in flood, violent mountain torrents; but when once the canals reach the level of the Doab table-land, their course henceforward lies generally on a ridge between the principal rivers, and they encounter few serious obstructions. In proportion to the activity and population of the districts traversed, canals have to be provided with a greater or less number of service bridges, or other means of passage from bank to bank; these crossings are often necessary at very frequent intervals, and form no inconsiderable item in the total cost of the irrigation.

In the upper parts of Doab canals especially, where the slope of the natural ground is very much greater than it would be proper, or possible to give to the canal beds, and where the width and depth of the canals is at a maximum, arrangements have to be made to compensate for the excessive slope. This is done by laying out the bed of the canal in a series of *steps*. The points where the bed is let down from a higher to a lower level are called ‘falls’ or ‘overfalls,’ and it is evident that such falls must be constructed of masonry, or other durable material strong enough to withstand the wearing action of the water. Often for reasons of economy, or on other grounds, the position of a ‘fall’ is made to coincide with some bridge,

super-passage, or other necessary work. Overfalls are made in a variety of ways; sometimes they are vertical, and are provided with gratings arranged like the teeth of a comb, to break the force of the water, and with cisterns to act as water-cushions below them, or they are made in a curved or 'ogee' form, so as to deliver the water at the lower level with as little violence as possible. These works on some canals are often of considerable magnitude and cost. Locks, escape-weirs, and channels for discharge of surplus waters are also frequently required, as well as extensive drainage works in some instances, to prevent the adjoining country being made swampy and unhealthy.

Such are some of the chief classes of construction met with on irrigation and navigation canals. In the outline sketch of the various canal systems of India which follows, it is obvious that considerations of space will not permit a detailed notice of more than a few individual works; but the reader will now be in a position to follow and understand the general references made to these works which he will meet with. Our task in the following pages is to convey to the reader, in the smallest possible compass, a clear idea of the very great mass and value of the irrigation works of India, which have been carried out up to the present time by the British Government. Unhappily for our purposes, irrigation works are almost completely outside the knowledge and acquaintance of the general public. Unlike the fine works constructed all over the country in connection with railways, for instance; the magnitude and utility of which in course of time and travel, have become more or less familiar to the eye and knowledge of thousands, the splendid examples of engineering constructions executed for the provision, control, and distribution of the huge volumes of water required to fertilise the ever-thirsty fields of the country, are in general situated far from the main lines of public traffic, are more or less entirely hidden from popular view, and are familiar only to those whose duties or interests may be in one way or another connected with them. Vastly important as large irrigation works are, and interesting as feats of engineering skill and daring—scarcely second indeed to railway operations, they nevertheless embody a class of works which, as a whole,

appeal far less forcibly to popular imagination than those connected with railways, owing in great measure, no doubt, to this relative unfamiliarity. The works we are about to sketch, in mere skeleton outline, embody an enormous aggregate; yet large as this aggregate undoubtedly is, it represents but a fraction of what is becoming more and more desirable, in order that the agricultural operations and productions of India may keep pace with the general advancement in other directions.

Punjab Irrigation.

Western
Jumna
Canals.

The Punjab system of provincial canals contains the first irrigation work undertaken by the British Government, which was the restoration of Shah Jehan's old Delhi branch-canal. About the year 1753 this branch—taken off, as we have lately seen, in 1626 by Ali Murdan Khan, from Feroze Shah's old line to Hissar—ceased to flow. In 1817 the British Government appointed Captain Blane to restore it, and in the year 1820—after a closure of about sixty-seven years—water was again introduced into Delhi; irrigation having been commenced during the previous year.

A few years later, viz., in 1823, the restoration of Feroze Shah's original canal to Hissar was commenced, and during the next twenty years the system now known as the 'Western Jumna Canals' was fully developed. The head of the main channel was situated on one of the numerous side streams into which the Jumna is divided as soon as it issues into the plains from the Sewalik, or sub-Himalayan range. Here, by deepening the channel, and by running out spurs or dams either partially or completely across the main stream, the water used to be intercepted. The dams or spurs were rudely constructed of boulder stones and coarse gravel, taken from the bed of the river; the smaller materials being packed into cribs or frames of basketwork. The intercepted water was first led by an artificial cut into the Putralla river, and then along the bed of that stream as far as its junction with the Sombe. In order to pass the canal water beyond the latter river, a permanent masonry dam 777 feet long, in place of the old earthen dam which was formerly employed, and which had to be annually reconstructed, was substituted in the year 1833.

The foundations of the dam consist of masonry blocks sunk eight to eleven feet into the river-bed under the piers. The

blocks are connected on both up and down stream sides, by lines of curtain works, and the floor is formed on flat arches abutting on the pier foundations. Both above and below the dam there is an 'apron' or slope formed of stone, and rough masonry, retained by timber piles driven closely together. Beyond this piling, on the down-stream side, is another flooring of river stone, packed in cribs, and secured against movement by another line of smaller piles. The floor stretches across the bed of the Sombe, with abutments twelve and a half feet high on each side. The whole width is divided into sixty openings of ten feet each, by fifty-nine piers six feet in height and three feet wide. The banks of the river are well protected by long revetment walls—that on the west side, 750 feet long, connects the dam with a bridge across the canal. The overfalls are made to diminish in height towards the centre, with the object of keeping the strength of the current in the middle of the river, and prevent its setting along either of the abutments. The piers are furnished with grooves to receive the sluices.¹ The peculiar position of this dam and dependent works at Dadupur, near the confluence of several torrents, all liable to severe and violent floods, and having no established beds, has exposed them to many dangers, which have called for the greatest vigilance in maintaining them. The canal, once extricated from these rivers, is carried on its course with comparative ease. The main Western Jumna canal may be said to commence at the Dadupur dam. As far as Karnal it was originally carried along the low land of the Jumna river, soon however gaining the level of the higher country to the westward, where it presently divided into two branches; one carrying the water to Hansi and the other to Delhi. During comparatively recent years the Western Jumna system has been completely remodelled, in order to remove the evils due to its originally defective and low position, which caused a good deal of unhealthy swamping of the country along its course, also to increase the volume of water, to extend and regulate the distribution, and to improve the navigable character of the main channel.

¹ *Vide* Colonel Baker's Report on the Western Jumna Canals.

In 1864 an investigation into the condition of the canals was ordered, many plans for their improvement were suggested, but a definite scheme was not sanctioned until the year 1874. The main features in the alterations of the older works carried out, were, the construction of a permanent weir and head-works on the Jumna; a new main line of canal taken off from the old channel 15 miles above Karnal, extending as far as the Delhi branch, in place of about 50 miles of lower and very defective line, and a new channel along 55 miles of the Delhi branch itself, together with a considerable extension of distributing channels and various drainage works.

At the head the main canal is 360 feet wide, decreasing gradually to 120 feet as water is drawn off. The total length of the Western Jumna main and branch canals is 280 miles, of which 243 miles are navigable, with over 900 miles of distributing channels, irrigating in good years about 550,000 acres. It is said that during the terrible famine of 1837-38 the value of the crops saved by its waters was £1,462,800, supporting the inhabitants of 500 villages, who would otherwise probably have died of starvation. From the beginning it has been an exceptionally remunerative undertaking. At the end of the year 1890-91 the accumulated net profits at credit of the canal amounted to very little short of three millions sterling.¹ An important new branch taken off from the main channel about the 45th mile, and running to Sirsa, has lately been commenced. This branch will be 138 miles long, with 500 miles of distributaries, irrigating about 175,000 acres.

Bari Doab
Canal.

Very soon after the annexation of the Punjab in 1849 a project for providing irrigation in the arid districts lying between the Ravi and Beas rivers was taken up by the Government. As previously mentioned, in this district, known as the 'Bari Doab,' an old native canal existed, constructed in 1633 under the Emperor Shah Jehan, called the 'Husli' canal. Although constructed primarily for the supply of water to the royal gardens at Lahore, the channel served to irrigate a certain area situated in the upper part of the Doab; but its course was generally so defective that no use could be made of it in the

¹ Revenue Report of the Irrigation Department, Punjab, 1890-91.

alignment of the modern 'Bari Doab Canal,' although small portions of it have been incorporated in the distributive system.

The 'Bari Doab Canal,' as now existing, was commenced in the year 1850, but progress on it was much delayed by various revisions and alterations of the original project. A few miles of the present system was opened in 1859, but up to the year 1868 no permanent head-works had been constructed, and only a comparatively small portion of the main and branch canals were completed. The system has, in fact, been gradually developed almost up to the present time. The head of the canal is situated on the Ravi at Madhopur, where the river issues from a low portion of the Himalayan range. Here, in 1868, the construction of a permanent weir was commenced, which was completed in 1873. The bed of the river at Madhopur is composed of boulder stones of large average size, and the fall is 26 feet per mile. With such a heavy inclination as this the velocity and force of the current is of necessity exceedingly great.

The weir consists of two parallel walls of masonry 35 feet apart and 5 feet high, the intermediate space being filled in with boulders set in cement for a thickness of 3 feet, and there is a long protective apron or slope of boulders below the down-stream wall. The weir was constructed straight across the river at right angles to the direction of the current, but this was subsequently found to be a mistake, as, owing to the nature of the river bed the scouring sluices provided in the body of the weir failed to keep up a sufficient scour, so that the boulders rolled along by the rapid current were banked-up to the top of the weir-wall, almost across the whole width of the river, and the deep-water channel near the canal entrance could hardly be kept open. This, and other experience, has taught canal engineers that dams or weirs across boulder streams having a great inclination of bed should be made obliquely to the line of the current. At Madhopur the difficulties imposed by the original faulty alignment of the weir have by various remedial measures been now largely surmounted.

The canal entrance is provided with regulating sluices, and the canal, 120 feet in width, is led away from the river through

a deep cutting in the high bank of the river. In the first few miles of its course it crosses two mountain-torrents, after which it soon gains the table-land between the Ravi and Beas rivers. At the 30th mile a main branch diverges and carries the water to Kasur, near Ferozepur, and from the upper part of this branch another is carried nearly parallel with the Beas to a point opposite Sabraon, near the junction of the Beas and Sutlej. At the 55th mile the Lahore branch is taken off, and extends to Mean Meer and Lahore. The main canal itself, after traversing the central part of the Doab, tails into the Ravi some 60 miles below the last-mentioned town.

The Bari Doab system of canals has a total length of main line and branches of 362 miles, with 1048 miles of distributaries, commanding an irrigable area of 535,000 acres, or 836 square miles. The estimated value of the crops annually irrigated by it now amounts to over £1,600,000. The financial results of working the canal during recent years exhibits a steady advance.

Sirhind
Canals.

The tract of country lying between the upper waters of the Jumna and Sutlej rivers contains the watershed or ridge line of division between the Indus and Ganges basins. This watershed lies much nearer the Jumna than the Sutlej, and the space between it and the latter was once watered by the Ghaggar, the ancient Saraswati, a river which, in its higher portion, has been for a long time unpleasantly familiar to all visitors to Simla. The Ghaggar formerly flowed through the heart of the country, from the mountains to the Indus, near Rori, in a direction almost parallel with the Sutlej; but its vast lower beds, locally known by the names of 'Hakra' and 'Sankra,' have long been dry hollow wastes. The water in the modern river, even after the heaviest rainfall, is soon swallowed up in the ever-encroaching desert sands to the southward.

In this almost rainless region, comprising the districts of Ludhiana and Ferozepore and the native States of Puttiala, Jind, and Nabha, west of the Ghaggar, the want of water for purposes of cultivation was extreme. In the year 1840 Captain (afterwards Sir William) Baker took a line of levels across the country from Karnal to Ludhiana. He found that the greatest elevation of the watershed between the Jumna and the Sutlej

(lying comparatively near the former river) was 68 feet, and after further preliminary investigation he ascertained the perfect feasibility of conducting water from the Sutlej into an immense culturable area, then almost a dry desert. Nothing at this time, however, was done, owing to various causes, but chiefly owing to the difficulties imposed by the intervention of several native States, which would have to be traversed by the canals proposed. Twenty years later the project was revived, mainly on solicitation of the Maharajah of Puttiala, who, so far as irrigating his own territory was concerned, offered to defray all expenses connected with the preliminary investigation and survey, whether the scheme proved practicable or otherwise. In the year 1869 the matured project for the existing 'Sirhind Canals' was finally settled, the upper portion of the works was commenced, and in 1873 an agreement with the several native States interested was concluded. The main features of this agreement were, that the work was to be designed and carried out by the British Government, and that the entire cost of the main canal and preparation of the project was to be borne by that Government and the native States, in proportion to the quantity of water allotted to each. As regards the branches and distributing channels, each party was to bear the cost of its own portion. The management of the main canal and branches was to rest with the Government of India, but each party was to have entire charge of its own distributaries, and defray all expenses of maintenance in proportion to the share of the water supply allotted in each case.

The Sirhind canal system as carried out consists of a short trunk canal drawn from the Sutlej at Rupar. At the 41st mile a division of the water is made; one main branch extending westwards to Ferozepore, mainly for the supply of water to British territory, and another main branch south-eastwards to Puttiala, principally to supply the wants of the native States of Puttiala, Jind, and Nabha. Numerous secondary branches extend from the above, roughly parallel with each other, in a south-westerly direction, carrying the water-supply nearly as far south as Sirsa, and to the upper border of the Bahawalpur State on the west. The trunk and main branches to Ferozepore and Puttiala respectively are navigable, and a navigable exten-

sion, 55 miles long, through the watershed, from a little below Puttiala to a point on the Western Jumna Canal above Karnal is contemplated, which will form a junction between the Punjab and Bengal systems of inland navigation, through the Delhi connection with the Agra canal in the North-west Provinces.

As usual in the case of canals drawn from rivers not far from where they issue from the mountains, the heaviest portion of the works on the Sirhind canals lies in the first few miles from the head, where the channel has to cross several mountain torrents which intersect the Sutlej valley. A masonry dam or weir is constructed across the Sutlej nearly opposite the town of Rupar, and just above the weir a regulating bridge crosses the commencement of the main canal, 200 feet in width. The canal is carried through a hill spur in a cutting 45 feet deep in the highest portion, and with an average depth for about nine miles of 28 feet. The cross drainage of the valley is conveyed over the canal by two large masonry over-passages. Prison labour was very largely employed on this portion of the works.

The total length of main-line and branches is 542 miles, with 4385 miles of distributing channels. 189 miles of the canals are navigable, of which 143 are British, and 46 are in native States. The system commands an irrigable area of over 800,000 acres, or 1250 square miles of cultivation.

Swat River
Canal.

The only remaining perennial canals in the Punjab are the 'Swât River Canal,' and the Chenab Canal, the latter a very recent work, as yet only partially developed, for irrigating the 'Rechna' Doab, lying between the Chenab and Ravi rivers. The Swât River Canal is a small work, 22 miles long, with 140 miles of distributing channels, situated in the north-east corner of the Peshawur valley, where the rainfall is exceedingly small and uncertain. The canal, which was commenced in 1876, is drawn from the Swât river, above a dam constructed not far from the frontier post of Abuyae, where the river issues from the mountains. It irrigates an area of about 89,000 acres out of 120,000 acres commanded.

Chenab
Canal.

The Chenab system of irrigation in the Rechna Doab, which, when fully developed, will be the largest and most important

in the Punjab, is derived from the river Chenab, over which a fine permanent weir, with connected canal head works at Khanke, a few miles below Wazirabad, has quite recently been completed. The main canal (hitherto, pending the completion of the head works, worked as an inundation canal) is carried down the high land of the Doab, passing close to the town of Hafizabad, irrigation commencing within a very short distance of the head. The area irrigable by the existing project is 400,000 acres. The length of main channel and branches was in 1891 91 miles out of 125 projected, with a length of completed distributaries of 283 miles out of 529. It is under proposal to double the capacity of the present main channel, to enable the full power of the new head works to be utilised, the effect of which will be to very largely extend the irrigable area, viz., from 400,000 to over a million acres, or 1563 square miles, at a cost of about a million and a half sterling (150 lacs of rupees).

A great number of Inundation Canals have from very early times been in operation all over the Punjab Province. Under systematic administration these canals as a whole may be ranked as amongst the most remunerative irrigation works in India, although from the unavoidable irregularity and uncertainty in their supply of water, they are of far less certain value to the cultivators than the perennial canals. The greater portion of the inundation systems now in operation under the management of the Government of India Irrigation Department, are based on old native constructions, which have been enlarged, restored, or improved, by English engineers since the year 1849, others are of entirely British origination. The lower Sohag and Para canal is drawn from the right bank of the Sutlej, about 50 miles below Ferozepore. It has 95 miles of main channel and branches, with about 40 miles of distributaries, and an irrigable area of 93,000 acres; the area annually irrigated varying greatly, according to the season, as is the case with all this class of irrigation works.

An interesting example of one of these canals of recent British construction is the 'Sidhnai' taken from the lower part of the Ravi near its junction with the Chenab. Owing to the small depth of water in the Ravi at the time of year when it is

chiefly required, it was found necessary to construct a dam to head up the water. Subsequently a lock to provide for a small amount of river navigation was added. The dam has been constructed on a principle borrowed from a French source, called the 'needle' system. In this system the level of the water on the up-stream side of the dam is raised or lowered as required, by the insertion or removal of a line of vertical timbers called 'needles'; each needle being 7 feet 6 inches long, with a handle 18 inches long in continuation, and 5 inches by $3\frac{1}{2}$ inches in section, weighing about 40 lbs. The needles are made to abut closely the one against the other, in a slightly inclined position, resting against a timber beam above, the lower end falling into a notch cut along the crest wall of the main dam. The insertion or removal of the needles is effected from a small foot-bridge, provided with rails for the passage of trollies. The masonry dam is 737 feet long, and is divided into bays or spaces of about 20 feet each, by dwarf piers which serve to support the upper beam against which the needles rest, and to carry the small rail-bridge.

By closing up, pushing forward, or bodily removing a sufficient number of the needles in any or all of the bays, the level of the water in the river above the dam is maintained at the height required to feed the canal, which is drawn off through a regulating bridge with sluices above the dam. The canal was commenced in 1884, and the whole irrigation system was in full operation in 1887. The main channel at its head is 80 feet wide, and 6 feet in depth at full water, and has a slope of 1 foot in 8000 feet. The length of main line and branches is 58 miles, with 146 miles of distributing channels, irrigating an area of about 122,000 acres. From the very commencement the work has proved exceptionally remunerative. In 1891, the balance of net revenue to the credit of the canal, after paying interest charges, amounted to over £25,000, after but little over four years of actual operation. The remaining systems of minor inundation canals in the Punjab are the 'Upper Sutlej series,' derived from the right bank of the Sutlej below Ferozepore; the 'Lower Sutlej and Chenab series' near Multan; the 'Indus' and 'Muzaffargarh' series, and the 'Shahpur' series; the latter drawn from the left bank of the Jhelum. These

groups of canals have an aggregate length of main line and branches of 2605 miles, with 591 miles of distributaries, irrigating about 1,016,000 acres, or 1558 square miles.

As commercial undertakings the irrigation canals in the Punjab have been very successful. In the whole Punjab Province the total expenditure by the British Government on such works, up to the end of the year 1890-91, amounted to £6,435,818, in addition to a further sum of £1,402,450 contributed by native States. The total mileage of completed main and branch canals was 4058 miles, with 7545 miles of distributing channels, of which 223 miles of main channel and 1940 miles of distributaries are in native States. Of the main channels 432 miles are available for navigation. The perennial canals, in the year 1890-91, irrigated an area of 2601 square miles, and the inundation canals irrigated 1840 square miles. The whole area irrigated was therefore 4441 square miles of cultivation, and the estimated value of the crops raised by canal irrigation throughout the Punjab in the same year reached the enormous total of £8,815,777. On the seven large 'productive' works constructed by the British Government, the percentage of revenue earned to capital outlay was 5.91 per cent., and the net surplus of revenue for the year, after deducting all interest charges, amounted to £132,747. The accumulated balance of net revenue at the credit of the system of productive canals in the province, for which interest accounts are kept—principally due to the valuable Western Jumna system—was £2,203,187, and including all the inundation canals £2,926,936.¹

¹ For details of individual works in the Punjab *vide* Appendix A.

CHAPTER IV

NORTH-WEST PROVINCES

North-west Provinces irrigation—Eastern Jumna Canals—Ganges Canal—Inception—Head works—General course followed—Branches—First twenty miles—Slope of the country—Ramipore torrent—Superpassage—Patri River superpassage—Rutmoo torrent—Solani valley and aqueduct—Aqueducts and ordinary bridges compared—The Solani torrent—General description of aqueduct—Embankment—Masonry revetment walls—Execution of earthworks—First locomotive engine used for constructional purposes in India—General description of the Solani River crossing—Details of construction—Piers and abutments—Foundation works and arching—Completion of Ganges Canal—Opening by Lord Dalhousie—Subsequent remodelling of canal.

North-west
Provinces
Irrigation—
Eastern
Jumna Canal.

IN the North-west Provinces the earliest work undertaken by the English Government was in connection with the Eastern Jumna Canal. This canal, which, as we have seen, was originally constructed by Ali Murdan Khan, under the Emperor Shah Jehan, was abandoned in 1628 shortly after its construction, owing to the excessive slope of the bed and the difficulty of maintaining its passage across the mountain torrents near its source. It is said to have been partially restored in 1764 by a chief named Zabitha Khan, but again fell into disuse. The canal was re-opened under the British Government in 1830; the work of improvement having been commenced in 1823. The original defect of excessive slope, however, soon again made itself apparent, and to remedy this, the construction of a series of masonry over-falls, to correct and regulate the slope of the bed, was constructed. A portion of the canal was again remodelled in 1854. A new cut of more than 5 miles in length was excavated, and the adjustment of the bed slope was finally completed.

The head of the Eastern Jumna canal is about 3 miles

below that of the Western Jumna system, on the opposite bank of the river. For the first part of its course it occupies the shingly bed of the Budhi Jumna for 4 or 5 miles to Nayashahr, where a masonry dam with 30 sluices was constructed across that stream. It then enters a difficult tract of country, having to cross on the level four mountain torrents within a distance of 10 miles. Two of these, the Nowgong and the Muskarra, are wide and rapid, and are furnished with masonry dams to regulate the flood waters. On gaining the high ground between the Jumna and Hindun, the canal continues nearly parallel with the former river, and only a few miles distant from it, until it again re-enters the parent stream at Delhi. For a length of about 40 miles the canal is carried on embankment from 6 to 12 feet above the level of the country. Its length is 130 miles, with 640 miles of distributing channels, watering a tract about 120 miles long and 15 miles broad. The canal commands a culturable area of 589,000 acres, of which 350,000 acres are irrigable by the present channels. The Eastern Jumna is one of the best-paying canals in India, returning a very high percentage on the capital expended upon it by the British Government, which, however, is short of the full value of the work, by whatever sum may be assigned as the value of the old native works utilised.

Encouraged by the favourable results of the Western and Ganges Canal. Eastern Jumna canals, the English Government of India took up in a large and liberal spirit the consideration of numerous irrigation projects. In the year 1836 the first studies for a large original canal to be derived from the Ganges, for the irrigation of a considerable portion of the Ganges Jumna Doab, were made, and the supreme necessity for such a work was terribly illustrated by the fearful loss of life and sacrifice of revenue entailed by the calamitous famine of the following year, 1837-38. Complete investigation and detailed surveys and estimates for various projects were made, and exhaustively discussed, labours which eventually resulted in the well-known Ganges Canal.

When this magnificent scheme, which was practically commenced only in 1848, was, after various vicissitudes, completed in 1854, it was the largest work of the kind in existence in the

world. Even at the present time there are few canals that can compete with it in boldness and originality of conception, and although the original design and execution of the work in some important particulars was almost of necessity injuriously affected by the absence, at the time of its projection, of previous experience in canal-engineering on anything like so large a scale, it still remains one of the most remarkable public works of its class to be found in any country. The early history and minute description of its engineering details, written by its able designer and constructor, Sir Proby Cautley, has rendered it also perhaps better known to those specially interested than almost any other similar work.

The Ganges Canal commences at Myapore, at a short distance below the sacred town of Hardwar, almost at the point where the Ganges river, forcing its way through the 'Sewalik' sub-Himalayan range, debouches into the plains. A little above Hardwar the Ganges divides into two branches, which again unite about a mile and a half below the town. The canal is taken off from the southern, and smaller, of these two branches, which is carefully regulated and kept clear to feed the canal.

A permanent masonry dam, provided with sluices, is thrown across the river branch. This dam is 517 feet long between the flanks, and is pierced in the centre by fifteen openings, each 10 feet wide. The piers, which are 8 feet high, are fitted with grooves for the sluice-shutters. On either side of the central openings are overfalls of stepped masonry 18½ feet in maximum height. A tramway, provided with a travelling crane for working the sluices, extends along the top of the dam, and is a later addition. At the entrance to the canal is a regulating bridge of ten openings, each 20 feet wide, furnished with sluice-gates, which can be raised or lowered by means of capstans. The bridge, besides serving to carry the canal head sluices, carries the public roadway from Hardwar to Kunkhut.

By means of the two sets of sluice-gates, viz, those in the dam, and at the regulating bridge, either the whole amount of water in the river branch can be intercepted and sent down the canal, or the whole, or any part of it, can be shut off from the canal, and allowed to escape through the dam, to rejoin the main Ganges river below.

From the regulating bridge the canal flows in one continuous stream for 180 miles, with a bottom width at the commencement of 140 feet, and not far short of 200 feet on the surface of its full water, diminishing gradually to 80 feet bottom width at the 181st mile. Here the canal bifurcates into two separate canals; the point of bifurcation being provided with a regulating bridge fitted with sluice-gates, precisely similar to that at Myapore, to control the quantity of water passed down either branch. One of these branches, 170 miles long, and navigable throughout, extends with a gradual reduction of width to 20 feet, to Cawnpore. Passing between the cantonment and the city, it re-enters the Ganges through a series of locks and gates, adapted for the entrance and exit of boats. The other branch, also after a course of 170 miles, and a gradual reduction of width to 20 feet, passes into the Jumna near Hamirpur.

For the first 20 miles of its course from Myapore to Roorkee, the main canal passes over the 'Khadir,' or low valley land of the Ganges river, and is taken across a number of large mountain streams, subject to sudden and violent floods, which descend from the neighbouring sub-Himalayan range of hills. Along this tract of apparently level country the slope of the ground is in reality so great that the beds of these streams for the greater part of the year consist only of dry sand and shingle, but during the rainy season they become wild and foaming torrents. 'To carry the great canal—itself a small river—across such a country—to see it pass silently on, uninterrupted and uninjured by these torrents, while the torrents themselves pass through the canal unchecked, as well as over it, and under it in several places—is a triumph of art and engineering ability.'¹

About 6 miles from the head works, the Ramipore torrent is passed over the canal by a masonry aqueduct or 'super-passage.' This aqueduct carries a volume of water 196 feet wide and 14 feet deep. The canal passes below through eight arched openings, each of 25 feet span, on the up-stream side of which a masonry overfall of 9 feet carries the canal to a lower

¹ 'Public Works in the Bengal Presidency,' by Major-General B. H. Tremenhoe. *Minutes of Proc., Inst. of Civil Engineers*, vol. xvii.

bed. On the left there is a lock and channel, by means of which boats can pass round the aqueduct. In the 10th mile the Patri river is conveyed across the canal by a grand aqueduct, similar to that at Ramipore, but on a still larger scale; the width of waterway for the river being no less than 296 feet, carried on nine arches, extending the whole width of the aqueduct. The canal passes beneath through eight of these arches, and a curved masonry line of descent on the up-stream side carries the water to a 9 feet lower level. The ninth arch opening is utilised for the lock, bringing the navigable channel down to the same extent.

In the 13th mile the canal meets the Rutmoo torrent on the same level with itself. The flood-water of this torrent, which carries the drainage of 126 square miles of country, and which has a bed-slope of 8 feet in every mile, is allowed to mingle with the water of the canal. It is admitted through an inlet-dam, consisting of a masonry platform provided with regulating sluices, and it passes out over another masonry escape-dam, situated opposite the inlet one. The torrent is only passed completely across the canal during the period of highest floods, when communication with the lower portion of the canal is shut off to the extent required, by the flood-gates of a regulating-bridge just below the cross-passage. At such times the flood-waters of the torrent, and the head-water of the canal itself, both pass over the escape-dam, and are carried away down the lower channel of the torrent. The escape-dam is provided with 47 sluice-openings, each 10 feet wide, separated by piers $3\frac{1}{2}$ feet thick, the bottom of the sluice-openings being flush with the bed of the canal. On each side of the central portion there are five additional sluices of the same width, viz. 10 feet, but having the bottom, or 'sill' of the sluices placed 6 feet higher. Beyond these higher sluices, on each side, a masonry platform extends at a height of 10 feet above the canal bed. Up to 6 feet in depth of water, therefore, there is a free passage 470 feet wide. Above this, up to a height of 10 feet, the width of the free passage is increased by the ten higher sluice-openings to 570 feet, and if the water should rise higher than 10 feet it passes over the whole width of the masonry platform, with a total waterway 800 feet long.

In the 16th mile of its course from the head-works at Hardwar, the Ganges canal encounters the Solani valley and river, at the very extremity of the low 'Khadir' land of the Ganges, and just before it gains the high ground of the Doab, a short distance beyond Roorkee. This valley is crossed on a magnificent aqueduct, having a total length of nearly 3 miles, a work which at the time of its construction was the most considerable then attempted in India.

A canal aqueduct differs in no way from an ordinary bridge, except that it has to carry a water-channel over it, instead of a road or railway. It is often of much greater width than other kinds of bridges, and it is obvious that the carriage of a volume of water, probably of considerable depth, and exerting considerable pressure, requires that the side walls or parapets, which in this case support the water, should be made much thicker than those required for road or railway bridges. Special precautions also are necessary to prevent leakage in every part of the structure. The term 'railway-bridge,' or 'road-bridge,' is usually confined to the masonry or iron structure crossing the ordinary water-channel of the river; but it is usual in the case of canal 'aqueducts' to include in the term, not only the real bridge spanning the water-channel, but also the whole length of the approach embankments across the river valley, where these are carried at a considerable elevation above the natural ground. The reason of this is, that in the case of railway or road-bridges, the raised approaches on either side crossing the valley of the river, are usually plain earthen embankments; whilst in the case of canals, the embankments are commonly lined with masonry throughout their entire length, or some other special expedients are adopted to prevent the percolation and escape of water through their sides.

As we have already seen, when a canal meets a natural river, and it is necessary that it should be carried forward beyond it, it must either be conducted *over* the river on a raised bridge or aqueduct, or it must cross on the *level*, or it must be carried by a syphon or tunnel *under* the river. The adoption of one or other of these expedients will chiefly depend upon the relative necessary levels of the water in the canal and the river, at the point of their intersection.

The Rutmoo torrent in the 13th mile having been passed on the level, in the manner lately described, the Ganges canal is carried through the 'Peeran Kulliar' ridge, in a deep cutting 40 feet deep from the canal-bed to its highest point, and nearly two miles long. On emerging from this cutting, the passage of the Solani valley and river commences. The Solani is a mountain torrent of considerable size, draining an area above the aqueduct of about 216 square miles; the drainage basin being about 27 miles long and 8 broad. About a quarter of the area lies on the Sewalik range of hills, and the remainder on rapid but gradually decreasing slopes. At the site of the aqueduct the fall in the bed of the river is 5 feet a mile, and at highest floods the torrent discharges 35,000 cubic feet of water per second. The width of the river valley at the point where it is crossed by the canal is 13,265 feet, or a little over $2\frac{1}{2}$ miles; and the total length of the masonry works of the aqueduct required to convey the canal over it, from one extremity to the other, is 15,698 feet, or within a few feet of 3 miles. The Ganges canal on meeting the valley is 140 feet in bottom width, with side slopes of $1\frac{1}{2}$ to 1, carrying a body of water having a maximum depth of 10 feet.

Essentially, the works constructed to enable these large natural and artificial water channels safely to get clear of each other, consist of a massive masonry bridge or aqueduct having fifteen arched openings of 50 feet each, carrying the canal at a height of 24 feet above the river bed, and two masonry protected earthen embankments, which connect this structure with the high land on either extremity of the valley; the masonry protected embankment on the south or Roorkee side of the river being 2733 feet, or over half a mile long; and that on the north side being 10,713 feet, or over two miles long. In addition there are various works for the regulation of the river during floods, to prevent it wandering beyond its assigned limits, and for the proper control of the water flowing over the masonry aqueduct itself.

The general design of the Solani aqueduct will be gathered from the adjoined illustration and figures. It is not only one of the largest works of its kind in India, but taking into account the early date of its construction, it may be considered



SOLANI AQUEDUCT.

70 1940
AUGUST 10

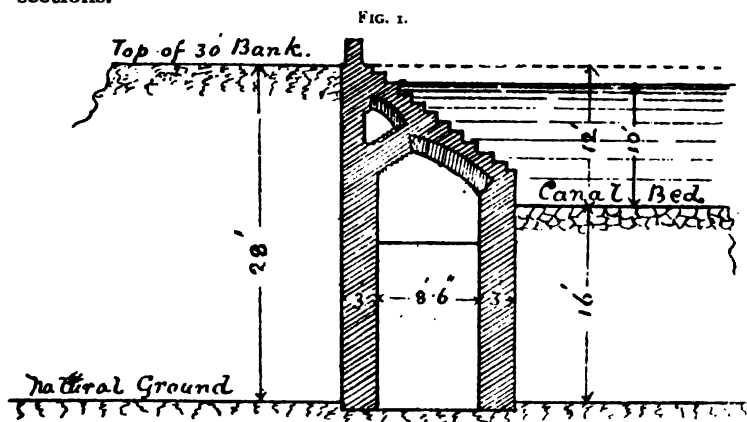
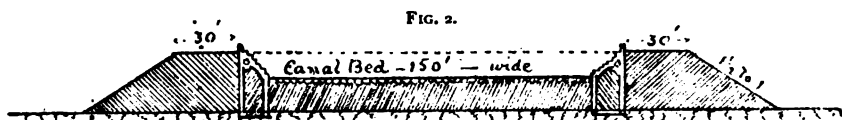
as the most interesting and remarkable modern structure in that country. The total elevation above the river-bed is 38 feet only. Owing to this deficiency of height, as compared with length, the aqueduct as seen from below is by no means specially imposing; but when viewed from above, where its immense breadth and solidity are apparent, with its line of masonry-channel extending for nearly 3 miles, the effect is most striking.

Work was commenced on the earthen embankment lying north of the river in the cold season of the year 1845, and the whole aqueduct was practically completed by the year 1854. During the first two years much time was of necessity expended in manufacturing the enormous quantities of bricks and other materials required for the masonry; in collecting the necessary working-plant, and in bringing together, organising, and in great measure educating, the skilled labour needed, which at that time was greatly, if not almost entirely, wanting.

The height of the earthen embankments on the north and south sides of the river, from the surface of the natural ground up to the bed of the canal, is variable, but averages about 16 feet over its entire length, and reaches a maximum height of 24 feet. Above the level of the canal bed, the two portions of the bank forming the canal sides, rise to an additional height of 12 feet, the width of each being 30 feet on the top. The total height of earthwork, therefore, averages 28 feet, with a maximum of 36 feet. At the level of the canal bed the embankment is 290 feet wide, reaching 350 feet in width on the lowest ground surface.

Longitudinally through the whole length of the embankments, masonry walls, at a distance apart of 150 feet (or the width of the canal), are carried. These walls are founded in the natural ground, and are built up to above the highest water level in the canal, they are entirely concealed in the earthen embankment, except the inner portions lying above the canal bed. This portion is worked back into a series of steps, which form the interior sides of the canal, along which the water flows. The internal construction of the aqueduct embankments, with the enclosed revetment-walls, will be best

understood from a glance at the figures 1 and 2 below, which represent an embankment and wall cut open from top to bottom, on lines drawn across them—or what are called ‘cross sections.’



It will be observed that each line of revetment is formed of double walls of masonry 8 feet 6 inches apart, and 3 feet thick; the two walls being joined together above by archwork, arranged so as to admit the super-construction of the series of steps forming the actual revetment of the canal sides. The pair of walls forming the masonry heart of the embankment are also joined together at intervals of every 15 feet of their great length of more than twice $2\frac{1}{2}$ miles, by cross walls built up nearly to the level of the canal bed. All the hollow spaces between the brick walls, and up to the under side of the archwork is filled in with earth or clay, well beaten down, which formed, in fact, the ‘centering’ or support on which the archwork was built.

The earthwork of the embankment was executed in a variety of ways. On the early commencement of the work on the north side of the river in 1845, earth was dug from side trenches 188

feet wide and $5\frac{1}{2}$ feet deep, and was thrown up to form a raised bank along the central axis of the alignment. On the south side the canal excavation through the high ground near Roorkee furnished material for the first portion of the aqueduct embankment which was pushed forward, and carried out into the valley by ordinary basket-labour, and by means of wheel-barrows working on continuous lines of planks. It soon, however, became necessary to lay down a tramway of light rails, and to employ large numbers of tip-wagons. At first the tip-wagons were propelled by manual labour, but as time went on horses in great measure took the place of men. Eventually, on the 22d December 1851, a steam locomotive was got to work to haul trains of earth or 'ballast' wagons across the whole extent of the valley. This engine, which was named the 'Thomason,' is interesting as being almost certainly the very first locomotive engine used for constructional purposes in India.

It was a small but compact machine, with both engine and tender on one frame, and it was supposed to be able to draw a maximum load of 200 tons on the level at four miles an hour. The engine, however, did not turn out a success; meeting with a bad accident it was discarded at the end of a few months' use. Shortly afterwards it was dismantled and utilised for driving machinery in the workshops at Roorkee. Inexperience in management—perhaps a little prejudice against it—and the want of proper facilities for expeditiously carrying out repairs, were no doubt the chief causes of the failure.

The double pair of walls in the embankment were built up to the level of the canal-bed gradually in proportion as the earthwork advanced in height. The line of rails occupied a bank raised along the central axis of the work, and at intervals of every 200 feet cross banks of earth were extended laterally, right and left, to the revetment walls. These cross banks served a double purpose, viz., as a passage for carrying earth for the embankments outside, or to the rear, of the masonry walls, and also for forming a series of rectangular hollow spaces, each about 200 feet long, between the central line of rails and the side walls, which acted as reservoirs or ponds for receiving and holding water during the rains, thus ensuring a good compression and consolidation of the earthwork in that part of

the embankment immediately below the canal bed, where it was most desirable.

Outside the revetment masonry, the earthwork above the level of the canal bed was completed by tip-wagons running on lines of rails carried along these portions of the bank. The earthwork filling between the double walls was brought up to the height necessary to serve as a centering on which the archwork connecting them was constructed, this done, the masonry steps forming the visible revetment along the sides of the canal were finished off. At each end of the aqueduct embankments, the masonry revetment walls and earthworks terminate on the high ground at the edge of the valley, in contact with masonry bridges and structures built across the canal.

The Solani aqueduct embankments north and south of the river, over $2\frac{1}{2}$ miles in combined length, contain approximately about five million cubic feet, or nearly 200,000 cubic yards of brick masonry, and 59 millions of cubic feet, or nearly $2\frac{1}{4}$ million cubic yards of earthwork,—a mass of material that, piled together, would form a pyramid about 700 feet square on the base, and 400 feet in perpendicular height.

The Solani River itself is crossed by a masonry bridge 1110 feet in clear length. The open waterway is 750 feet long, composed of 15 arched openings each of 50 feet span. The *width* of the arches from face to face is no less than 192 feet, and their thickness at the crown is 4 feet 6 inches. They are segmental in form, with a rise of 8 feet in the centre. The piers are 10 feet thick at the springing of the archwork, and $12\frac{1}{2}$ feet in height. Above the arches the parapet or side walls of the aqueduct are 8 feet thick and 12 feet high above the canal bottom. Between these parapets the water flows with a width of 172 feet, and a full depth of 10 feet, but the complete width is divided into two channels, each 82 feet wide, by a longitudinal partition-wall along the centre. At each end of the partition-wall cross piers are built, fitted with grooves, corresponding with similar grooves in the side parapet-walls, into which planks can be inserted, so that either half of the aqueduct longitudinally can be closed and cleared of water whenever necessary for carrying out repairs. The water in the closed half is got rid of by discharging it into the Solani River

through sluices and passages in the aqueduct abutments provided for the purpose.

As seen from above the four corners of the structure are terminated by rusticated wing-walls, surmounted by pedestals, each carrying a recumbent lion, constructed of masonry and stuccoed. The lions face inwards towards the river, seeming to guard the portal by which the Solani is permitted to pass through the works. Other lions facing outwards are placed at the extreme ends of the masonry-protected approaches.

The piers and abutments of the main aqueduct are founded on blocks of brick masonry, sunk 20 feet deep into the river bed, which consists of sand intermixed with clay. The blocks are each 20 feet square, and are therefore cubes of brickwork of 20 feet a side. They are each pierced with four rectangular (or octagonal) openings or 'wells' through which the river-bed material was withdrawn during the process of sinking. Other blocks of varying dimensions support the 'cutwaters' or projecting portion of the piers, and the wing-walls and defences of the abutments. When the blocks were sunk to their full depth the well-openings were filled in and arched over at the top, so as to form a level platform on which the piers or abutments were built up.

The total width of the foundation works of the Solani aqueduct is 252 feet, and the quantity of masonry sunk out of sight below the river bed is probably not far from that visible above it. The construction of the archwork was commenced on the 1st December 1851, and the last arch was keyed in on the 4th July 1853. As we have stated, the total width of the archwork is 192 feet, but in order to lessen as far as possible the liability to distortion from any unequal settlement of so wide a mass of masonry, and for purposes of economy in centering, and general convenience, the archwork was constructed from shore to shore, in two half-widths, each of 96 feet. This series of up and down stream arches lie quite close to each other, but are not actually in contact. The construction of the whole magnificent work was practically completed by the end of March 1854.

In addition to the fine works above specially referred to, the

Ganges Canal in its short passage of about 20 miles across the low-valley land of the sacred river, admits into its bed five other smaller torrents, controlling these uncivilised and turbulent kinsfolk by means of suitable masonry works. The width of water-passage for these torrents is in two cases 150 and 100 feet respectively, in two cases 50 feet, and in one case 30 feet. At Roorkee the canal gains the high land of the Ganges-Jumna Doab, and continues its course free from the immense obstructions encountered in its first section. The main canal lies along the centre of the table-land between the Ganges and the Jumna, throwing off several main branches along the ridges between the intermediate smaller rivers, all adapted for internal navigation, as well as for irrigation. Irrigation commences just beyond Roorkee, at a little over 20 miles from the head-works.

Water was admitted into the canal by Lord Dalhousie on the 8th April 1854. It is said that before the opening of the canal a considerable body of the Hindu priests, attached to the numerous temples situated along the bank of the river in front of the town of Hardwar, steadily refused to believe that the water of the Holy Ganges would ever consent to enter the canal, and so confident were they in this opinion that they formed themselves into a solid phalanx in the bed of the canal, just below the intake of the water, so that when the sluices were opened they might from this apparently dangerous position, duly emphasise before the assembled people the great miracle that would take place. As however the Ganges water proved amenable to the laws of gravity, the canal bed was expeditiously abandoned very soon after the gates were opened. This story may have some slight basis of fact, but is probably in the main apocryphal. The enormous benefit conferred on the community by the Ganges Canal is illustrated by the statement that probably as many lives were saved by it in Bengal during the year 1865-66 as perished during the same terrible year in Orissa. From statistics showing the amount of grain carried down country from the canal districts by the East Indian Railway, and by river transport, it is estimated that the canal in that year fed little short of $2\frac{1}{2}$ millions of people. In the same year it repaid to the country more than its then total cost.

Subsequent experience showed that the slope allowed to the bed of the Ganges Canal was too great to allow, without dangerous erosion, the passage of the full volume of water originally contemplated, and some considerable remodelling was necessitated, which has proved successful in removing the main evils.

CHAPTER V

NORTH-WEST PROVINCES

Lower Ganges Canal : outline of newer system—Description and details of weir at Narora—Original Nadrai aqueduct—Partial destruction by floods—The new Nadrai aqueduct—Details of the structure—Foundation arches and general construction—Agra Canal—General course followed—Description of head works at Okla—First example of a weir in India crossing a river bed of fine sand of unknown depth—Betwa Canal—Origin of project—Particulars of head weir—Minor canals in the North-west Provinces—The Dun canals—The Rohilkund and Bignor canals—General results of irrigation in the North-west Provinces.

Lower Ganges
Canal.

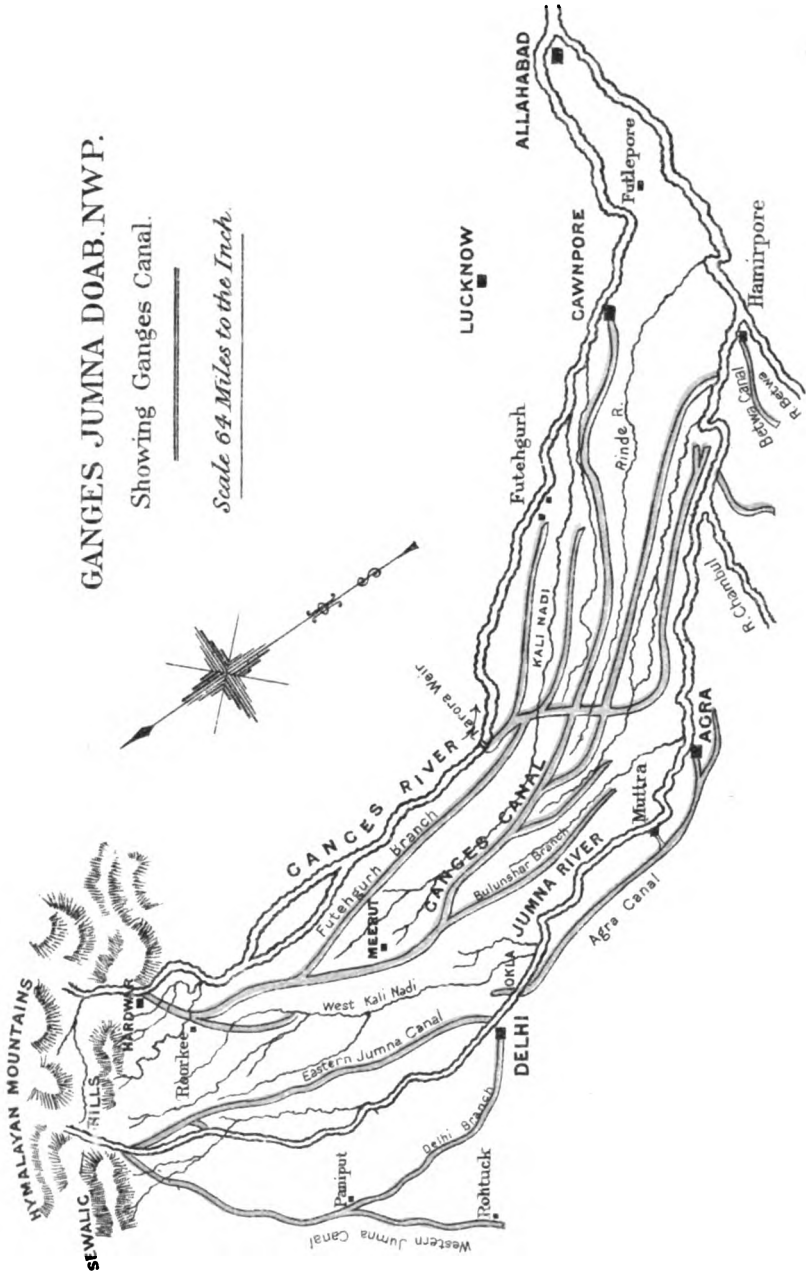
THE Ganges Canal as originally constructed was fully able to supply the wants of the upper portion of the Ganges-Jumna Doab, but lower down there remained large districts over which its influence did not, and could not, extend. This consideration led to the projection and subsequent construction of a lower system of canals derived from the Ganges, from above a weir which has been constructed at Narora, a place situated a few miles below Rajghat, where the Oudh and Rohilkund Railway crosses the river. In order to apportion a better distribution of the available water between the upper and lower halves of the Doab, various additions and extensions of the main branches and distributaries of the original work were incorporated in the new scheme.

The whole system of irrigation in the Ganges-Jumna Doab has for purposes of administrative convenience of late years been divided between what are now called the 'Upper' and 'Lower' Ganges Canals, the lower portions of Sir Proby Cautley's original work forming a part of the latter. The lines of main canal and principal branches of the whole combined system are exhibited on the accompanying map, and it will be convenient to consider the details of the upper and lower canals separately,

GANGES JUMNA DOAB. N.W.P.

Showing Ganges Canal.

Scale 64 Miles to the Inch.



To my
Algebra

as they are now officially divided. The Upper Ganges Canal has a length of main line and branches of 456 miles, of which 213 miles are navigable, with upwards of 2500 miles of distributing channels. The maximum discharge of water by the canal is 6799 cubic feet per second, and it commands an irrigable area of 1,600,000 acres, irrigating in favourable years about 1,500,000 acres, or 2344 square miles.

The Lower Ganges Canal system, fed from the Ganges River at Narora, has a total length of main line and branches of 557 miles (including about 300 miles of what originally formed part of the old Ganges canal), with over 2000 miles of distributing channels. It commands an irrigable area of 1,187,326 acres, or 1855 square miles, but the system has not yet developed anything like its full working capacity, actually irrigating somewhat less than half of this area. The weir across the Ganges at Narora, with the adjoining scouring sluices, canal head, and navigation channel with lock, forms one of the finest and most imposing engineering constructions in India. It was begun in the year 1873, and was completed in 1878. This splendid weir, including the scouring-sluices in prolongation, is 4244 feet in length, or considerably over three quarters of a mile. At the point where the weir is constructed, the bed of the river consists of a very fine smooth sand, which, when wet, is almost fluid. Into this sand a long line of hollow blocks or wells, each 10 feet square, was sunk, down to a depth of about 30 feet for a distance of 500 feet from the scouring-sluices, which immediately adjoin the canal head, and to a depth of about 10 feet for the remaining part of the length of the weir. When sunk to the required depth the hollows in the blocks were filled in solid with concrete, and on this block foundation the main weir-wall was constructed, consisting of a wall of masonry 9 feet 9 inches high, and 8 feet thick, extending for a length of 3800 feet. Owing to the difficulty and expense of obtaining stone, the work has been constructed as an 'overfall' weir; there is, therefore, on the lower side, a floor 40 feet wide and 5 feet thick to receive the water falling over the weir-wall, and along the lower edge of this floor a line of circular wells, each 8 feet in diameter, is sunk to a depth of 20 feet below low water. To prevent the escape of the fine sand between these wells, the

small spaces between them are filled in by piles driven as closely together as possible. For a long distance on the down-stream side of the floor, an apron or slope of large heavy blocks is thrown to protect the river-bed from the action of the water. The weir is designed to raise the old cold-weather level of the water 7 feet, and in order to prevent a heavy deposit of sand taking place above the weir, which would inevitably block up the entrance to the canal, a line of scouring-sluices 444 feet in length, consisting of forty-two openings, each of 7 feet 3 inches clear width, is constructed on the side adjoining the canal head, in continuation of the weir proper. The scouring-sluices superstructure forms a handsome double-storied building, and stands on a stone and concrete flooring 5 feet thick, 427 feet long, and 155 feet wide, the whole being enclosed and supported by foundation blocks or 'wells,' 10 feet square and 12 feet deep.

At an angle with the line of the weir, the entrance of water into the canal is controlled by a regulating bridge having thirty sluice-openings, each 7 feet wide; and to admit the entrance and exit of boats, a navigable channel, having a lock 150 feet long and 20 feet wide, has been provided at a short distance above the regulator. About 32 miles from the head-works the main channel crosses the Kali Nadi at Nadrai by a splendid masonry aqueduct.

The existing Nadrai aqueduct is a recent structure, having been commenced in the year 1885, and completed in October 1889, in replacement of an older work which was destroyed by heavy floods occurring in the years 1884 and 1885. As it is the latest, so it is also one of the finest of the many remarkable canal aqueducts to be found in India.

During the construction of the main Lower Ganges Canal, the original Nadrai aqueduct across the Kali Nadi, or River, was built in the years 1874-76. The river above the site of the work was said to receive the drainage of over 2500 square miles. Owing, however, to its reception of spill-water from Ganges floods, the data for estimating its true maximum discharge was somewhat uncertain. The original aqueduct consisted of five arched spans of 35 feet by 14 feet, providing 2450 square feet of waterway, and for an estimated discharge of about 18,000 cubic feet per second. The piers and abutments were

founded on wells sunk in sand to a depth of 18 to 20 feet below the bed of the river. The canal passed over the aqueduct in a channel 192 feet wide and 9 feet deep, with a water velocity of 3 feet a second. On the 2d October 1884, this less than ten-year-old aqueduct was partially destroyed by a very heavy flood in the Kali, which undermined the foundations and carried away about a fourth of the structure. On the 17th July of the following year a still heavier flood occurred, which completed the destruction of the aqueduct, and it became necessary to design and commence the erection of an entirely new work with a greatly increased waterway.

About half-a-mile below the site of the work was an old native road-bridge, said to have been built more than a century ago, having a waterway consisting of seven openings of 10 feet 6 inches by $14\frac{1}{2}$ feet, and two side openings of 8 by 5 feet, giving a total water area of 1146 square feet only—or less than one-half that of the canal aqueduct. This old native bridge—the existence of which had been supposed to justify to some extent the waterway allowed in the case of the original Nadrai aqueduct, was in no way injured by the floods which destroyed the latter. It happened—as had no doubt happened many times before—that the earth approach-banks on either side were washed away for the length of perhaps half-a-mile, giving an ample passage for the water, and leaving the bridge itself—not exactly high and dry—but isolated, as an island, in the middle of the current. It is in this way that many of these old native bridges of small dimensions find relief, and are saved from destruction in the highest floods, whilst the massive and substantial approach embankments of a canal aqueduct, or of a lofty railway bridge, confine the flood waters to the particular open waterway assigned, so that if this waterway happens to be insufficient the bridge is either undermined or overwhelmed.

After the partial destruction of the aqueduct in 1884, and its complete destruction in 1885, fresh investigations and calculations were made to ascertain the true maximum discharge of the river, and it was eventually determined to allow in the new structure an area of waterway more than four times greater than in the old one destroyed.

The new Nadrai aqueduct over the Kali river, the architec-

tural features of which are illustrated by the accompanying engraving, is constructed of brickwork, and is 1220 feet long over all, consisting of fifteen segmental arch openings of 60 feet each, carrying the canal, 130 feet wide and 7 feet deep at full water, at an elevation of 24 feet 3 inches above the bed of the river. On one side it carries a roadway, 10 feet, and on the other a bridle path, 5 feet in width. The breadth of the structure from face to face of the arches is $148\frac{1}{4}$ feet; the extreme width from nose to nose of the piers being 181 feet. The thickness of the arches at the crown is 3 feet 9 inches. The piers are 10 feet thick at the springing of the arches, 12 feet at the bottom and $11\frac{1}{4}$ feet high above the river bed.

For purposes of economy and convenience the fifteen arches are divided into three bays or groups of five arches each, by two abutment piers, which are twenty feet thick at the top.

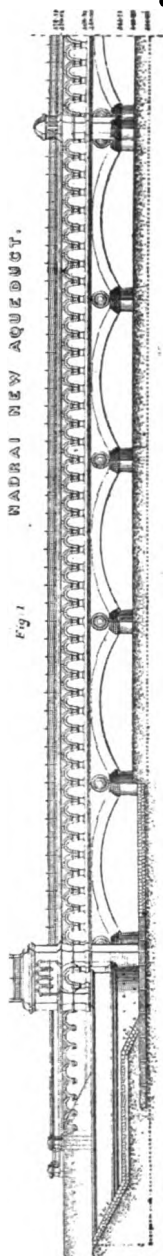
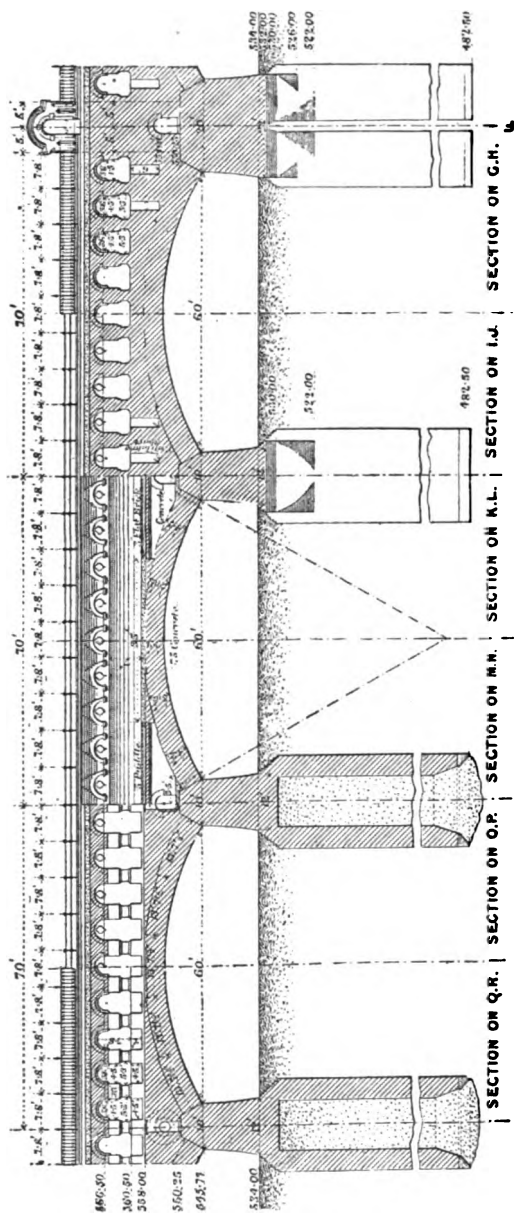
The aqueduct superstructure is founded on circular wells, those under each ordinary pier consisting of a single row of eight wells, each 20 feet in external, and 11 feet in internal, diameter. The abutment piers and shore abutments are founded on double rows of wells of 13, and 12 feet external, and 6 feet 3 inches internal diameter. These wells were sunk from 45 to 50 feet into the river bed; the first 25 feet or more being sunk through sand, and the remainder through a hard, tenacious clay. When pushed down to the full depth the wells were filled in with concrete, and the tops were overlaid with a solid masonry platform 4 feet in thickness, to form the base of the superstructure. The number of wells sunk was 268, and their united length was 15,019 feet, or nearly three miles of brick well-work.

Owing to the great breadth of the aqueduct, the arches were turned in three, and latterly in two, sections, each one-third or one-half of the total width of the archwork. The line of separation between the sections was, after the arches were completed and had finally settled into position, covered by arch rings of brickwork, 5 feet wide and 15 inches thick, let into the upper surface of the archwork.

The main arches cover an area of over three acres, and weigh over 30,000 tons. The centering on which this immense mass of arch masonry was constructed, 75 feet in width and 60 feet

NADRAI NEW AQUEDUCT.

Fig. 1



long, were moved bodily on wheels and tram-roads, from section to section, or from arch-group to arch-group. By this means a very great saving in time was effected, with the result that the arches were built in 176 days, or at the average rate of less than twelve days per arch, out of which twenty-five days only were occupied in moving the centerings. Upwards of fifty-eight millions of bricks were used in the construction of the aqueduct, and the total cost of the work, including subsidiary operations, amounted to about £360,000, or thirty-six lacs of rupees.¹

Another of the principal canals of the North-west Provinces **Agra Canal**. is the 'Agra Canal,' taken from the right bank of the river Jumna at Okla, about eight miles below Delhi. The Eastern and Western Jumna Canals, situated higher up the river, draw off the whole of the water from the Jumna in the dry season, leaving the bed quite empty; nevertheless, by the time the river has reached Delhi underground filtration and intermediate drainage has furnished a fresh supply, amounting to an average of about 700 cubic feet per second during the hot weather. At first it was contemplated to utilise this water in the Ganges Jumna Doab, to supplement the irrigation in the Ganges Canal districts, but eventually it was decided to construct a large canal on the right bank of the river to irrigate a very dry and parched tract of country lying between Delhi and Agra.

As it was designed to draw off the whole of the water in the river Jumna at Okla during the dry season, the bed of the river between Delhi and Agra would be left practically dry, all navigation by the natural stream being of course stopped. The Agra Canal, therefore, has been made navigable throughout, so that boats quitting the Jumna at Delhi proceed by the canal, and rejoin the river through a navigable channel and lock at Agra. A navigable branch also connects the main canal with the populous city of Muttra, and an extension of the Delhi branch of the Western Jumna Canal, to link it with the Agra Canal, was also designed. Through this link, when the Punjab

¹ The data in this description is abbreviated from a paper on the construction of the new Nadrai Aqueduct, by Mr. W. Good. Vol. cv. *Proceedings of Institution of Civil Engineers*.

system of canals is completed, inland navigation will extend through the watershed separating the Ganges and Indus basins, so that boats will be able to traverse the whole length of country from the mouths of the Ganges to the mouths of the Indus.

The Agra Canal was opened in the year 1874. It has a total length of main line and branches and navigable channels of 134 miles, with nearly 600 miles of distributaries, commanding an irrigable area of 240,000 acres, or 375 square miles. The head of the canal is situated just above the weir thrown across the bed of the Jumna at Okla. This weir was the first made in India in a river bed consisting of fine semi-fluid sand. It consists of two parallel masonry walls 26 feet apart and 2428 feet long, laid on the river bed itself, without any sunk foundation. The space between the walls is filled in with large blocks of stone, well packed. On the up-stream side of the front wall a heavy protection of loose stone, 40 feet or more in width, and having a slope of 1 foot in every 4, is carried from the river bed to the crest of the wall. On the down-stream side of the rear-wall there is a wide apron formed of heavy stone, no less than 180 feet in width, with an easy slope of 1 foot in every 20 feet. The total width of the weir, therefore, over all is more than 250 feet, and the main weir walls are so encased and protected by masses of packed stone on either hand as to be quite beyond the reach of any scouring action of the water.

The front wall is 8 feet thick at the bottom, where it rests on the sandy bed of the river, and 4 feet thick at the top, which is placed at 7 feet above the lowest water-level. The rear wall is somewhat smaller. The rise of the river in times of high floods is about 11 feet, and at such times the obstruction presented by the weir causes a fall in the surface of the water of between 3 and 4 feet. There is, consequently, a very severe action on the down-stream apron of packed stone, which, soon after the weir was first made, did a good deal of damage, necessitating the subsequent breaking up of the rear slope, and binding it together by additional longitudinal walls carried through it. On the side of the river, where the canal head is situated, there is a set of scouring sluices, to prevent

the accumulation of sand above ; and an embankment is carried along the river bank for about eight miles to protect the adjoining lands from inundation, and to prevent the water wearing its way round the end of the weir. From its regulating bridge at Okla the canal follows a course nearly parallel with the Jumna, and at no point very far from it. The tail end of the canal is led into the river Utongou, about twenty miles below Agra.

So far back as the year 1855 a scheme was proposed by *Betwa Canal*. Captain (afterwards Major-General) Strachey for a canal to be drawn from the left bank of the river Betwa near Paricha, a point about thirteen miles east of Jhansi, to irrigate the tract of country lying in the angle between the Betwa and the Jumna, in the centre of which is the town of Jalaun, and a party sometime afterwards appointed to investigate the subject perished during the Mutiny. Nothing was done until the years 1867 to 1869, when a detailed project and estimates were prepared, which, however, fell to the ground, and the scheme was in abeyance until 1872-73, when further studies and estimates were made. A matured project was finally sanctioned as a famine 'protective' work in 1881, and the existing Betwa Canal was opened in the year 1885.

A fine masonry weir was constructed across the Betwa at a point where the river is crossed by several rocky barriers. The weir, which is of serpentine form, taking in an island and a reef of rocks in its passage, is 4246 feet long, including the island, and 4000 feet of clear construction. In height, owing to the irregularity of the river bed, it varies from 3 feet up to 60 feet in the deepest channel. At right angles to, and adjoining the canal head, a set of four under sluices with a training wall, stands in front of the canal mouth. The regulating bridge across the entrance to the canal has five openings of 6 feet each, provided with sluice gates, and divided by piers 4 feet thick. The canal starts with a bottom width of 25 feet, and at a little over twenty miles from the head it divides into two main branches, one extending to the Jumna near Hamirpur, and the other tailing into the same river higher up, near Kathaund. From the Hamirpur branch a secondary branch runs to Kalpi.

The canal has a mileage of main line and branches of 168 miles, with over 300 miles of distributing channels, command-

ing about 150,000 acres, but hitherto irrigating only a comparatively small portion of this area. Incorporated with the Betwa canal a small amount of irrigation is carried on from the Jhansi and Hamirpur lakes through about 70 miles of distributaries, irrigating about 2000 acres.

Minor Canals. The remaining minor canals in the North-west Provinces are the 'Dun Canals,' the 'Rohilkund Canals,' and the 'Bignor Canals.' The Dun Canals are situated to the north of the Sewalik range, between the Jumna and the Ganges. There are five principal channels, having a total length of 74 miles, and irrigating from 20,000 to 25,000 acres. The Rohilkund Canals are a group of small irrigation channels situated in the Bareilly district between the Ramgunga and Sarda rivers. They consist of 20 miles of main canal, with 337 miles of distributaries, irrigating about 95,000 acres. The Bignor Canals are a much smaller group in the Moradabad district, having about 38 miles of channels, and irrigating about 9000 acres.

General results North-west Provinces Canals.

In the whole North-west Provinces, up to the year 1889-90, there have been constructed by the British Government 1465 miles of main canal and branches, of which 535 miles are navigable, disseminating the fertilising influence of water through 6646 miles of distributing channels, and irrigating two millions of acres, or 3125 square miles. The capital cost of these works amounted to £8,059,300. In the year mentioned above the total net direct and indirect revenue derived from the whole of the provincial canals amounted to £370,563, or 4.58 per cent. on the capital expended.

The accumulated surplus, after deducting interest charges, amounts to £689,615, or over 8½ per cent. on the capital cost of the works, due, however, to the Eastern Jumna Canal, which, taken alone, exhibits a clear accumulated net revenue of £1,357,699. The total value of the crops irrigated by the North-west Province Canals in the year 1889-90 amounted to no less than £6,527,234.¹

¹ For details of individual works in the North-west Provinces *vide* Appendix B.

CHAPTER VI

BENGAL AND CENTRAL INDIA

Bengal Canals—New conditions of rainfall, and peculiarities—Outline of Bengal Canal system—Orissa Canals—Delta Canals and formation of Delta lands—East India Irrigation Company—Description of Orissa Canal system—Head works and weirs at and near Cuttack—Midnapore Canal—General course and particulars—Sone Canals—Largest scheme in Bengal—Early history—Description of Sone Canals—Details of weir at Dehree—Construction—Hidgellie Tidal Canal—Orissa Coast Canal—Particulars of works—Calcutta and Eastern Canals—Sarun Canal—Eden and Madhuban Canals—General results of irrigation in Bengal—Central districts of India—Colonel Dixon and Rajputana tanks.

PROCEEDING now to a consideration of the various irrigation and **Bengal** other canals constructed by the British Government in the **Canals.** province of Bengal, we find ourselves at the outset confronted with an entirely new set of circumstances and conditions. As we proceed eastwards from the irrigated districts of the North-west Provinces, and follow the Ganges river towards its delta at the head of the Bay of Bengal, we find the average annual rainfall gradually increasing, and the absolute necessity for irrigation becoming less and less, until, on reaching the extreme eastern side of the province, the rainfall is so large and invariable that any failure of the crops from scarcity of water is a contingency hitherto unknown.

In Behar, on the western side of the province, artificial irrigation of the soil from numerous wells, small surface tanks, or inundation canals, has for ages been commonly practised, more especially for the extensively grown winter crops, which cannot be efficiently cultivated without a regular supply of water. Farther to the south and south-east an increasing rainfall and a general prevalence of wet-season cultivation, causes artificial irrigation to be more and more a means of improvement, of enhancement of the out-turn, and an insurance against

bad years, than an absolute necessity : hence its introduction has been slow and difficult, being against the conservative tendencies of the cultivators, who have been, and still are, to a great extent apathetic, or even actively opposed, to the introduction of artificial irrigation—or rather to payment for the use of canal water. In the district of Orissa, bordering the sea, the rainfall is usually large and ample for the rice crops which are mostly grown, but sometimes, at long intervals, a total failure of the monsoon occurs, and from the formerly isolated position of the district such times have been attended with the most disastrous consequences, as in the terrible famine of 1866.

In this part of Bengal, as elsewhere over a great part of the province, although the out-turn of the rice fields is greatly enhanced by the systematic and regular employment of an unfailing water supply—and is absolutely dependent on it in bad seasons, the expense of canal water, even at the lowest rates, is sufficient to create in the minds of the peasants a strong disinclination to use it, and a disposition to trust entirely to the ordinary chances of the annual rainfall. On the eve of the famine year 1866 a new assessment of the land-tax was impending in Orissa, and a popular saying of the peasants is quoted, which at the time became famous, as follows : ‘ It is better that one or two of us in each family should die of famine, than that by using irrigation for our land we should give the government an excuse for raising the tax on ourselves and our children for generations.’ Of late years, however, some of this prejudice, and absence of intelligent foresight, has been slowly overcome, although much remains to be done before a knowledge of the full benefits and advantages, insured by an unfailing water-supply for purposes of cultivation, is likely to be at all widely diffused in Bengal.

From the above and other causes, amongst which to the circumstance that most of the large irrigation projects, as carried out in the Bengal Province, are truncated and contracted portions of larger schemes, each provided with initial main works capable of dealing with a far greater quantity of water than has hitherto been actually used, and consequently much more costly works than if they had been originally devised to irrigate only the smaller area, the financial working of

the Bengal irrigation canals has not as yet been a success. There appears, however, little reason to doubt that in course of time, as the demand for water increases, and the maximum number of distributaries capable of being fed from the main channels are called for and constructed, the canals may become commercially remunerative.

In the Province of Bengal there are three canal systems of large size and importance, all of which combine navigation with irrigation. These are the 'Orissa Canals,' the 'Midnapur Canals,' and the 'Sone Canals.' In addition to these there are three canals, which are entirely for navigation purposes, viz., the 'Hidgellee Tidal Canal,' the 'Orissa Coast Canal' in continuation, and the 'Calcutta and Eastern Canals.' There are also three small systems, viz., the 'Sarun,' the 'Eden,' and the 'Madhuban' canals, mostly used for irrigation purposes, and the 'Nuddea rivers system,' the works on which are designed for the improvement and maintenance of the river channels, and to secure a continuous supply of water from the Ganges to the Hoogly to facilitate navigation.

The 'Orissa' system of canals irrigate large tracts in the Orissa Canal. deltas of the Mahanadi and Brahmani rivers. The term *Delta* is usually applied to that fan-shaped area of country which lies between the two main branches of the series of channels, into which large rivers break up on entering the sea. This tract of country is generally formed somewhat like the Greek letter 'delta' (Δ), hence the name given to it. The term, however, strictly includes all the land at the river-mouth formed by overflow deposit from the river itself.

The formation of a delta is a continued process of land formation, incessantly going on at the mouth of every large river bringing down great quantities of matter held in suspension in its water. If we could accurately measure the precise quantity of solid material so brought down every year by any river, we should be able to measure the exact rate of the growth of its 'delta.' As soon as the river joins the sea, the 'silt' or solid matter brought down by its flood water is slowly deposited. In process of time a spur of land is built up, which gradually rises higher and higher. The velocity of the water becomes more and more checked, and the deposit during the highest

floods slowly builds up the adjoining land, and forms banks which are only occasionally topped by the river, which, so long as it continues confined to its channel, carries much of its solid material farther and farther out into the sea, lengthening the spur of new land. Presently the discharge outlet of the river becomes so impeded by the raised level in its front that during some extra high flood the banks are burst, and a new channel or channels are scoured out in the newly-made ground. Such channel or channels, which soon become important river branches, take the most direct and shortest road to the sea. As time goes on, the process repeats itself in the new branches themselves, and other channels are then successively scoured out, each in its turn building up new land in its vicinity, which thus becomes spread out into a fan-shaped prominence. The whole delta continues to extend itself farther and farther into the sea at a slowly diminishing rate, until the wearing away and transporting action of some oceanic current may balance the amount of deposit brought down by the river.

The irrigation of the Mahanadi and Brahmani deltas was first suggested about the year 1858 by Colonel (afterwards Sir Author) Cotton, who drew up a scheme intended to irrigate about $2\frac{1}{4}$ million acres, and comprised 530 miles of navigation channels. In the year 1861 a company called the 'East India Irrigation Company' was formed, which, under contract with the Government, undertook to execute in the Deltas extensive works for irrigation, the opening out of communications, and the protection of the country from the severe floods to which it was peculiarly liable. In this district, which is almost a level plain, the average annual rainfall is as high as 57 inches; but the cultivation consists almost entirely of wet-season crops, consequently any failure or early cessation of the rains leads to inevitable disaster, and the main object of the works which were intrusted to the Company was to ensure a large area of country against recurring risk of famine.

The works were commenced in 1863; but the progress and development of the scheme proving unsatisfactory, in the year 1868 the Company was bought out by the Government, and the whole project was revised and re-estimated. Under the scheme as actually initiated, the Orissa canals were intended to

irrigate 1,147,000 acres; but the project was eventually so curtailed that the works as now completed and contemplated, command an area of but little over 500,000 acres. The Orissa canal system—unlike the greater part of those systems which we have lately described in the Punjab and North-west Provinces—does not consist of a single main canal, giving off numerous lateral branches, but consists of several detached canals, derived from the Mahanadi or its offshoots, at the head of the Delta, from which point, as from a centre, they radiate, and spread out like the ribs of a fan, following a general course parallel to the Delta streams.

The head works of the system, which consists of several weirs and canal heads, lie at, and about, Cuttack, at a short distance below the point where the Mahanadi issues from the line of hills along the coast. The weirs near Cuttack are three in number. The first is situated a few miles above the town, at Naraje, and is thrown across the 'Katjooree' river, close to the point where this branch bifurcates, and leads off from the right bank of the Mahanadi. The Naraje weir is 3600 feet long, and 12 feet high above the river bed. During high floods, 15 to 18 feet in depth of water passes over the summit or 'crest' of the weir wall. Near the right bank a set of sluices supplies a channel conveying water to the town of Cuttack. The weir has no canal head above it, its object being merely to regulate the quantity of water allowed to pass down the 'Katjooree,' or the main Mahanadi channel, respectively. The vertical masonry wall, 12 feet high, forming the weir, is protected on the up-stream side by rough blocks of stone forming a slope of about 2 to 1. On the down-stream side, there is an apron of rough stone, varying from 120 to 300 feet wide, composed of very large stones, each about two tons in weight. The slope is broken up by two masonry walls running parallel to the main weir wall, and by numerous cross walls running at right angles to the same, thus dividing the apron into a series of rectangular compartments, into which the rough stone is carefully packed.

The second weir is across the Mahanadi itself at Cuttack. It is 6349 feet, or about $1\frac{1}{4}$ miles long, and 12 feet in height above the low-water level of the river, which rises over 20 feet

in high floods. The weir is formed of three vertical and parallel walls, founded on circular wells 6 feet in diameter, sunk 6 feet into the river bed. The space between the walls is filled in with rough stone, finished off at the top with blocks of stone of large size, set on edge, with an inclination towards the current. In the centre of the weir a set of scouring-sluices is provided, having wide bays or openings, 50 feet in width, fitted with folding-back gates or shutters, on the French system, nearly similar to those described further on in the case of the Sone weir. There is also a long set of 'under' or scouring sluices, on the right flank of the weir, adjoining the regulator of the 'Central Delta,' or 'Talundah' canal, which takes off at this point. The Talundah canal is 27 miles long, and not far from its head it gives off a main branch called the 'Mach-gong,' 32 miles in length.

The third weir is thrown across a second, and left branch of the Mahanadi, called the 'Beropa' river. This weir is 1980 feet long, and 9 feet high in the deepest part. In construction it is similar to that over the Mahanadi at Cuttack. From the pool above the Beropa weir, canals are taken off from both sides. It is therefore provided with two sets of scouring sluices, adjoining the canal heads. The canal drawn off from the right bank is the 'Kendrapurni' Canal, 55 miles long, giving off two main branches, viz., the 'Patamoondi,' 47 miles long; and the 'Gobree,' 21 miles long. The Kendrapurni channel runs parallel with the left bank of the main Mahanadi to Jumboo, on the sea coast. The second canal drawn off from the left flank of the Beropa weir is the 'High level canal,' 64½ miles long. This channel traverses the foot of the high ground from Cuttack to Bhuddruck, and forms a connection in its passage, between the Mahanadi, Brahmani, and Byturni rivers, obtaining from the two last-mentioned streams a supplementary supply of water by means of two secondary weirs thrown across them. A small independent canal 6½ miles long, called the 'Jajepore,' is also led off from above the Byturni weir.

The Orissa system of canals and distributaries is not yet fully completed. At the end of the year 1890-91 it had a total length of main and branch canals of 252 miles (of which 177 miles are

navigable), with 765 miles of distributing channels. In the same year it irrigated 189,299 acres. When the project is completed, as at present contemplated, it will have a total length of main canal and branches of 284 miles, with 2147 miles of distributaries, and will be capable of irrigating nearly 400,000 acres.

The 'Midnapore Canal,' the first portion of which was opened Midnapore Canal. in 1871, formed a portion of the original scheme for irrigation and navigation canals in Bengal, undertaken by the East India Irrigation Company, by which Company the works were commenced, but they were eventually finished by Government agency. The canal forms a navigable connection, through the Hooghly, between Midnapore and Calcutta. It is derived from the Cossye river, from above a weir which has been constructed at Midnapore. The total length is divided into four detached portions. The first length after a course of 25 miles again joins a lower reach of the Cossye at Panchkoora, where a second weir is built across the stream. After crossing the river through entrance and exit locks, the second length, 12 miles long, is locked into the Roopnarain river. Five miles lower down the Roopnarain channel, the canal again leaves it by a lock on the opposite bank, and the third length, after a short stretch of 4 miles, reaches the Damooda river, which it also enters and leaves by locks on either bank. The fourth length, 7 miles long, takes the canal to the Hooghly, which it enters by a lock at Oolooberia. From this point to Calcutta by the Hooghly channel the distance is 17 miles.

The Midnapore system of main and branch canals has a total length of 72 miles, all being navigable, and 339 miles of distributing channels. It commands an irrigable area of 180,000 acres, but actually irrigates from 80 to 100 thousand acres, according to the season; nearly the whole of the irrigated crop consisting of rice. A large portion of the revenue receipts from this canal is derived from the navigation, including the traffic worked by the steamers of the Calcutta Steam Navigation Company.

By far the largest scheme for irrigation in the Bengal Province is the system of 'Sone Canals,' irrigating an extensive triangular tract of country lying south of the Ganges. The

northern base of the triangle extends from Patna on the east to Dildarnagar on the west, the apex lying at Dehree, on the Sone, about 25 miles from the point where that river issues from the Kymore range of hills, and close to the fine causeway on which the Grand Trunk road crosses the Sone river.

The first suggestion for the irrigation of the districts west of the Sone was made by Lieut. (now Major-General) C. H. Dickens, in the year 1853, who proposed to employ storage reservoirs situated in the hills to the south. This idea was, however, abandoned, and a project for utilising the waters of the Sone river was substituted. In 1862 an offer was made by the East India Irrigation Company to carry out the works, and a very large amplification of the original proposal, by means of which connections would be made with Allahabad on the west, and with the Hoogly on the east, was mooted, but the scheme was considered by the Government to be of too extensive a character. In 1864 an agreement was entered into with the company for the construction of a restricted system of irrigation and navigable canals, more in accordance with the original project, lying to the southward of Patna on the east, and of Chunar on the west. The company, however, failed to raise the necessary capital, and, after some negotiations, the project was taken over by the Government in 1868; the small expenditure of £14,000 incurred by the company in preliminary operations being refunded. In 1869 the works were commenced by the Government, but in 1871 it was decided to restrict the scope of the scheme to the limits as now actually carried out, principally owing to considerations connected with the seasonable supply of water to be derived from the Sone river. The Sone Canals, in outline, consist of the following works. A magnificent weir across the Sone at Dehree, from above which two main canals are led off—one from each bank. That on the east side, or the 'Main Eastern Canal,' is a short navigable connection, $7\frac{1}{2}$ miles long only, from the Sone to the Poonpoon river. From about the middle of this length the 'Patna Branch Canal,' 79 miles long, and navigable throughout, issues, and is carried nearly parallel with the east bank of the Sone to the Ganges near Dinapore. This branch in its

course to the Ganges descends through thirteen locks, and irrigates by means of numerous minor channels the districts lying between the Sone and the Poonpoo rivers. The second canal taking off on the west flank of the weir, or the 'Main Western Canal,' is also of the short length of $21\frac{1}{2}$ miles. At the fifth mile the 'Arrah' navigable branch, $65\frac{1}{2}$ miles long, branches off, and runs with a fairly straight course to Arrah, terminating in the Gungi nala, which communicates with the Ganges. There are thirteen locks on this branch, with an aggregate fall of 161 feet. From its western bank two large irrigation branches issue, viz., the 'Dumaon' branch, $40\frac{1}{4}$ miles long, and the 'Behea' branch, 31 miles long. At the ninth mile the Main Western Canal crosses the Kao river by a large masonry aqueduct, and at the twelfth mile gives off the 'Buxar' navigable branch, $45\frac{1}{2}$ miles long, extending to the Ganges at Buxar. On this branch there are twelve locks, with an aggregate fall of 154 feet. At the nineteenth mile the Main Western Canal gives off the 'Chowsha' irrigation branch, $39\frac{1}{2}$ miles long, which tails into the Karunmasa nala a few miles south of Dildarnagar station on the East India Railway.

The whole system of 'Sone Canals' consists of $367\frac{1}{4}$ miles of main and branch canals, of which $218\frac{1}{2}$ miles are navigable, and $148\frac{1}{4}$ are exclusively for irrigation. There are also 1211 miles of distributing channels. The area commanded by the system is 1,728,509 acres. In the year 1884-85 the canals irrigated a maximum of 370,661 acres, but the average area irrigated for the ten years, 1881 to 1891, is 293,153 acres. Hitherto the Sone system has yielded no return on the capital, inclusive of interest, spent on its construction.

The site of the enormous weir across the Sone at Dehree is about 600 yards above the Grand Trunk Road causeway. It is the longest weir in one uninterrupted line of masonry that has yet been anywhere constructed, the total length between the abutments being 12,550 feet, or nearly $2\frac{1}{2}$ miles, and its construction involved the carriage and building up of 750,000 tons of stone. At the point where the weir crosses the Sone the river has a clear continuous waterway, with no islands in mid-channel to contract the length of the artificial works. The banks on either side—which are high—are not overtopped

by the highest floods, and the bed of the river is composed of coarse sand and pebbles.

The weir consists of three parallel walls, 9 feet high, above the bed of the river, the spaces between the walls being filled in with rough stone, finished off at the top by a course of large sandstone blocks regularly laid. It is founded on a series of hollow rectangular blocks, or 'wells,' of rubble sandstone masonry, sunk to a depth of about 10 feet, and the hollows filled in with concrete. The blocks are 10 feet by 6 feet in outside dimensions, with walls 15 inches thick. To prevent them from splitting during the process of sinking—which was effected by the use of mechanical excavators taking out the river-bed material from the central hollow spaces—sets of blocks were tied together by an arrangement of iron rods, so contrived that as soon as the set was sunk the rods could be withdrawn and utilised for the next set. On the up-stream side of the front wall there is a protective slope of rough stone, having a slope of 2 to 1. On the down-stream side the weir 'apron,' about 100 feet wide, extends with a slope of 1 in 10. There are three sets of 'under' or scouring sluices in the body of the weir, each set 500 feet long; one in the centre of the river and one adjoining each bank, just below the head sluices of the two canals led off. These under sluices are constructed with openings, or bays, of 20 feet each, and the bays are opened or closed by two sets of folding-back shutters, or gates, the front set being fitted with hollow iron backstays, or struts, which act as hydraulic brakes. When the shutter-gates are down the hollow tube forming the backstay fills with water, but in moving the shutter, either up or down, the water is forced out of a small vent hole by a movable piston, or plunger. The resistance of the water, escaping only through the small hole, acts as a brake, and prevents the sudden shocks apt to be caused by the force of the current against the shutters whilst in motion. The depth of water passing over the Sone weir during the highest floods is 7 feet, with a maximum velocity of about 8 miles an hour.

Hidgellee
Tidal Canal.

The 'Hidgellee Tidal Canal,' the 'Orissa Coast Canal,' and the 'Calcutta and Eastern Canals,' are navigation channels only. The first, having the Orissa coast canal in prolongation, com-

mences on the right bank of the Hooghly, just below the junction of the Roopnarain River, and the two canals together serve to connect the Hooghly with the water system of Orissa. The Hidgellee Tidal Canal is 29 miles long, divided into two lengths—one of 11 miles from the Hooghly to the Huldee River, which it crosses through locks on either bank—and the other of 18 miles from the Huldee to the Russulpore River, which it enters by a lock nearly opposite another, admitting entrance into the 'Orissa Coast Canal,' which latter thence extends for a distance of $97\frac{1}{2}$ miles in a south-westerly direction through Balasore, keeping roughly parallel with the sea-coast.

The Orissa Coast Canal was fully opened in the year 1887-88. Orissa Coast Canal. It is divided into three ranges or sections, by locks at the passages of two important rivers, viz., the 'Soobarnrekha' and the 'Burbullong;' the middle section, or that between these two rivers, being divided into two sub-sections by locks at the crossing of the 'Panchpara' River. The lengths of the three main sections are 36, $23\frac{1}{2}$, and 38 miles respectively, the sub-sections in the middle range being 17 and $6\frac{1}{2}$ miles.

The works consist of the above-mentioned separate lengths of simple canal with level beds connecting the rivers named, provided with terminal locks at each extremity to retain in the canals the requisite depth of water required for the navigation. The bottom width of the canal varies from 46 to 50 feet, and the minimum depth of water retained is 7 feet. The canal embankments are carried to a height of 3 feet above the highest floods.

During the dry season the canal sections are fed by the tidal waters of the different rivers connected by them, and during the rainy season the drainage intercepted by the canals themselves is utilised. The navigation terminates on the left bank of the Metai River in Orissa (about 15 miles from Bhuddruck) in connection with the inland water system of the district.

The 'Calcutta and Eastern Navigation Canals' have an Calcutta and Eastern Canals. aggregate length of 47 miles, and serve to maintain communication between Calcutta and the Eastern districts of Bengal, through the numerous channels of the Sundarbans.

The 'Sarun Canal Scheme' is a small irrigation and drainage Sarun Canal. system on the Gunduck River, cuts from which supply water

to numerous old channels which intersect the district. The distribution of the water is undertaken by the landholders and planters immediately concerned. The length of main line and branches is 19 miles only, in addition to which about 28 miles of supply channels are maintained. The system commands an area of 64,000 acres, the area actually irrigated being very much less than this, but varying greatly from year to year.

Eden and
Madhuban
Canals.

The 'Eden Canal' is a small work for flushing some of the streams in the Burdwan district with water from the Damooda River, chiefly to give a good supply of drinking water, and the 'Madhuban' Canal is a very small irrigation work in the Champarun district.

General
results.

In the province of Bengal up to the end of the year 1890-91, there has been constructed under the British Government 710½ miles of main and branch canals for irrigation, and 173½ miles of canal for navigation purposes only, or a total length of 884 miles. The irrigation canals are provided with 2315 miles of distributaries, exclusive of numerous village channels. The area commanded is 2,483,781 acres, of which in the year 1890-91, 545,541 acres only were actually irrigated, but this area varies largely according to the rainfall of the year. The value of the irrigated crops in the same year was £1,665,481.

The capital cost of the Bengal canal systems was £7,200,196. None of the four large schemes classed as 'major works' have as yet given any return on the capital, inclusive of interest charges, and of the minor systems two only yield a small profit. The net deficit on the whole provincial system of canals in the year 1890-91 amounted to £224,449, and from the commencement, including interest on the capital, in the case of those works constructed with borrowed funds, the net deficit reached the sum of £2,754,253. The heavy cost of the Orissa and Sone systems, the high average rainfall, accompanied by the general prejudice against the use of canal water at anything like remunerative rates existing in the province, and the absence of any large irrigation works of long standing, such as exists in the Punjab and North-west Provinces, to balance the immediate loss on the newer works, has told with great severity against the comparative net commercial results of the Bengal canals, but when that length of time which nearly all irrigation works take

to fully develop has passed, these canals under careful and judicious management may yet arrive at the remunerative stage.¹

Westwards of the great basin of the Mahanadi, across the Central districts of India. line of tributaries to the Godavery and Nurbudda rivers, artificial irrigation is extensively practised on a small scale over considerable areas by means of surface tanks, but the country being for the most part broken up into more or less confined valleys, is destitute of large and important irrigation works. In the district of Nimar, acquired from the Peishwa in 1818, a storage tank 3 miles round, called the Lachma Lake—an old native work which was found to be in ruins, was soon afterwards restored, and over one hundred smaller tanks were put in working order. In the years 1845-46, Captain Ffrench, the political officer then in charge of Nimar, made a masonry dam across the Chuli ravine, and another large earthen dam across the Chapri, thus forming the considerable 'Chuli' and 'Mandleswar' tanks.²

In any account of the irrigation works of India it would be unpardonable to omit mention of the system of storage tanks in Rajpootana Tanks. in the districts of Ajmere and Mairwarra, initiated by Colonel Dixon in the year 1835-36. In the ten years, 1836 to 1846, upwards of 2000 tanks and over 9000 wells were constructed, irrigating 15,000 acres of cultivation. The soil of the districts, owing to its sandy nature, is unsuitable for earthen reservoir embankments. Colonel Dixon, therefore, largely employed masonry in his dams, in some cases supporting a wall of masonry by an earthen bank behind it, in others building the entire dams of stone. These works were carried out in the midst of a then notoriously turbulent population, which was by tact and energy led to agricultural pursuits, and gradually reduced to order and quiet. The unruly Mairs under the influence of the improvements effected, were rapidly converted into the peaceful and industrious peasantry which they have since remained.

Some of the tanks constructed by Colonel Dixon are of considerable size. The 'Kabra Tank' in Mairwarra has an embank-

¹ For details of individual works in Bengal, *vide* Appendix C.

² Parliamentary Paper, *vide* note, page 8.

ment faced with a heavy masonry wall 620 feet long, 27 feet wide at the base, and 10 feet thick at the top : the height from the foundation being 33 feet. Another reservoir in Ajmere has a dam 60 feet high, built entirely of stone, and many other works of scarcely inferior dimensions were constructed.

CHAPTER VII

MADRAS IRRIGATION

Madras canals—Delta irrigation schemes—Kaveri and Kalerun deltas—Distinguishing features of Madras irrigation—Rainfall—Varying conditions in Northern and Southern India—Immense extent of Madras irrigation—A few selected examples only possible—Kaveri delta canals—‘Grand *anicut*’—The ‘Upper’ *anicut*—Effect of works—Area irrigated—Particulars of irrigation—Godavery delta canals—Outline of system and works—Weir at Dowlaiswaram—Kistna delta canals—Kistna weir—Main canals—Pennair delta canals—Sangam irrigation—Srivaikuntham canals, and outline of system.

ALL the great ‘Delta’ irrigation schemes of India, with the exception of the Mahanadi in Orissa, of which we have already spoken, are situated in the Madras Presidency, and it is in Madras that this class of works originated. When the districts of Tanjore and Trichinopoly first came under British rule, a large amount of irrigation which had existed from very ancient times, was found in operation in the delta of the Kaveri and Kalerun rivers, by means of native works which had made these districts among the richest in India. The improvement of these old works—commenced in 1834, nearly sixty years ago—was, with the exception of the Western Jumna Canal in the Punjab, the earliest irrigation work carried out in India by the British Government. It is here that the characteristics and peculiarities of delta rivers, and the special adaptation of delta areas for purposes of irrigation on a large scale, were first studied and understood, and led to the extensive irrigation schemes since carried out in the larger deltas of the Mahanadi, Godavery, and Kistna, and elsewhere on the East coast.

These great delta schemes, and the wonderful amount of irrigation carried on by means of storage reservoirs, of which we have already made mention, constitute the chief distinguishing

features of irrigation as practised in the Madras Presidency. South of the Mahanadi basin the general slope of the country is from west to east. A high range of hills skirts the whole Western coast from the Gulf of Cambay to Cape Comorin, and on this range the main portion of the South-west monsoon is precipitated. A large portion falls over the crest of the *ghâts* and abundantly supplies the sources of the greater rivers, which flow from the eastern slopes of the range, across the peninsula into the Bay of Bengal, breaking through the line of 'Eastern *ghâts*' in their passage at varying distances, but comparatively near, their entrance into the sea.

Over all the central parts of the country the average rainfall is less than 30 inches, but below the Eastern *ghâts*—dependent on the North-east monsoon from the Bay of Bengal—the average annual rainfall lies between 30 and 40 inches. The great rivers, in ordinary years, bring down from the Western hills a practically unlimited supply of water, a supply, however, entirely dependent on the vicissitudes of the South-west monsoon, and which, owing to the heavy general slope of the country, is—if not intercepted—carried off with great rapidity.

The main crops in this part of India are grown from June to November, at the time when the rivers are at their maximum volume. Irrigation from the large rivers, therefore—unlike the conditions prevailing in Hindustan—is unlimited in average years. The Northern provinces of India possess in the snow-fed rivers of the Himalayan range, a regular and perennial source of supply, but on the other hand, the main crops being grown in the cold season, the area of cultivation has of necessity to be adapted to the comparatively small volume of water then available in the rivers. The essential distinction, therefore, between the ordinary conditions of Northern and Southern India is, that in the North, the area of main crops is restricted by a limited and more or less fixed quantity of water, whilst in the South the only limitation is the area of cultivable land. The North has the enormous advantage of a perennial, although limited supply, whilst the South is too often subject to the dire effects of a total or partial failure of the seasonable rainfall on which the irrigation depends. It is principally owing to this essential difference in the local conditions, that the extraordinary

development and wonderful extent of irrigation-work throughout the Southern Presidency, as compared with other parts of India, is to be attributed.

Outside the areas commanded by the large rivers, the country is mainly dependent on the comparatively small supply of water in the shape of local rainfall, or that brought up from the Bay of Bengal by the North-east monsoon. This supply is everywhere utilised, almost to the last drop. Throughout the whole of the Madras provinces, in every valley, arrangements of some kind exist for retaining, storing up, and utilising the water draining off its sides. There is scarcely a water-course which along its whole length is unprovided with a succession of dams, converting its course into a series of tanks, or reservoirs of greater or less dimensions, and along the foot of the Eastern *ghâts* almost every gorge offering the smallest facilities for the interception of the drainage by means of a dam, or dams, across its exits, is, or has at some time or other been so provided, and the precious water seized upon for the irrigation of the fields. The great body of water delivered by the South-west monsoon over the crest of the Western *ghâts*, and carried to the Bay of Bengal by the large rivers of the country—such, for instance, as the Godavery, with a current two or three miles broad and 25 feet deep—cannot necessarily be constrained to pay tribute to anything approaching an exhaustive extent, nevertheless a very large amount of this water is intercepted and utilised—especially at the head of the great Deltas by the splendid series of works, which have almost entirely been initiated and carried out by the British Government.

It would be impossible in the limited space available in this volume to give even a mere outline of each one of the large number of irrigation works initiated and constructed, or entirely remodelled and enlarged by the English Government in the Madras presidency; the purpose in view will be sufficiently attained by a selection of a few of the larger examples of each class of work, and a general summary of the whole.

There are eight principal systems of various size, classed as ‘major works,’ regarded specially as ‘productive,’ the expenditure on which has been incurred from Imperial loans, and twenty-one other works classed as ‘minor provincial works’

carried out by provincial funds ; of these last, three are large reservoir systems, and four are canals exclusively for navigation purposes. In addition to the above, there is an enormous aggregate number of smaller irrigation works of all classes administered by the irrigation department, but which individually are not sufficiently important to require separate capital or revenue accounts. Two large projects of the first class, estimated to cost £564,000 and £432,000 respectively, are (1893) under construction, but are not yet in operation. There are, therefore, thirty-one distinct systems, having separate capital and revenue accounts.

Kaveri Delta
Canals.

The largest—as regards irrigated area—oldest, and also the most remunerative of these works, is the Kaveri Delta system, irrigating over a million acres, which is a development and enlargement of a very ancient native system of irrigation in Tanjore. The river Kaveri, rising on the Western *ghâts* and among the hills of Coorg, drains an area of about 28,000 square miles. It flows in a general easterly direction to the Bay of Bengal. The head of its delta—which has an area of 2700 square miles—is situated nearly 100 miles from the coast at a short distance above the town of Trichinopoli, where the river divides into two separate streams at the western extremity of Seringham, formerly an island, and still so called. The upper, or northern branch, is named the Kalerun. This branch, which in reality is the main drainage line to the sea, has a greater volume, a more direct course, and a far heavier fall per mile, than the smaller and more useful southern branch, which retains the name of ‘Kaveri.’

The latter, after its separation from its main branch at Seringham, gains rapidly in elevation of bed, and flowing with a comparatively smooth and gentle current, soon divides and subdivides itself into numerous channels until its waters are spread over nearly the whole of the Tanjore district. In very ancient times, in order to counteract the tendency of the smaller and less rapid branch to become choked up with deposit, and to increase the volume of water passing down it, the large dam, or *anicut*, previously mentioned in the chapter dealing with native works, known by the name of the ‘grand *anicut*,’ was constructed across the river near the eastern, or lower end, of

Seringham island. This was the beginning of the delta improvement works, and its effect must have been of enormous benefit to the Tanjore irrigation. The supply of water, however, in later years became insufficient for the growing area of cultivated land in the delta, and the increasing amount of sand and silt, accumulating between the grand *anicut* and the point of separation of the two rivers, necessitated for many years the adaptation of various expensive expedients in order to prevent serious diminution in the supply of water.

In this state of affairs, when valuable and extensive tracts of rich country were gradually being thrown out of cultivation, Captain (afterwards Sir Arthur) Cotton, engineer of the Division, in the year 1834 devised and constructed the dam now known as the 'upper *anicut*,' across the Kalerun at a point about 100 yards below the bifurcation of the two rivers. This dam, obstructing only in a small degree the passage of high and destructive floods, at the same time diverted into the Kaveri all the water formerly carried wastefully into the sea, even in the driest seasons by the Kalerun branch, and rendered it available for the delta irrigation. Subsequently, in the year 1845, after the bed of the Kaveri had been deepened by the new volume of water thus thrown into it, a masonry regulating-dam was carried across that river on the opposite side of Seringham island.

The 'upper *anicut*,' or dam, is 2250 feet long, divided into three parts by two islands. It consists of a massive vertical wall of masonry, varying from $5\frac{1}{2}$ to 7 feet high, supported on lines of brick-cylinders or wells, 6 feet in diameter, sunk to a depth of 6 feet into the sandy bed of the river. A stone flooring 30 feet wide and 4 feet thick extends below the dam to receive the overfall of water, below which again is an apron of rough stone about 20 feet broad. Twenty-two sluices were provided in the body of the main wall for the purpose of creating a scour, and prevent the filling up of the bed above the dam. The rise of the water in high floods above the bed of the river is 14 feet.

The effect of these works was to give a perfect regularity of current to the Kaveri river, and perfect control over the water passing down both streams. The Kalerun, with its heavy fall, is the main drainage outlet of the delta, whilst the Kaveri

below the regulating dam is practically converted into an irrigation canal. In the year 1836 another dam of similar construction to the 'upper *anicut*' was constructed across the Kalerun, some seventy miles below it. Its object is to intercept and divert some of the water in the intervening part of the river bed—which is increased by drainage from cultivation and by springs—for the purpose of irrigating large tracts of very fertile land in the north-eastern part of the delta, and in South Arcot.

Before the construction of these works the area irrigated dependent on the Kaveri and Kalerun rivers was but little over 600,000 acres; this area is now considerably over a million acres. The special peculiarity of the Kaveri delta irrigation is, that in all other cases of delta works the main distribution of water is carried on by means of a series of artificial channels, generally following a parallel course to the principal diverging river branches, but in the Kaveri delta the chief distribution is naturally effected by means of the river itself, and by the numerous branch channels thrown off by the Kaveri between the point of its separation from the Kalerun and the sea. From these branches innumerable distributing streams are led off to convey the water over all the village lands of the delta. To render this system effective it was necessary to regulate, divide, and sub-divide the water by regulating sluice-gates, placed at the head of all the main channels. In addition to these works, by degrees the various natural courses have for all practical purposes been converted into irrigation canals by straightening their channels and by correcting and making uniform the width of their beds. The whole has been rendered secure by various works, affording protection to the delta lands from the effects of inundation by flood-waters rising beyond what can be safely carried away by the irrigating streams.

In the Kaveri delta there are 844 miles in length of main irrigation channels, and 1250 miles of distributaries. In the year 1890-91 the area of land irrigated was 1,013,344 acres, with a total value of irrigated crops amounting to £2,530,345. Owing to the peculiar conditions and economical nature of the engineering works necessitated, the capital outlay has been relatively exceedingly small, whilst the area of irrigation affected

is exceptionally large. Hence the Kaveri system is the most remunerative in India, yielding a return of over 37 per cent. on the money expended by the British Government, and a large annual surplus revenue, after deducting interest charges.

The Godavery and Kistna deltas, lying between Cocanada and Pedda Gangam, on the East coast, adjoin one another, and form one extensive and connected irrigation area nearly 200 miles long and 50 miles broad. Both these rivers break through the line of the Eastern *ghâts*, within fifty miles of the sea, and in course of ages have built up the wide stretch of delta lands beyond them, for no doubt at one time the waves of the Bay of Bengal washed the base of the hills.

The head of the Godavery delta is at Dowlaishweram, from which point the river flows to the sea on an elevated bed, varying from 6 to 24 feet above the general level of the country. At Dowlaishweram the river forks widely into two branches, which we may call the 'Eastern Godavery' and the 'Western Godavery.' These branches divide the delta into three distinct areas, viz., the eastern delta, the central delta (lying between the forked branches), and the western delta. Each delta division is supplied with a separate system of irrigation canals, derived from the raised level of the Godavery, above a huge weir or *anicut*, which has been constructed at Dowlaishweram, just above the point where the single river separates and forms the eastern and western branches, and where the total width of the river is nearly four miles.

The Godavery works were commenced in 1844. The fine weir is one of the most magnificent of the many examples of such constructions in India. At the point where it crosses the river, the latter is divided into four portions by three intervening islands, which occupy about 3000 feet of the total width. The *anicut*, which, divided by the islands, may be considered as composed of four separate lengths of main weir, has a total length of masonry construction of $2\frac{1}{2}$ miles. The Godavery drains an area of about 115,000 square miles, and as the rise of its water in floods at Dowlaishweram is 28 feet, it will readily be conceived that the construction of the enormous weir, to raise and control its waters, was a most exceptional and formidable undertaking.

The lengths of the four portions of the weir, which are the same in general construction, with only slight differences in dimensions, are as follows, 4872 feet, 2862 feet, 1548 feet, and 2584½ feet, respectively. In structure the work consists of a mass of stonework, some 130 feet wide at the base, 12 feet high, and 2½ miles long. The front and rear walls rest on two lines of brick wells, each 6 feet in diameter, and sunk 6 feet below the deepest bed of the river. The space below the walls is filled in with river sand and quarry spoil. The cross outline of the weir consists of, first a level floor or waste board of masonry, 19 feet broad and 4 feet thick, next of a slightly concave tail slope, which is practically an inclined plane, 28 feet wide, and also 4 feet thick; the upper surface in each case being protected by a covering of strongly-jointed cut stone; and lastly, of a rough stone apron of massive blocks, which extends some 80 or 90 feet down stream below the tail slope. On both sides of each length of weir masonry, wing-walls and lines of revetments connect the work with the main or island banks, as the case may be, and prevents the water passing round the extremities. Between each length of weir a substantial embankment of earth, protected by stone, is carried across each of the islands. On the extreme right and left flanks there are fifteen scouring sluices, each 6 feet in width, and on each main river bank, canal head regulating sluices and locks, each 100 feet long, are constructed. On the central island, forming practically the point of division of the two main branches of the river, is situated the head sluices and lock of the main canal carrying water to the central delta lying between the branches.

From above the Dowlaishweram weir three main canals radiate. One to supply the eastern delta has a bottom width of 184 feet, and carries eight feet in depth of water. One to supply the central delta is 114 feet wide, and carries 7 feet in depth of water; and one to supply the western delta—the water being here carried by several channels, but where collected together in one—225 feet wide and 10 feet deep.

From each of these main canals numerous branches issue, spreading over and commanding the greater part of the delta area, and generally terminating on the sea coast. One of the principal canals in the central delta is carried across a minor

branch of the Godavery on a fine brick aqueduct, having forty-nine arched openings, and a total length of 2248 feet.

Altogether, in the Godavery delta there are 506 miles of main and branch canals, of which practically the whole are navigable, and 1732 miles of smaller distributing channels. The cultivable area commanded is 772,000 acres, of which nearly all is under irrigation. In the year 1890-91 the value of irrigated crops raised was over a million and a half sterling, and the net revenue earned was nearly 12½ per cent. on the capital outlay, with a surplus of £114,000, clear of interest.

The delta of the Kistna river, as we have already stated, immediately adjoins that of the Godavery, and is divided by the river into two portions, each of which is covered with irrigating channels, fed from main and branch canals derived from above an *anicut* or weir, situated at Bezvada, exactly at the apex of the delta, where the river narrows in its passage through a line of rocky hills on either bank. The Kistna weir was commenced in 1852. In position and in conditions of construction it is entirely different from that over the Godavery. Above and below the gorge across which the weir is thrown the Kistna has a width of nearly one mile and a half, but is contracted in its passage between the hills to 3900 feet. The velocity and depth of the current is consequently very great. The site was chosen, however, on account of the excellent supply of good stone immediately available. The weir is 3840 feet long, and consists of a single front wall of rough masonry, 16 feet high above the summer level of the water, 21 feet above the deepest bed, and 12 feet thick at the base. The wall is founded on a double row of wells 7 feet deep, which fill up the space between the deep bed and the lowest water level, around which a broad base of heavy stones was deposited. An apron of rough stone, 200 feet in width, extends below the weir, and at 100 feet from the latter a second parallel dwarf wall of rubble masonry, founded on the rough stone, was built after it had well settled. On each flank of the weir sets of scouring-sluides of fifteen openings, each 6 feet wide, are provided to keep a clear channel in front of the regulating head-sluides of the two main canals which there take off. In high floods the water rises nearly 20 feet above the top, or crest of the weir, with a

Kistna Delta
Canals.

velocity said to approach 11 miles an hour. Just above each canal head a lock and channel for the navigation is constructed in the river bank.

The main canals taken off for the supply of the eastern and western portions of the delta are 200 and 230 feet wide respectively, each carrying a maximum depth of water of 8 feet. The Kistna delta canals have a total length of main line and branches of 325 miles, of which 284 miles are navigable. There are also 1614 miles of distributing channels, commanding over 800,000 acres. In the year 1890-91 the value of irrigated crops raised was £1,123,705. The system like that of the Godavery and other delta irrigation works in Madras is exceedingly remunerative.

Pennair Delta Canals.

The delta of the river Pennair has a very much smaller area than either the Godavery or Kistna. An *anicut* across the river at Nellore was first proposed in 1849, and it was completed in 1855, but was a few years after partially destroyed during a furious storm. It was restored, and again completed in 1861. In the year 1871 it was lengthened to its present dimensions. The *anicut*, which is now 2031 feet long, crosses the Pennair close to the town of Nellore, and a system of canals having 142 miles in length of main line and distributaries, is derived from above the weir on its right flank, and provides irrigation on the south side of the river. The water supply, which is very precarious, is supplemented by storage from the Nellore and other tanks.

Sangam Irrigation.

Subsequently, in 1886, a second weir, 4076 feet long, and 12 feet high, was constructed across the river about 17 miles higher up, opposite Sangam, for the supply of irrigation to the tracts lying to the north of the Pennair. Two main canals taken off above the Sangam weir lead the water into several large reservoirs, and the irrigation of the district is supplemented by water stored in numerous other tanks. There are in all 259 miles of main line and distributaries connected with the Sangam irrigation. The combined area irrigated on the north and south sides of the Pennair delta is about 133,000 acres.

Srivaikuntham Canals.

In the extreme southern part of the Peninsula the Tambrapurni river flows into the sea a few miles south of Tuticorin in

Tinevelly. Mention has already been made of the many ancient *anicuts* placed at intervals across the Tambrapurni, and the large amount of irrigation carried on by means of the numerous channels led off from it to feed old native reservoirs, which are dotted over the whole face of the country.

Notwithstanding this extensive irrigation, some portion of the Tambrapurni water still escaped to the sea, and to intercept and utilise this an *anicut* thrown across the river at Srivaikuntham, about 16 miles from the coast, was constructed and completed in 1874. From each side of the *anicut* main irrigation channels are led off, which convey water for irrigation purposes, over the whole of the tracts lying immediately north and south of the Tambrapurni, between the *anicut* and the sea. The canals irrigate directly, but chiefly serve to feed innumerable tanks, some of very large superficial area, which are scattered over the district. From the upper end of the Karampallam tank—the northern extremity of the series—a fresh-water channel provided with head sluices conveys water to the town of Tuticorin. The project, although of relatively small size, is yet of considerable value and importance. The Srivaikuntham *anicut* system has 28 miles of main and branch canals, and 62 miles of distributaries, irrigating about 30,000 acres.

CHAPTER VIII

MADRAS IRRIGATION

Madras irrigation continued—Soonkesala, or Kurnool-Cuddapah Canal—Guaranteed company—Early days of public works—Madras Irrigation Company—Employment of irrigation companies unsatisfactory—Kurnool-Cuddapah Canal the financial drag weight of Madras system of irrigation—Outline of project and main works—Weir over the Tungabhadra at Soonkesala—Course of main canal—Works on Pennair river—Peculiar features of Kurnool-Cuddapah Canal—Larger irrigation schemes in Madras—Minor canals too numerous for detailed mention—Main results—East Coast, or Buckingham Canal—Outline history of project and constructive features—Periar project—Description and scope of scheme—Particulars of concrete dam and principal works—General results of irrigation in Madras.

Madras
Canals, con-
tinued.
Soonkesala,
or Kurnool-
Cuddapah
Canal.

LEAVING now the great delta schemes of the Madras Presidency, we will turn our attention to one of the principal works in the upper country, viz., the 'Soonkesala Canal,' or as it is officially designated, the 'Kurnool-Cuddapah Canal.' This canal presents the only example in India of an extensive irrigation work constructed by, and for a long period worked under the administration of, a guaranteed company. In early days all public works in India were projected and carried out by the Engineer Department of the army, working under a military board; and all expenditure incurred was charged against the revenue of the year, but as the necessity for opening up the resources of the country increased, it was soon found necessary to discriminate between the two great classes into which public works are naturally divided, viz., those of special and marked public utility, such as 'railways,' 'canals,' 'harbours,' etc., by which the wealth and prosperity of the country is directly promoted, and those works such as civil and military buildings, local roads, etc., whose chief end is to facilitate and render effective the general administration. The first class of works are virtually

large commercial undertakings, and these soon, of necessity, came to be constructed by means of borrowed capital; the second class remaining, as before, a charge against the general or local revenues of the year. In 1846, the construction of railways by companies, on whose capital expenditure the Government guaranteed a fixed interest, was initiated, and continued in force up to the year 1868. Two attempts only were made to apply the same system to the construction of irrigation canals. In the year 1858 the 'Madras Irrigation Company' was formed, which under a Government guarantee of 5 per cent. on a capital of one million pounds, undertook to carry out the works of the Kurnool-Cuddapah Canal, of which we are about to give an outline description, and a few years later the 'East Indian Irrigation Company' was formed, and undertook—but without any guarantee—the construction of canals in Orissa and Bengal. This Company carried out a good deal of work in the districts named, of which we have already made mention, but was bought out by the Government in 1867-68. The 'Madras Irrigation Company' constructed and administered for many years the existing Kurnool-Cuddapah Canal, but the works were eventually purchased, at a cost of over two millions sterling, by Government in the year 1882. Both these cases of the employment of companies for the construction of irrigation and navigable canals proved expensive failures to the State, the causes of which we are happily not here required to enter into.

The original Tungabhadra project—as the work we have now under consideration was then called—contemplated a canal for irrigation and navigation, derived from the Tungabhadra river, a few miles above Kurnool, passing *via* Cuddapah, and ending in the Kistnapatam estuary on the sea-coast a few miles south of Nellore. Only the portion between Kurnool and Cuddapah was, however, actually carried out, the work on which was practically completed by the Company in 1871. The remaining length of about eighty miles, between Cuddapah and the coast, or some modification of the original proposal which will place a large area of the interior upper country in convenient navigable connection with the 'East Coast Canal,' and with the capital city of Madras, will probably before long be undertaken.

The Kurnool-Cuddapah Canal is unfortunately the financial drag weight of the Madras system of irrigation works, failing at present to pay its ordinary working expenses, and showing a net deficit at the end of 1890-91 of over £800,000. It is practically the only irrigation project in the Madras Presidency on which any important deficit occurs, the majority yielding a considerable yearly revenue. The canal commands the large area of 321,500 acres, but irrigates only about 25,000, whilst, owing to its disconnected position, the navigation traffic is small. The population of the districts affected by the canal are largely unused to wet cultivation, and the project—unlike the greater number in the Madras Presidency—does not so much afford facilities for the extension of an already highly-valued irrigation, but in reality introduces it for the first time, requiring for ultimate success the virtual substitution of a wet for a dry system of cultivation. The difficult character of the country through which the upper portion of the canal had to be carried has moreover weighted the project with a heavy initial outlay.

The canal begins at Soonkesala (17 miles above Kurnool), with a weir across the river Tungabhadra, 1500 yards, or not far short of a mile, in total length of clear overfall, which is broken into two lengths by an intervening island. This weir is constructed partly of solid rubble masonry, and partly of concrete, faced with masonry in front and rear. In height it varies from 6 to 26 feet, with an average height of 18 feet. The maximum flood waters pass at a depth of 7 to 8 feet over the crest.

The weir is built on the rocky bed of the river, and is not carried in a straight line across it, but follows in a serpentine course the line of the highest sound rock. The down-stream face of the weir wall in the highest portion is vertical; the water falling on to the natural gneiss rock below. Of late years the bed, especially below the scouring sluices, has shown signs of erosion and disintegration, necessitating a protective covering of masonry.

From the right-hand side of the pool above the weir the water is admitted into the canal by head-sluices, the river faces of which are kept clear by a line of ten under-sluices placed at

a low level in the adjoining weir; the current being forced across the line of canal sluices by a long curved spur, or 'groin.' The canal for the first 75 miles of its descent has a bottom width of 90 feet, and carries 8 to 9 feet in depth of water. In this length it has a very tortuous and difficult course, crossing many tributaries of the Tungabhadra by aqueducts, of which the principal is that over the Hindry, carrying the canal 90 feet broad, and 8 feet deep, over the river at an elevation of 32 feet above the bed, on fourteen arches, each of 40 feet span. The total length of the aqueduct is 651 feet.

At the 75th mile the canal passes through the watershed, or ridge of separation, between the Tungabhadra and Pennair drainage systems, by a long and deep cutting. From this point the natural watercourses of the country become the main-supply channels, the water being taken at four points by means of *anicuts* thrown across the Kali, Koondur, and Pennair rivers. Between the 75th and 95th miles the canal drops 180 feet through twelve locks, each 120 feet long and 20 feet wide, and between the 118th and 146th miles it passes through seventeen locks, with an aggregate fall of $187\frac{1}{2}$ feet, the width of the canal being here reduced to 50 feet. At the 146th mile the canal touches the Koondur river at Rajoli, where a supply weir is thrown across the river. At the 172d mile the irrigation channel ceases. From thence to the river Pennair at the 181st mile (to which it descends $90\frac{1}{2}$ feet through nine locks) the canal is a still-water navigation channel only.

The works on the Pennair river—which is crossed by the canal—consist of a masonry weir, with head and scouring-sluices, and an entrance lock, the gates of which are 25 feet high. The weir, which for the greater portion of its length lies on sand, is supported on double and single rows of wells, sunk deeply into the river bed. Below the down-stream slope of the weir there is a rough stone apron, 105 feet wide. Beyond the Pennair river the canal at present extends for a distance of 8 miles only, irrigating a small area. The length is in fact the first portion of the proposed extension to the coast near Nellore.

The peculiar feature of the Kurnool-Cuddapah Canal is the height and length of many of its embankments. These range

up to a height of 50 feet from the ground surface to the water-line in the canal, and are 35 and 40 feet high over long stretches. The banks are constructed in various ways, the largest being faced with masonry walls, supported by gravelly banks on the outside. Some have a core of clay, or 'puddle,' in the centre, on each side of which rough stone is packed. Others have a thickness of clay puddle on the inner face of the slope, overlaid with loose stone. There are altogether some 10 or 12 miles of these embankments, presenting somewhat novel and unusual forms of construction.

The total length of the Kurnool-Cuddapah Canal, which is navigable throughout, as at present constructed, is 190 miles, with 313 miles of distributing channels. As already stated, it irrigates only about 25,000 acres out of 321,500 acres commanded. In the year 1890-91 the value of irrigated crops raised was £70,050.¹

The above works represent the most important of the large irrigation systems of the first class in the Madras Presidency. The eight works comprising this class, which have been constructed at a capital outlay of borrowed money of over 5½ millions sterling, yield a yearly revenue of £372,000, or nearly 7 per cent. on their cost, and £174,000 annually after deducting interest charges. This revenue would be far greater were it not for the heavy loss sustained in the case of the Kurnool-Cuddapah Canal. The combined eight works irrigate an area of over 2½ million acres, or 3666 square miles, and command upwards of 3,000,000 acres. Of the enormous number of the works of the minor class, constructed by provincial or local funds, there are twenty-one systems of a prominent character, of which four are exclusively canals for navigation. Space will not admit of any separate consideration of these works, which, however, include the numerous ancient tanks, or reservoirs, restored and maintained by the Government, some of which are of very great magnitude, such, for instance, as the Cummun and Chembrambaukum Tanks, of which we have already spoken in the chapters dealing with native works, as well as the 'Palar'

¹ Adapted from a paper on the 'Soonkesala Canal,' by J. H. Latham. *Vide Minutes of Proceedings, Institution of Civil Engineers*, vol. xxxiv.

and 'Lower Kalerun' *anicut* systems, each irrigating about 100,000 acres.

The comparatively few large 'productive' works, as they are officially designated, are of great value and importance, both to the people and to the State, but they are surpassed in local value by the aggregate of minor works of secondary individual importance. These minor works irrigate a total area of no less than 3,167,452 acres, or 5000 square miles, by means of 2422 miles in length of main canals and distributaries, and yield a yearly revenue of £435,000.

Of the four works constructed exclusively for navigation purposes, one only is of any special interest, and will serve as an illustration of this class of canal. The 'East Coast,' or 'Buckingham' Canal, is a salt-water tidal channel, extending along the east-coast of the Madras Presidency for a distance of 262 miles, of which 196 miles lie north of Madras city, and extends to Pedda Gangam, at which place it is in communication with the navigable canal systems of the Kistna and Godavery deltas. South of Madras city the canal extends 66 miles to Merkanum, a place situated about 23 miles from the northern boundary of Pondicherry.

The canal runs everywhere quite close to the sea, and is nowhere more than 3 miles distant from it. It has been constructed by degrees, at varying intervals, almost from the beginning of the century. The general features of the sea coast on this side of India consist of long parallel lines of sand dunes, lying along the shore, and between these dunes there are often considerable stretches of shallow depressions or hollows. These hollows, frequently forming backwaters, are filled with sea-water, and are of sufficient depth in many places for navigation, being supplied through the bars of the rivers, with which they are in connection.

So far back as the year 1801, the narrow strips of backwater found at the mouth of the river Kortalayar, suggested to a Mr. Heefke the idea of obtaining a Government concession to cut a canal, about 11 miles long, from Madras to the southern end of the Ennore breakwater. This permission was granted, and Mr. Basil Cochrane became surety for the projector. Mr. Cochrane subsequently obtained entire control of the work,

which he called 'Lord Clive's Canal,' and shortly afterwards he extended the navigation 16 miles further north, to Pulicat lake. This gentleman remained sole proprietor of the canal, with authority to levy tolls, for forty-five years, dating from 1802. In 1837, he having left India, the canal got into bad order, when his rights were bought out by the Government, who paid him at the rate of £1406 a year, up to the year 1847, when his lease expired.

This was the commencement of the 'Buckingham Canal,' then known as 'Cochrane's Canal,' a name which still adheres to the older portion, and later as the 'East Coast Canal.' In 1854 a lock was built $7\frac{1}{2}$ miles north of Madras, partly as a sanitary measure, and to maintain a sufficient depth of water for the navigation. The channel was also extended to 69 miles north of the same place. About the same time the canal was excavated south of Madras 40 miles to the Palar river. At intervals, for many years afterwards, further extensions in both directions were made, the ultimate object in view being to effect a junction with the Kistna delta navigation in the north, and to connect the canal with the French possession of Pondicherry in the south.

In 1876-77, under the pressure of famine, it was decided that considerable extensions of the canal should be carried out by famine labour, and under the orders of his Grace the Duke of Buckingham, then Governor of Madras, large gangs of work-people from the famine-stricken districts of Bellary, Kurnool, and Cuddapah were marched down to the coast, and were set to work along the whole line. At one time it was reported that 100,000 men, women, and children were thus employed. On the termination of the famine the whole length of the existing Buckingham Canal—as it then came to be called—may be said to have reached a certain stage of completion. Subsequently, in the year 1883, funds were assigned for the full completion of the canal, from Pedda Gangam on the north to Merkanum on the south. The work throughout is of a simple character, consisting for the most part of a cut carried along the sand dunes, taking advantage of all the natural backwaters, having a bottom width varying from 20 to 30 feet, with side slopes from $2\frac{1}{2}$ up to 4 to 1, according to the nature of

the material, and a depth of 3 feet below the lowest recorded tide in each reach. The several reaches of the canal, which intervene between separate drainages, are for the most part isolated by means of flood-gates, so as to exclude whenever desired all extraordinary floods, and at all points where drainage crosses the line of the canal the watercourses are trained, so as to preserve a deep channel for the passage of boats. The side embankments are made up to a level of 3 or 4 feet above the highest known water level.

The canal affords 307 miles of cheap water communication out of 387 miles, which intervene between the city of Madras and the Hyderabad coalfields, and also places that city in direct water communication with the well-irrigated deltas of the Kistna and Godavery rivers, and thus forms a most valuable line of connection during periods of famine.

In the year 1884 a project of an exceptionally interesting and novel character, having some features of enormous proportions, was commenced, and is now approaching completion, in the Madras Presidency, of which it would be a great omission not to make mention in this outline description of the principal Madras irrigation works. South of the Kaveri river the districts of Madura and Ramnud depend for their supply of water (other than the scanty local rainfall) on the river Vaiga, which rises on the eastern slopes of the hills of Travancore. The streams which form its sources are very little affected by the south-west monsoon, here scarcely topping the crest of the *ghâts*, and the supply of water afforded is altogether inadequate for the wants of the districts named, which frequently have suffered severely from famines. It is said that not a drop of the Vaiga water reaches the sea, and that its channel in some years runs dry, even a few miles below the town of Madura. Yet whilst such a scanty and insufficient supply of water reaches the thirsty Eastern plains, the great river Periar, rising among the valleys on the other, or *western* side of the hills, under the influence of over 100 inches of annual rainfall, carries an enormous volume rapidly down to the coast, where it is for the most part dissipated and lost in the backwaters of Cochin. The object of the Periar irrigation project, the works of which are now nearly completed, is to utilise a considerable portion of

this superabundant rainfall running to waste down the western slopes of the *ghât* by catching and diverting it to the opposite or *eastern* side of the dividing ridge. This is being effected in the following way. At a selected point in the upper valley of the Periar river a lofty dam will intercept the water draining from 300 square miles of its catchment basin, raising its level at the waste-weir of the dam to a height of no less than 144 feet above the deep bed of the river, and forming behind it an immense reservoir, storing 13,300 millions of cubic feet of water.

At a height of 113 feet above the bed of the river, at the dam, but at the opposite or upper extremity of the reservoir, a deep cutting is carried northwards for a distance of 5400 feet. At this point the cutting is replaced by a tunnel 6650 feet, or $1\frac{1}{4}$ miles in length, through which the water will be conveyed from the western to the eastern side of the dividing range of hills, and will be discharged into a tributary of the Vaiga river.

Of the total water stored in the reservoir, when full to the level of the two waste escapes, one on either side of the main dam, 6815 millions of cubic feet is available for irrigation in the eastern districts, and it is estimated that about 30,000 millions of cubic feet will be annually available. The Periar dam, which closes the valley of that river, is 220 feet long at the bottom, and 1200 feet long on its top line, and rises to a height of 155 feet above the deep bed of the river. On the summit is a parapet-wall 5 feet in height. The dam is being constructed entirely of concrete, made by mixing together hydraulic lime, sand, and broken stone; the latter obtained from the excavations for the escape weirs, occupying saddles in the adjoining rocky hillsides. At its highest portion the dam is 116 feet thick at the base and 12 feet thick at the top, 4 feet of the top width being occupied by the parapet wall.

On each side of the main dam the waste weirs have a length of 500 feet and 420 feet respectively, their crests being 11 feet below the top of the dam. The water falling over the escapes is received into basins, which form water-cushions below them. The rock-cutting, over a mile in length, conveying the water from the upper end of the reservoir to the mouth of the tunnel

or subterranean aqueduct is 21 feet broad, with a fall of 12 feet per mile, and it gradually increases in depth up to 30 feet, when the tunnel is commenced. The tunnel through the high portion of the ridge is 12 feet wide and $7\frac{1}{2}$ feet high, with a fall of 1 foot in 75. Suitable regulating sluices control the entrance of water into the tunnel, and are elsewhere provided as necessary, so that perfect control may be exercised over the movements of the water, whether at ordinary times or during periods of extraordinary floods. On the eastern side of the ridge various works are constructed to regulate the flow and distribution of the water.

The scheme, when completed, will provide irrigation for 140,000 to 150,000 acres of land, commencing at about 80 or 90 miles from the head reservoir. The estimated cost of the project is £634,000. It is one which will be of enormous benefit to the districts affected, and will doubtless prove very remunerative after it has been a reasonable time in operation.

We can now briefly sum up the quantities and values resulting from the mass of irrigation works constructed in the Madras Presidency, as exhibited in the official returns, which—it should be remembered—only include those works under the care and administration of the Government Irrigation Department. Altogether, there existed in the year 1890-91, 3089 miles of main and branch canals, and 6627 miles of distributing channels (exclusive of a large mass of minor works, for which this particular detail is not given, but which, together, irrigate an area larger than that irrigated by the mileage of channels above stated). Of these canals, 1275 miles are navigable. General results.

The area actually irrigated, including all the minor works, was 5,514,184 acres, or 8615 square miles. The capital outlay incurred by the British Government in the Madras Presidency on the major and principal minor works amounts to over $6\frac{1}{2}$ million pounds, yielding a net revenue of £751,000, and a surplus annual revenue, after paying interest on money borrowed, of over £550,000.¹

For details of individual works in the Madras Presidency, *vide* Appendix D.

CHAPTER IX

SCINDE AND BOMBAY IRRIGATION

Bombay and Scinde canals—Inundation canals in Scinde—General results—Bombay irrigation—Principal rivers—Main object of Bombay Irrigation Engineers—Area irrigated small as compared with other Provinces—Works of the first class—Jamda canals—Khrisna Canal—Ekruk Tank—Fife reservoir and Mutha canals—Nira canals—Bhatghar reservoir—Mhasvad reservoir—Hathmati Canal—Minor systems—Areas irrigated—General results of irrigation in Bombay—Concluding remarks, and general summary of irrigation throughout India—Recent review of irrigation works in India up to end of the year 1890-91—Conclusion—Note on Government classifications of canals.

Bombay and
Scinde
Canals.

IN the British province of Scinde, on the lower part of the Indus valley, and forming a part of the Bombay Presidency, a very large area of cultivation is annually irrigated by means of a complicated network of inundation canals and their branches, originating in the Indus. The average rainfall in this part of India is barely 9 inches, and many localities may be said to be practically rainless. Unlike the rest of India, therefore, cultivation is here entirely dependent on irrigation, either from the canals or from wells. The annual rise of the Indus, due to the melting of the Himalayan snowfall, which commences in May, again subsiding in August—by which rise the inundation canals are fed—takes the place of the annual monsoon in other parts of the country.

In the previous chapters dealing with ancient native irrigation works, mention has been made of the enormous development, from very early times, of the system of inundation canals in the Indus basin, and of the main features of this kind of irrigation work. As the large majority of the inundation canals in Scinde are old native works, in many cases enlarged and improved under the British Government, it will not now be necessary to do more than indicate the general results of their working. Anything like a detailed description of these

numerous channels, which, although of the utmost simplicity in their constructive features, are yet in some aspects among the most interesting class of works in India, would nevertheless probably fail to enlist the interest of the general reader.

It has already been mentioned that the chief difficulty attending the working of these inundation canals is the incessant labour required to keep them clear owing to the enormous deposit brought down by the Indus. Formerly this constant clearance was effected by means of statute labour, and each cultivator was legally bound to furnish a number of labourers during the cold season, from December to April—when the clearances were chiefly effected—proportionate to the area of land cultivated by him. Statute labour was, however, abolished by the Government in 1856, and the annual work of keeping the channels clear of deposit, has since become the chief source of expense to Government in the maintenance of these canals.

The whole of the Scinde inundation canals are, for administrative purposes, divided into seven district groups, which contain an aggregate length of irrigation channels amounting to 5924 miles. To protect particular areas from excessive and violent inundation during the period of highest floods, there have also been constructed, and are maintained, upwards of 650 miles in length of protective embankments.

In the year 1889-90, the total area irrigated by the system of inundation canals in Scinde was 2,349,819 acres, or 3671 square miles. This area varies annually according to the extent and duration of the summer rise of the river. Four important canals, viz. The 'Desert Canal,' 'Unharwah,' 'Bigari,' and 'Eastern Nara Works' are classed as major (productive) works, and yielded a return of about $8\frac{1}{2}$ per cent. on the capital expended, and show an accumulated net revenue of £153,237, after deducting interest charges. The numerically large group of works classed as 'minor' yielded an aggregate net return of 22 per cent. During the same year, the net revenue earned on the whole of the irrigation canals in Scinde amounted to £232,365.¹

General re-
sults—
Scinde Canals

¹ For details of individual works in Scinde, *vide* Appendix E.

Bombay
Canals.

In Bombay proper, three principal rivers take their rise on the Western *ghāts*, and flow eastwards, viz., the Bhima, Krishna, and Tumbudra. These, uniting below Kurnool, form the single Kistna river, which, after traversing the Madras Presidency, enters the Bay of Bengal. Fed by numerous tributaries rising among the same hills the upper portions of these three rivers pass through the south-eastern section of Bombay, and their waters are utilised in various ways for irrigation. The difficulties, however, in the case of these larger rivers, are very great, owing to the comparatively slight fall of their channels, and the small volume of water they carry during the dry season. In the northern portion of the Presidency (excluding Scinde) the Nurbudda and Tapti rivers flow from west to east and enter the Arabian Sea.

The main object of the Bombay Irrigation Engineers, is, first, to retain and store up the ample supplies of water delivered by the south-west monsoon, and prevent its running to waste during the rainy months; secondly, wherever possible, to give it a sufficient elevation to command the dry and thirsty lands situated on the sides of the valleys of the country. For the most part the natives of the Bombay Presidency have not attempted to store the waters of the larger rivers; but small tanks on the minor tributary streams are very numerous.

As compared with the other provinces of India, the area of land artificially irrigated by means of large Government works in Bombay is very small, and, as a rule, the works that exist command a far larger area than they actually irrigate; the amount of irrigation being enormously affected by the occurrence of favourable and well-distributed monsoon seasons. In such years, principally owing to scarcity of labour, the crops which require to be matured by artificial irrigation are largely reduced in favour of other crops that are best matured by direct rainfall.

In the Bombay Presidency there are nine irrigation works of the first class in actual operation; and two projects are in course of construction. Works of the second or minor class number 27 in all. In actual operation, therefore, there are 36 separate irrigation works, the larger number of which are of small size and importance.

The earliest work of any consideration undertaken by the Government in the Deccan was the Jamda Canals, the construction of which was commenced in 1863. These consist of two canals, drawn, one from the right, and the other from the left of the Girna river, a tributary of the Tapti. The head works of these canals are situated at Jamda, in Khandesh, where a weir 1540 feet long, and 18 feet in maximum height, founded on a rocky bottom, is constructed across the river. The canal drawn from the left bank is 27 miles long, that on the right being 12 miles only, with 75 miles in all of distributing channels. A portion of the left bank canal was opened in 1866, and has therefore been in operation for 26 years. The right bank canal was not brought into use until 1878, owing to the small demand for water for monsoon crops. The canals command an irrigable area of 30,500 acres, but actually irrigate but a very small portion of this.

In the same year, viz., 1863, a canal derived from the Krishna (the upper part of the Madras 'Kistna' river) was commenced, and was completed in 1868. Above the head-works of the Krishna canal, the river, rising in the Western *ghâts*, drains an area of over 1200 square miles, having a rainfall of 30 inches, it has therefore a considerable volume in the rainy season. A weir of rubble masonry, 1200 feet long, and 21 feet high in the highest portion, is built across the river, along a rocky barrier, which is situated at Korsee, close to the town of Karad, in the Satara district, where the Koina and Krishna channels meet each other. From above this weir the Krishna canal, 61½ miles in length is derived. The bed of the canal is 4 feet lower than the crest or top of the weir, which is provided with a line of scouring sluices. The canal is calculated to discharge 140 cubic feet of water per second, for eight months in the year; but in order to take advantage of freshes, the works are designed so as to be capable of passing 300 cubic feet per second, whenever such a supply is available. Provision is also made for constructing at the end of the rains a temporary earthen bank on the top of the weir, with suitable escapes at each end, in order to store water brought down by the slight freshes, which often occur in April or May. The Krishna canal commands an irrigable area of 25,533 acres, but irrigates only about 4000.

Ekruk Tank. One of the finest of the earlier works of the reservoir class in Bombay is the Ekruk Tank, situated four or five miles due north of Sholapore. The construction of this reservoir was commenced in 1866. An earthen bank or dam, 7000 feet, or $1\frac{1}{2}$ miles in length, with masonry flanks, and 76 feet in maximum height, is reared across the valley of the Adhila river—a tributary of the Bhima. This dam is designed to raise the water to 60 feet in depth, when the reservoir is full, at which time the area of its water surface is 4640 acres, or $7\frac{1}{4}$ square miles, and its contents 3350 millions of cubic feet of water. The sites of five villages were submerged under its area. The surplus water passes over two waste-weirs, having a combined length of 750 feet, into a ravine channel, which rejoins the Adhila about a mile below the dam.

Three canals are fed from the reservoir, having an aggregate length of 48 miles. Two of these, drawn off at the high-level of 14 feet below the full water-line of the reservoir, are designed to furnish irrigation for four months in the year only, and are 18 and 4 miles long, respectively. The third or low-level canal, 26 miles long, is drawn off at 39 feet below full water, and is a permanent canal, providing perennial irrigation. Each of the three canals is capable of extension, commanding an additional area.

At present the total area commanded is 15,320 acres; but the area irrigated in 1890-91 was 2599 acres only, partly owing to a favourable rainfall in that year, but greatly due to a diminished capacity of the main canal in the first eight miles. This channel is designed to carry a maximum of 70 cubic feet of water per second; but only 30 cubic feet could be passed down it, pending some necessary repairs and improvements. The construction of the Ekruk reservoir dam was completed in 1869, but the canals were not completed to their present lengths for many years afterwards.

**Fife Reservoir
and Mutha
Canals.**

Another exceedingly large and important combined irrigation and water-supply scheme is the Fife reservoir and Mutha canals system near Poona. This scheme was proposed by Colonel Fife, R.E., in 1863, and was commenced in 1868. The Fife reservoir has been formed by the construction of an enormous masonry dam across the valley of the Mutha river,

at a point about ten miles south-west of Poona. This masonry dam at the time of its construction was probably the largest work of the kind then attempted.

The Mutha river is a tributary of the Bhima, and rises in the Western *ghâts*, some 20 to 25 miles above the reservoir. The catchment area is 196 square miles, with an average rainfall of 34 inches. At the point selected for the reservoir dam, sound rock was met with near the surface. The dam is constructed of uncoursed rubble masonry—its length, exclusive of the waste-weir, being 3683 feet, the waste-weir being 1453 feet long. The maximum height of the dam, from foundation to summit, is 106 feet, or 96 feet above the lowest bed of the river. The crest of the waste-weir is 87 feet above the same point, or 11 feet below the top of the dam.

The contents of the reservoir when full is 5200 millions of cubic feet, and the area of the full water-surface is 3300 acres, or slightly over five square miles. In order to gain the elevation necessary to command the station of Poona, and the districts beyond, the level of the bed of the canals fed by the reservoir is placed at 59 feet above the river-bed. There is, therefore, 28 feet in depth of available storage between the bed-level of the canals and the crest of the waste-weir, representing 2680 millions of cubic feet of water, or a maximum of 3283 millions of cubic feet, when, at the end of the rains the water-level is raised some 4 feet above the top of the waste-weir, by means of posts and sliding planks which are fixed along the crest. It is estimated that during an average season the reservoir fills sixteen times, and that one-sixth of the whole discharge of the river is utilised.

Two canals are supplied from the reservoir, one, on the right bank of the Mutha, about 70 miles long, passes through the station of Poona, then turning to the eastwards, it irrigates a long tract of country lying in the dry zone of the Deccan, between the river and the foot of the hilly range to the south. The second canal, which is $14\frac{1}{2}$ miles long, extends only a short distance beyond the military station of Kirkee, at which place water is supplied to the powder-works.

The total area irrigable by these canals is nearly 50,000 acres, but only about 11,000 to 12,000 acres are actually irrigated.

Besides providing for irrigation, the project is designed to furnish an abundant supply of pure water to the city, civil station, and cantonments of Poona and Kirkee, and to numerous villages lying along the course of the canals. A considerable portion of the yearly revenue is derived from this source. In the year 1890-91, nearly 277 million gallons were delivered from the canals for the Poona water-supply, the population of the area served being by the last census 32,242 persons, and the average consumption per head per day amounted to 23 gallons.

The water-supply for the city is drawn off at the 10th mile, and through the station of Poona—in order to avoid interference with public buildings and the parade ground—the canal is carried underground in two tunnels. At the end of the first tunnel, near the centre of the cantonment, there is an overfall, the force of which has been utilised to drive a large undershot water-wheel, which works a set of pumps for raising the canal water into the filter-beds, settling-tanks, and covered reservoirs of the high and middle-service systems of the water-supply. For the low-service system, mains and branches are led off directly from the canal itself.

Nira Canal.

The 'Nira Canal' and Bhatghar reservoir, is a project carried out to a great extent in recent years. The main Nira Canal was opened in the year 1885. It is derived from the left bank of the river Nira, an important tributary of the Bhima at Vervadi, situated about 40 miles south-east of Poona. The completed length of the canal and branches is designed to be a little over 100 miles, of which $95\frac{1}{2}$ miles are now open, with 109 miles in length of distributing channels. The canal follows a very winding course along the foot of the high ground lying north of the Nira, passing near Baramati, and extending to Sudrapur, near the confluence of the Nira and Bhima. Numerous branches are carried down from the canal towards the former river, irrigating about 17,000 acres. The total area irrigable by the complete project is given as upwards of 227,000 acres.

Bhatghar Reservoir.

The water-supply of the river is supplemented from a very large reservoir situated a few miles above the head of the canal at Bhatghar. The Bhatghar reservoir has a catchment area of

128 square miles, with an annual average rainfall of 145 inches. The water is retained by a masonry dam, 127 feet high above the lowest foundation, and 108 feet above the river-bed, forming above it a huge lake, containing an available storage-supply of 5500 millions of cubic feet, and having a water-surface area of 3584 acres, or more than $5\frac{1}{2}$ square miles. The estimated cost of the complete work is £637,000.

Another recently constructed reservoir of great size is the Mhasvad Tank, in the Satara district. An earthen embankment, 80 feet high, closes the valley of the Mau river, cutting off a catchment basin of 480 square miles, having, however, but a small annual rainfall. The reservoir stores an available water-supply of 2633 millions of cubic feet, and has a water area of 4013 acres, or $6\frac{1}{4}$ square miles. The reservoir feeds 27 miles in length of main irrigation canals, and $66\frac{1}{2}$ miles of branches and distributaries, which first came into operation in the year 1887. In that year the canals irrigated but little over 1000 acres, but by the year 1890-91 this had increased to 7106 acres. The total acreage irrigable by the existing works is 106,000 acres.

The Hathmati Canal was commenced in the year 1869, and was brought into partial operation in 1873. It is derived from the Hathmati river—a tributary of the Salarumati, about 40 miles above the town of Ahmedabad. The head-works of the canal consist of a weir of rubble masonry, 1000 feet long, and 22 feet in maximum height. From the pool above the weir the canal, which is 21 miles long, with 30 miles of distributaries, is drawn. The canal commands an irrigable area of 8000 acres, of which it actually irrigates rather less than half.

The above works comprise all the more important of the Bombay irrigation projects of the first class. Space will not permit any separate mention of the numerous minor systems of the secondary class, which number twenty-eight in all. These Government works, however, are very far from representing the true extent of irrigation carried on in the Bombay Presidency. The thirty-six major and minor works taken together irrigate only about 76,000 acres of cultivation; but, in addition to this area, over 145,000 acres are irrigated by the aggregate mass of still smaller works, 1270 in number, scattered all over the Presidency districts, which are looked after and kept in repair

by the Irrigation Department. For the most part these lesser works consist of small tanks, and of weirs called *bhandaras*, on the smaller streams, the larger number being of ancient or modern native construction. In the Dharwar district alone there are said to be 473 tanks, irrigating 65,000 acres.

General
results—
Bombay
canals.

According to the official returns, there are in the Bombay Presidency 606 miles of main canals and branch canals supplied with 564 miles of distributing channels. During the year 1890-91, 221,464 acres of land, or about 34½ square miles, were irrigated, yielding a total value of irrigated crops of nearly £400,000. The total capital outlay by the Government on all classes of irrigation works in Bombay was £2,465,024, earning a net revenue of £56,033, or 2·2 per cent. on the capital cost. Including interest, however, the thirty-six works of the major and minor class resulted in a deficit of £70,743. The mass of smaller agricultural works taken together yielded a profit of £33,913, giving a net deficit of £36,830.¹

We have now sketched in general outline the main features of the irrigation works of British India, both as regards the type and character of early native constructions, and the extensive improvements and additions introduced by modern engineers since the country has been brought under British rule. The picture we have been able to draw is, of necessity, projected on so small a canvas as to be altogether inadequate to convey to the eye more than a mere outline of individual works—nor has it been attempted to do more than this. The object aimed at has been to implant in the mind of the reader a fairly correct impression of a great whole by means of a rapid exhibition of the general dimensions, number, and value of its main component parts. To do this, it has been unfortunately, but unavoidably, necessary to quote largely figures expressing volumes, areas, and linear dimensions, as well as money expenditures and revenue returns, which, it is feared, may have unduly taxed the patience of the reader. Nevertheless, in conclusion, it will perhaps serve to impress more firmly on the mind what we especially desire to imprint, if the main figures and results of irrigation works throughout British India are

¹ For details of individual works in the Bombay Presidency, *vide* Appendix F.

finally summed up in one general statement, the reader being careful to bear in mind that these totals are approximate only; some of the figures entering into them being for the year 1889-90, and others for the year 1890-91. Although not, therefore, comparable with the statistical data of any single year, they will nevertheless serve the only purpose we have in view, viz., to convey to the reader a general and approximate idea of the large total value and extent of irrigation and navigable canal operations in India, exclusive, it need not be said, of that large amount of secondary irrigation carried on by unassisted native agency.

In the whole of India about 16,000 miles of main and branch canals have been constructed by the British Government, of which 2882 miles are navigable. These canals distribute their waters by means of over 23,500 miles of minor channels, and irrigate from 12 to 13 millions of acres, or about 20,000 square miles of country. The annual value of irrigated crops, excluding Scinde, for which the figures have not been obtained, is probably not far short of 30 million pounds. The capital sum expended by the Government on all classes of irrigation and navigation canals throughout India is a little above the same amount, and the net revenue annually earned is nearly $1\frac{1}{4}$ millions sterling, or about $5\frac{1}{2}$ per cent. on the capital cost. The sum realised, after defraying interest charges, is over £725,000 annually.¹

In a recent review of irrigation works up to the end of the year 1890-91 by the Government of India, dealing with those works for which both capital and revenue accounts are kept, the directly remunerative character of the total outlay incurred on irrigation throughout the country is clearly exhibited. As this review is based on figures far more complete than those we have been able to utilise, and is moreover brought up to a uniform, and in some instances to a later, date, the following general results will be of interest. It is shown that, for irrigation works only, the capital expenditure on major 'productive' works to the end of 1890-91 amounted to £25,465,011, yield-

¹ For approximate total results of irrigation and navigation canals in all India, *vide* Appendix G.

ing a net return of 4·81 per cent., without taking into account the old irrigation in Madras. Including this, the net return is given as 5·80 per cent., whilst including 'protective' works, and that portion of the minor works for which capital and revenue accounts are kept, the total percentage of net revenue on capital outlay is shown to be 5·69 per cent. The protective works taken alone yielded 0·79 per cent.

The direct capital outlay on navigable canals, including both major and minor works, is £1,887,033, the net revenue being 0·82 per cent. on their cost.

Altogether, on 120 works of irrigation and navigation, costing £31,620,310, the net revenue derived in 1890-91 was £1,710,136, or 5·40 per cent., and the area of land irrigated, excluding the lesser classes of minor works, was 9,275,102 acres, or nearly 14,500 square miles.¹

These results include figures relating to projects such as the Chenab Canal, the Sangam, and the Periar works, which, being incomplete, yielded nothing on their capital outlay. The very unremunerative Orissa and Kurnool-Cuddapah canals are of course included. It is stated that 'on the whole, the returns from the systems which fulfil the conditions of being productive, are more than sufficient to cover the deficits on systems which, although classed as productive, do not attain to the necessary standard.' The estimated value of the produce for one year on all the irrigation canals of India is shown to be nearly equal to the whole of the direct capital outlay incurred on the works.

A list is given of important irrigation projects that have been submitted to the Government of India, but upon which work has not yet begun. These are, the 'Jhelum Canal,' the 'Kalingaroyen channel,' the 'Chenab extension project'—all of which have been sanctioned—and the Cawnpore branch of the Lower Ganges canal, a project which is under preparation. The additional area that will be irrigable by the above works amounts to 1,291,000 acres, or 2017 square miles, and the estimated returns are calculated at over 13½ per cent. The Chenab Canal extension is to take precedence over the Jhelum Canal. A considerable and profitable outlay is contemplated

¹ *Vide* Appendix H.

on works in Upper Burma, where scientific irrigation has as yet hardly commenced, and proposals are awaited from the Bombay Government for the improvement and extension of irrigation works in Scinde, upon which question a committee assembled early in 1892.

In conclusion, if we placed end to end all the main and branch canals of India, they would reach nearly two-thirds of the distance round the world, and the navigable portion would be represented by two canals—one stretching from Cape Comorin to Peshawar, and the other from Calcutta to Bombay, a combined distance equal to nearly the whole breadth of Europe. The minor distributing channels, placed together, would extend almost completely round the earth's circumference.

Note.—Under the Government system of accounts, irrigation and navigation works in India are divided into two main classes, respectively called 'major' and 'minor' works. The major class comprises all those works estimated to be directly 'productive' within ten years from completion, and certain special works called 'protective,' primarily undertaken to protect certain districts from famine, whether likely to be directly profitable or not.

The second or 'minor' class is, for accounts purposes, divided into several sub-classes, viz. :—

- (1.) Works for which both capital and revenue accounts are kept.
- (2.) Works for which only revenue accounts are kept.
- (3.) Works for which neither capital nor revenue accounts are kept.
- (4.) Agricultural works (sub-divided in the same manner), being chiefly river embankments, etc.

The quantitative and financial results of irrigation works, as exhibited in general Government returns, relate only to those works for which both capital and revenue accounts are kept. The exact total figures for the last three sub-classes of 'minor' works not being available, these are necessarily excluded from general statements of irrigation operations.

Collectively, however, these lesser sub-divisions of the minor works class are of importance and interest. So far therefore as it has seemed possible to ascertain and extract them from the various provincial returns, we have included them in the totals of the tabular statements A to G, which will be found as an Appendix at the end of this volume, as well as in our general summary of irrigation works throughout India.

RAILWAYS IN INDIA

CHAPTER I

ORIGIN OF RAILWAYS

Origin of railways—Wonderful influence in regenerating India—Caste-barriers largely affected—Reduction of distances—Birth of the locomotive engine—Rude germs of a line of railway in old Italian stone tracks—Timber wheel-roads in colliery districts—Tramroads—Use of cast-iron for rails—‘Edge’ railway—Early inventors and improvers—Steam-power—Stationary engines and horses—Messrs. Trevithick and Vivian—Mr. Thomas Gray—The man with one idea—His book on steam land-conveyance—Working out practical details—Mr. Blenkinsop—George Stephenson—Sketch of his life and work—Stockton and Darlington Railway—The Quaker family of Pease—Opening of the Stockton and Darlington line—The ‘Experiment’—The Liverpool and Manchester Railway—Motive power—Premium offered for best locomotive—Public trial—Success of the ‘Rocket’—Causes of superiority—Condition of early railroads in England—Extract from a speech by George Stephenson.



HERE is perhaps nothing more surprising to be met with in the history of human progress than the startling rapidity with which the lives and habits of mankind have been beneficially revolutionised by the introduction of steam locomotion. Compared with the effects of any other social influence that can be named, this rapidity is only fitly to be measured by the difference between the speed of an express train, and that of all

Origin of
Railways.

former instruments of human progression.

If we reflect how very slow in operation, and how very gradual in results great social movements usually are, it becomes truly

startling to consider that the whole of those wonderful ramifications and systems of railways and ocean steam-lines of transit, which in modern times have so profoundly modified the fundamental conditions of human intercourse, and which to-day bind together every part of the civilised world, and bring into such close and intimate relations the inhabitants of every civilised country, is the growth of a period of time well within the limits of an ordinary human life. That all those facilities of movement and intercommunication to which we have grown so accustomed, and which now appear to us so indispensably necessary to the prosecution of the most ordinary business and pleasures of existence, have been virtually acquired under the rule of the present reigning sovereign of Great Britain.

In the Western world the diffusion of happiness and prosperity, and the entirely altered conditions of human progress which attended the invention and introduction of the locomotive engine was surprising enough, but for some period before its introduction, especially into England, the extensive use of navigable canals, and the rise and ultimate prevalence of excellent lines of good macadamised roads, with the employment of an organised system of fast and well-appointed coaches between important centres for passenger and for the lighter forms of commercial traffic, materially smoothed the transition, and gradually paved the way to that more rapid means of locomotion, and that manifold multiplication of productive energy subsequently inaugurated, and rapidly developed by the railway system.

It is in the relatively roadless East, and particularly in the great continent of India, that we are enabled to witness in its full proportions the extraordinary awakening, and the wonderfully rapid subversion of previous habits of life and thought, which has been so notably effected within the space of a few years, by the operation and under the regenerating influence of railway communication.

The generality of Europeans, on grounds of a sufficiently extended experience, have long been accustomed to regard the Asiatic as a being passively, but hopelessly, resistant to all forms of innovation ; as apathetic, torpid, unenterprising, and incur-

ably wedded to the practice and routine of bygone centuries; but in our own day it has been reserved as one of the most remarkable triumphs of the steam locomotive to have aroused and awakened the Eastern world, to have undermined, and in great measure overturned, the larger number of those deep-rooted ancient prejudices which in India have so long and so tenaciously resisted all previous assaults.

The strong barriers of one of the most rigid and exclusive caste systems in the world have been penetrated on every side by the power of steam. In India for many years past, caste prejudices have been practically extinguished within the fences of a line of railway, and the most sacred Brahmin will now contentedly ignore them rather than forego the luxury and economy of a journey by rail, whilst everywhere the usually imperturbable and lethargic Eastern has been aroused out of sleep, has learned to move with alacrity, and even to acquire the virtue of punctuality, under the uncompromising and imperious tuition of the locomotive whistle.

Railways in India have reduced the effective size of that continent to less than one-twentieth of its former dimensions, so that places situated 400 miles from the home of an intending traveller or producer of goods for the market, are now as practically near to him as others only 20 miles distant formerly were, and journeys which would have occupied the time, imposed the fatigue, and consumed the daily charges of the best part of a month, can now, with ease, comfort, and economy, be performed within the compass of a day.

To attempt an adequate delineation of the enormous social, commercial, and other advantages which India has derived from railway communication would carry us beyond the limited space at our disposal, and would, moreover, in these days be as superfluous as a thrice-told tale. 'It may be said, without undue enthusiasm or exaggeration, that this great invention has imparted a stimulus and a vital energy into all the affairs of man, whether connected with business or pleasure; has multiplied in a manifold degree our capacities and opportunities of enjoyment; has vastly increased the volume of trade and manufactures in the country; and has in a thousand ways contributed more to the happiness

and welfare of our race than any other discovery or invention that could be named.'¹

The story of that portentous birth, which ushered into the world the infant Hercules of the nineteenth century—the early and vigorous efforts of its sturdy iron members, irresistibly impelled by the imprisoned and forceful spirit of its mighty solar ancestor. In other words, the story of the conception and birth of the locomotive steam-engine, and the consequent rise and development of the railway system, is one of perennial and of the deepest interest to mankind. The story has been written and re-written with the most loving care, and in the most eloquent detail by numerous able pens. Nevertheless, to the younger rising generation, especially in India, the interesting narrative may be less familiar than to the children of those in whose immediate presence the stirring events of railway history were enacted. It will possibly, therefore, not be altogether unprofitable if, before recounting the introduction and growth of the railway system of India, we cast a brief retrospective glance at the early history of the locomotive and of the railway in the land of its inception and birth.

The first rude germs of a line of railway are probably to be found in the smooth parallel stone tracks, which were laid down for draft purposes in the streets of many of the older Italian cities. In England the practice of laying down timber wheel-roads in the colliery districts of the North, and elsewhere in the neighbourhood of mines, for the easy passage of heavily-laden vehicles drawn by horses, appears to have arisen as early as the beginning of the seventeenth century. These timber wheel-tracks obtained the name of 'trams,' or 'tram-roads'—supposed to have been a popular abbreviation of the name of a Mr. Outram, who either originated, or at an early date was extensively connected with their employment. They appear, however, to have been also called 'way-leaves.' Roger North, writing in the year 1676 with reference to a visit paid by his brother, Lord Guildford, to the neighbourhood of Newcastle, mentions this name, and says: 'When men have pieces of

¹ Paper read at the Society of Arts, February 14th, 1890, by Geo. Findlay, Assoc. Inst. Civil Engineers, on *Modern Improvements of Facilities in Railway Travelling*.

ground between the colliery and the river they sell *leave* to lead coals over the ground, and so dear, that the owner of a rood of ground will expect £20 per annum for this leave. The manner of the carriage is by laying rails of timber from the colliery down to the river, exactly straight and parallel, and bulky carts are made with four rowlets fitting these rails, whereby the carriage is so easy that one horse can draw four or five caldrons of coals, and is of immense benefit to the coal merchants.'

It was not, however, until about one hundred years later that these wooden tramroads were superseded by the employment of cast-iron plates, laid on the surface, and firmly bolted to the timber-ways. At Colebrook Dale, about the year 1760, it happened that the price of iron was exceptionally low, and the demand for it was so small that, rather than close the furnaces, the owners decided to cover the upper surface of their wooden tramroads with plates of cast-iron, in order to decrease friction, and render the ways more durable. It was thought that, in case the price of iron suddenly rose, these plates could be lifted and sold as 'pig' iron. The advantages, however, of the cast-iron surface were soon found to be so great, that instead of the plates being removed, their use was gradually extended over the whole district; and before long tramways exclusively of iron, supported on blocks of wood or stone, came into extensive use, especially in South Wales, where by the year 1811, 180 miles of such tramways are said to have been completed.

The first solid iron rails that appear to have been used were cast in section like an ordinary angle iron, in short lengths of from 3 to 5 feet, and they were frequently spiked down to cross supports of wood, named 'sleepers,' let into the ground. The vertical flange of the angle-iron rail was always placed *inside* the wheels of the vehicles, which rolled along the flat, or horizontal portion. Various other sections of 'metals,' as they soon came to be called, were tried in the different mining districts of England and Wales. One of the most successful was the 'edge' railway, introduced into the slate quarries of Caermarthenshire. In this tramroad—or railway, as it truly was—the rail was supported above the level of the wooden cross-

sleepers, and had a flat or slightly rounded top or 'edge.' The guiding flange was transferred from the rail to the wheels of the vehicles or 'wagons,' which in the first instance were made with flanges on each side, forming a grooved wheel-rim, which fitted over the rail-head. This double-flanged wheel was soon found to be unnecessary, and a single projecting flange inside the rail was presently adopted. The ends of the 'edge' rails were secured into an iron box or 'chair' of cast-iron, securely screwed down to the sleepers. So remarkably easy was the haulage on this rail- or tram-way, that it was found that two horses could rapidly draw a train of wagons weighing up to 24 tons, and the effective service of the two horses was calculated to be equivalent to that of 400 working on a common road-surface.

The various forms of horse-tramroad in use were for a long time entirely confined to the vicinity of mines and to the purposes of mineral traffic, but in the very early years of the present century the improvements effected in their construction, and the wonderful success and economy of these roads, began to attract a wider attention. Many ingenious minds bestirred themselves, and numerous enthusiastic projectors began to bring forward proposals for their more extended application in the service of the general public. A Dr. Anderson, in the year 1800, proposed that iron rails should be laid down along the sides of the principal turnpike roads, and be at the service of all who might choose to employ them under suitable regulations. Subsequently he advocated the construction of independent lines of way, having easy gradients and curves, bridges, and even tunnels. The idea was so far realised that in 1801 the 'Surrey Iron Railway Company' obtained an Act for the construction of a horse-tramway for general merchandise, from Wandsworth to Croydon, and experiments were made which showed that a single horse could draw on the level, at the rate of 6 miles an hour, twelve wagons each laden with three tons of stone—or thirty-six tons—a load subsequently increased to more than fifty-five tons.

At this time the use of steam was already known as a motive power, and it had been successfully applied for the working of stationary pumping engines in numerous mines throughout

England and elsewhere. In the mining districts the tramroads employed in the mineral traffic generally descended from the neighbourhood of the pits' mouth to the wharves, usually situated on some river in the valley below, so that the inclinations of the roads were in favour of the loaded vehicles. When the difference of level was very great, as it often was, it was common to manage the descent, not by making the road one uniform inclined plane, but by interposing one or more steep slopes; the remainder of the way being kept tolerably level. The laden wagons were allowed to run down the steep inclines by their own weight, and very often by the aid of a rope and pulley; the descending heavy wagons were made to pull up the return or empty ones.

It soon became general, however, during the first decades of the century, to employ stationary steam-engines for hauling the empty wagons up the steep inclines, while horse labour continued to be everywhere used on the other or more level parts of the tramroad. In this way steam-engines and horses came to be associated almost side by side, and shared the work between them, and men's minds gradually began to entertain the idea of uniting the two, so as to produce a movable engine or 'steam-horse.' Various experiments with this object in view were tried in different parts of the country. Even so early as the year 1804 a rude locomotive machine, worked by steam and moving on rails, was tried at an ironworks in Wales. Messrs. Trevithick & Vivian, engineers, produced several steam-locomotives with some measure of success, and before very long in a good many of the colliery districts small locomotives might be seen which, 'with much clanging and rattling, puffing and smoking, from both steam vent and chimney, drew along at the sufficient pace of 2 or 3 miles an hour, a dozen or more small iron wagons laden with coal; a man would walk by the side to open gates, remove impediments, and assist at a difficulty. The colliers themselves would sometimes jump into the empty wagons, as a tired carter will get into his empty dung cart, or sit on the shaft.'¹

Such was the general state of matters about the year 1819,

¹ *Our Iron Roads.* By F. S. Williams.

when some one remarked to the celebrated canal-making Duke of Bridgewater, 'You must be making handsomely out of your canals?' 'Oh, yes,' he replied, 'they will probably last my time, but I don't like the look of these tramroads, there's mischief in them.' What the shrewd Duke foresaw, no doubt many other persons may have vaguely anticipated, but it is the persistent man of 'one idea' who generally succeeds in fixing and forcing the attention of the public mind. Such a man was Mr. Thomas Gray—the really first public proposer, in the year 1820, of a general system of transit by railways. Mr. Gray, according to the well-known story, which marks the first awakening of his 'idea,' was travelling about the year 1819 in the North of England on commercial business, and one day stood looking at a small train of coal wagons impelled by a snorting and puffing steam-engine along a tramroad which connected one of the collieries of that district with the wharf at which the coals were delivered. 'Why?' he asked of the engineer, 'are not these tramroads laid down all over England, so as to supersede our common roads, and steam-engines employed to convey goods and passengers along them so as to supersede horse-power?' The engineer looked at the questioner with an amused smile: 'Just you propose that to the nation, sir, and see what you'll get by it. Why, sir, you'd be worried to death for your pains.' Thomas Gray made no reply, but went thoughtfully away—the *idea* had firmly lodged itself into his brain, and worry or no worry, he could not get rid of it—railroads, steam-engines, horse-power and common roads superseded—the words kept repeating themselves over and over again; he could think of nothing else; he could *talk* of nothing else. He soon became a bore and a nuisance to his friends and acquaintance, and was doubtless regarded by them as more or less deranged. 'Railroads, steam-engines, horses and common roads superseded'—nobody would listen to him, and the engineer's words seemed likely to prove true. But the 'idea' of Thomas Gray was a genuine and workable idea, and would not allow itself to be suppressed. The pregnant words were dinned with renewed energy into the private and public ear by innumerable letters to friends, to newspapers, by circulars, pamphlets, and at length by a printed book, the first edition of which was

published in 1820, with the lengthy title : 'Observations on a General Iron Railway, or Land Steam Conveyance, to supersede the necessity of horses in all public vehicles, showing its vast superiority in every respect over all the present pitiful methods of conveyance by turnpike roads, canals, and coasting traders, containing every information relative to railroads, and locomotive engines, by Thomas Gray.'

Slowly the man of one idea emerged from the crowd. A few commercial men began to entertain a glimmering notion of his meaning, and to become interested. People of note looked at the idea, discussed it, and ended in advocating it almost as enthusiastically as Mr. Gray himself; even timid capital began to listen to it, and to come to its aid, until at last the minds of business men were sufficiently aroused to give the proposed scheme its first great public trial on the road between Liverpool and Manchester. This, however, was not until four or five years of persistent agitation, and after several editions of Mr. Gray's book had been published. The trial on a large scale was made, and suddenly the idea ceased to be at all wonderful, or even novel. It was only what everybody had always firmly entertained, and what everybody took the credit of.

The merit of first advocating a novel and workable idea, and persistently and successfully forcing it on public attention is undoubtedly very great, even allowing that in a very short time some other person would infallibly have done so. But it is to the practical workers-out of *detail* that the success of railway locomotion is really due. The solitary engines that here and there throughout the country laboured with so much difficulty along the tramroads, at 2 or 3 miles an hour, or if a greater speed was attempted at once broke down, and had themselves to be ignominiously hauled away by horses, would never have emerged from their first obscurity, and have revolutionised the world, if patient practical minds had not long and painfully laboured to evolve workable simplicity out of that wonderful complexity which is always the first offspring of the inventive genius of man.

It was believed that there never could be sufficient adhesion between the wheels of the locomotive and the iron rails, and it was found in many of the strangely-compounded early tramroad-

engines, that if the speed was at all augmented the driving-wheels would revolve on the smooth rails without advancing the load a single yard. The ingenious Mr. Blenkinsop at once devised the remedy. The plan was to notch the rails in the form of a rack, and the wheels of the engine and wagons were cogged with teeth to work into the notches. One of Mr. Blenkinsop's engines of 4-horse power impelled a carriage lightly loaded at the rate of 10 miles an hour, and hauled a train of thirty coal-wagons at about a third of that pace. Fortunately it was soon discovered that the conclusion on which Mr. Blenkinsop and others had been working was too hasty, and that the amount of adhesion between a smooth wheel and a smooth rail could easily be made quite sufficient for all purposes of traction.

The united labour and experiments of numerous practical mechanics throughout the United Kingdom were devoted to perfecting almost piece by piece, and joint by joint, the iron anatomy of the infant locomotive, until there presently emerged, and towered above his fellow-workers, a man whose name has become a household word, and whose title of originator of the modern locomotive engine is beyond dispute.

George Stephenson, the first of the great locomotive and railway engineers, rose to eminence from the humblest ranks of labour. His father was a working collier, and the son from his earliest years was dependent on the hard toil of his hands for his daily share of bread. He was born in a small cottage in the village of Wylam, on the banks of the Tyne, not far from Newcastle. As a young child he was sent out to work in the fields, from which he was shortly promoted to the more lucrative employment of picking over coal heaps at twopence a day. So young was he when thus engaged that he was obliged carefully to keep out of sight of the overseer, lest he should be considered too small to earn even this moderate wage. In his early manhood he was successively employed as a 'brakesman' on a tramroad, and as a stoker to a winding engine at the wages of a shilling a day. When this was doubled he is recorded to have declared himself 'a made man for life.' Steadily working and toiling, often having to rise at one and two o'clock in the morning, and labour until late at night, he struggled

with his destiny, but at so low an ebb were his fortunes in the first years of the century that he had almost decided to emigrate to the new world. Happily, however, for his country, he continued resolutely to battle with the difficulties of his life in his native district, where, as time went on, he gradually earned the character of a steady, observant, and resourceful man. At the age of 22 he married, and in 1803 his only child Robert was born—a child destined to become, in the world of railways, the peer of his distinguished father. As this son grew in years, it is related that George Stephenson, in order to meet his increasing responsibilities, and especially to provide for his son's education, had to turn his hand to almost every variety of work. It is recorded amongst other items that he taught himself to mend his neighbours' clocks and watches, to cut out clothes, make shoes for the pitmen and his poorer relatives, and, above all, to read, write, and to seize every opportunity of improving his mind.

His inventive genius was almost constantly at work, and so great was the local reputation that his steadiness, ingenuity, and sturdy integrity of character at length obtained, that about the year 1812 he was intrusted by Lord Ravensworth, and the Killingworth colliery proprietors, with money to make a practical trial of a locomotive engine, on which his time and thoughts had been for some time engaged. The engine was built and tried on the Killingworth tramway in the month of July 1814, and from this date the future railway engineer became in reality what he had himself anticipated at a much earlier period, viz., 'a made man for life.' His name and abilities became known over the whole of the Newcastle district. Engine stoking was left far behind, he became viewer at a colliery and engine-wright, was employed in laying down a tramroad at Hetton, and then, for the modest sum of £115, undertook to execute the survey for a proposed tramway, or railroad, from Stockton to Darlington, and afterwards became principal engineer to that line, to which we must now for a moment turn our attention.

For many years previous to the year 1816, much discontent had arisen in the commercial world, especially in the northern districts of England, owing to the extravagant charges and

general inefficiency of the navigable canal service as a means of transport. The canal proprietors, possessing a seemingly secure monopoly, had become arrogant and careless, or, it may be, unobservant of the growing requirements of trade. In the coal districts of Durham an extensive field was that situated a short distance north-west of Darlington, from whence coals were carried to Stockton, a place in communication with the sea, near the mouth of the Tees, and in this district the difficulties of transport had long been seriously felt. The construction of a canal had been proposed, but, after long dispute between the proprietors of Darlington and the merchants of Stockton, had been laid aside. The Stockton merchants, adopting the motto *Meliora speramus*, convened a public meeting to discuss what could be done, and a special committee was appointed to investigate the relative advantages of a canal or a tramway; still, nothing was effected; but the friends of some form of tramroad gradually gained the ascendant. Their proposals were modestly limited to a timber road, over which the traffic could be drawn either by horses or by ropes attached to the winding gear of stationary engines, and it was estimated that one horse could lead downwards from Darlington to Stockton ten tons of coal, and in returning about four tons of load, exclusive of the weight of the vehicles. No idea of conveying passengers was dreamt of.

A company was at length formed towards the end of the year 1816, and George Stephenson, who had been engaged on the preliminary surveys, was appointed engineer to the proposed line of tramway, or railway, and lost no time in urging upon the promoters the employment of iron rails in the place of wood. The raising of the requisite capital was only effected with extreme difficulty, principally through the subscriptions and exertions of the wealthy Quaker families of the neighbourhood. George Stephenson strove hard to impregnate the directors of the project with his own sanguine views as to the certain success and economy of steam locomotion, but the merchants and leading men of the district regarded his proposals with suspicion and ridicule, and persistently closed their purses. The capital, however, was at length raised, and the company went to Parliament, not indeed with the declared

intention of employing locomotives for the work of transport, but desiring only powers to provide 'for the making and maintaining of the tramroads, and for the passage thereon of wagons and other carriages by men and horses or *otherwise*.'

So great was the opposition that on three occasions the bill was negatived, and it was not eventually passed until the year 1821. On Tuesday, the 27th of September 1825, the Stockton and Darlington Railway was formally opened.

The most influential friends and advocates of this comparatively insignificant line of railway, which practically solved the great question of improved transport, were the Quaker family of Pease. One day in 1821 George Stephenson had a momentous interview with Mr. Edward Pease; induced him to visit Killingworth, where he could see for himself what a locomotive working on iron rails could do, and from that hour it was mutually decided by these two strong and energetic men that every nerve should be strained to obtain powers to work the traffic of the Stockton and Darlington line by steam locomotives. Fifty years later, on the occasion of the jubilee celebration of the Stockton and Darlington Railway in 1875, Mr. Henry Pease remarked, that it was surprising that the world should have been so many thousand years old 'before it was thoroughly known to what extent two simple parallel bars, laid at a given distance apart, would facilitate the intercourse of mankind.' He detailed in an amusing speech some of the early struggles and difficulties of the project. How one of its opponents had said, 'It is folly; you will never get your wagons to travel on the railway.' And another, 'I am sorry to find the intelligent people of the North gone mad on the subject of railways,' or 'It is all very well to spend money, it will do some good, but I will *eat* all the coals your steam-railroads will carry.' 'He did not live,' said Mr. Henry Pease, 'until the year 1874 when 127 millions of tons of coal were carried by railway, and I hope he had many good dinners on more digestible materials.'

At the opening of the line in 1825, in the presence of a great concourse of people, a train was formed, weighing 80 tons, consisting of one of George Stephenson's engines, 'No. 1,' driven by that able engineer himself, six wagons laden with

coals and flour, a covered 'coach' containing directors and proprietors, twenty-one coal-wagons fitted up for passengers, and filled by a promiscuous crowd, and lastly, six more loaded coal-wagons. This train, gaily decorated, started off with a horseman carrying a flag at its head. Crowds of people stood along the line, or ran on foot after the train, and gentlemen on horseback galloped across the fields to keep up with it. The speed was gradually increased to 10 miles an hour. At a favourable part of the road Stephenson determined to try the powers of his engine, he called upon the horseman with the flag to get out of the way, put on steam, and now 12 miles an hour, then 15 miles an hour were attained, and the runners of foot and the gentlemen on horseback were soon left far behind. 'When the train reached Darlington it was found that 450 passengers occupied the wagons, and that the load of men, coals, and merchandise amounted to about 90 tons.'¹

The subsequent results of the opening of the Stockton and Darlington Railway were surprising in every way, both to the proprietors and to the public. It had not been intended to employ the line for the conveyance of passengers; but the demand for carriage became so great that the company was soon induced to provide the necessary accommodation. In October 1825, it was announced that the company's 'coach' called the 'Experiment' would run from Darlington to Stockton and back, every day except Sunday, making one journey each way per day. Each passenger was allowed to travel and take one package not exceeding 14lbs. in weight, at a fare of one shilling.

George Stephenson's interesting engine, 'No. 1,' which had cost the modest sum of £500 only, was before long supplemented by other improved and stronger engines, and the roadway itself was quickly brought into better order. As the traffic increased a double line was laid, and trains weighing up to 92 tons were run daily at 5 miles an hour. The rate for the carriage of merchandise per ton was lowered from 5d. to $\frac{1}{4}$ th of a penny per mile. The cost of the carriage of minerals dropped from 7d. to 1½d. per ton per mile, and the price of coals for shipment fell from 18 shillings to 8 shillings and six-

¹ *Our Iron Roads*, by Frederic S. Williams, London, 1888.

pence per ton. As a consequence, the export trade rapidly increased, and the company's shares rose to £40 premium each, 'with plenty of buyers, but no sellers.'

The small Stockton and Darlington Railway was constructed and carried through by a body of energetic local capitalists; but the first line made by capital raised in the public market and for the public benefit—and which in a more special manner marks the birth of the railway system of England and of the world—was that between Liverpool and Manchester. It was in the preliminary struggles of this railway, from its first inception to its final successful accomplishment, that the decisive battle between the new system of locomotion and the united forces of ignorance, prejudice, and avarice, was fought out and won; and it was this decisive victory that threw open the doors of public enterprise, and inaugurated the modern era of railways.

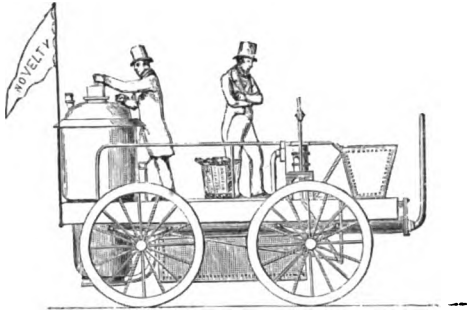
To recount the absurdities and extravagances, the ignorance, narrow-mindedness, and prejudice, displayed in this great encounter would probably raise a smile; whilst to picture the rapaciousness and greed aroused by alarmed self-interest, or by calculated avarice, would excite indignation and disgust. The interested reader will find the minutest particulars duly recorded in Dr. Smiles' *Lives of the Stephensons*. Early alive to the serious defects of transport and the dawning of a new era, the merchants of Liverpool in the year 1821 formed themselves into a committee, drew up a scheme, and established a company for the construction of a tramroad or line of iron rails between Liverpool and Manchester, wisely leaving open, as too contentious and combustible a question, the motive-power to be employed. So great, nevertheless, was the alarmed opposition of ignorance and vested interests, that it was only by stealth, by many ingenious stratagems—in the darkness of the night—or by actual armed force, that the first surveys could be made.

It was not until the end of four years, viz., in April 1825, that the first Parliamentary Bill, after a desperate struggle in committee with canal proprietors and landowners, extending over 38 days, was at length 'put and *negatived*' amidst the frantic cheers of its opponents. Nothing daunted, the projectors carried out fresh surveys, appeasing some of the most

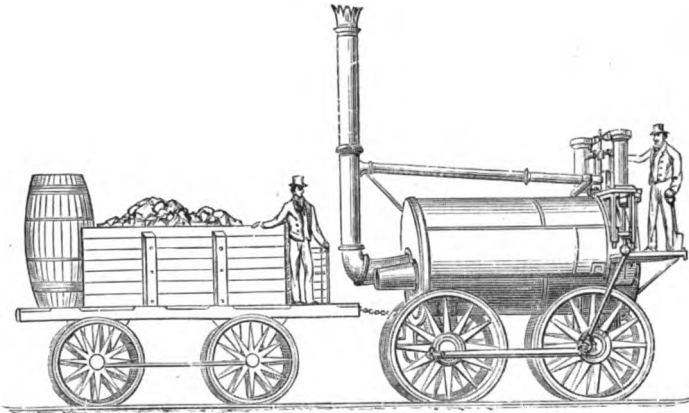
powerful opposition, and made a renewed application to Parliament in the ensuing year, when the third reading of the bill was at last carried by a majority of 88 to 41, at a cost to the company of £27,000. George Stephenson was at once appointed principal engineer, at a salary of £1000 a year. The works were vigorously prosecuted, and the line, in spite of many severe and unprecedented difficulties, was opened for public traffic on the 15th September 1830.

The question of motive-power to be employed on the new railway was virtually decided by the company's selection of their chief engineer. George Stephenson, assisted by his able son, had devoted himself now for many years to the perfecting of the locomotive-engine, and so numerous were the improvements he had devised and introduced, that the superiority of the locomotive for purposes of traction over fixed engines was now scarcely disputable. In the early part of the year 1829, the directors of the Liverpool and Manchester Railway appointed a committee of experts to inquire into the relative merits of locomotives and stationary engines, and, as the final result of the recommendations of this committee—who had visited the tramroad systems of the North of England, and had thoroughly investigated the different methods of motive power there employed—it was decided to publicly offer a premium of £500 for the best locomotive that might be brought forward by manufacturers, to compete under certain fixed regulations, the principal of which were:—That the engines should consume their own smoke; that if they weighed 6 tons they should be capable of drawing a train of 20 tons weight, including tender, at a speed of 10 miles an hour on a level railway; that each engine should have two safety-valves—one beyond the control of the driver; and that the height of the engines, including chimney, should not exceed 15 feet. Lastly, it was stipulated that the price of the engine was not to be more than £550.

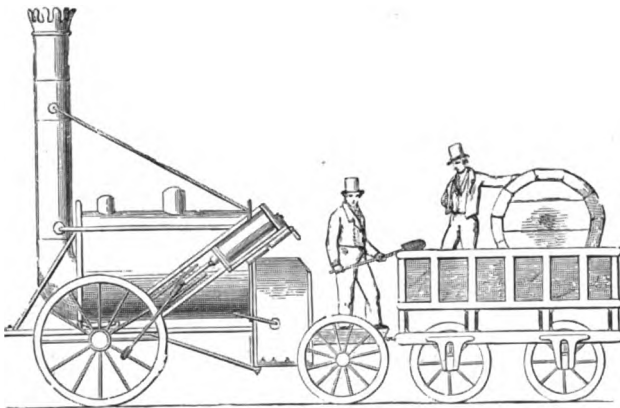
Only three locomotives entered the lists, viz., the 'Novelty,' by Messrs. Braithwaite & Ericson; the 'Sans Pareil,' by Mr. T. Hackworth; and the 'Rocket,' by Mr. George Stephenson. It was well understood that the prize of the competition was in reality the construction for the company of its entire stock



THE NOVELTY.



THE SANS PAREIL.



THE ROCKET.

of engines, and each competitor had strained every nerve to ensure the success of his machine. The merits of the respective engines were to be decided by the directors, assisted by three selected experts. On the day appointed for the trial, a level section of line about $1\frac{1}{2}$ miles long was marked off, over which each engine in turn had to travel backwards and forwards ten times, making a total 'run' of 30 miles. The 'Novelty' succeeded only in passing twice over the distance, when the joints of the boiler gave way. The 'Sans Pareil,' on examination, was found not to be in strict accordance with the conditions; but it was decided that a trial of it might be made. After passing over the measured course eight times, the pump that supplied the boiler failed, and ended the experiment. The 'Rocket,' with a load of 17 tons attached, twice performed the distance of 30 miles; the first time in two hours and a quarter, and the second in two hours and seven minutes. The maximum speed attained by it was estimated at 30 miles an hour, and the average speed was about 14.

The great superiority of this engine over every other that had hitherto been made was due:—First, to the introduction by George Stephenson of a tubular form of boiler, consisting of an arrangement of tubes passing through the water-space, by which a very large heating surface was provided; and secondly, to the admirable contrivance of the 'steam-blast,' which directed the waste steam, after performing its main work in the cylinders, into the chimney of the engine, thus creating and maintaining during the whole time of working, a powerful draught, which secured a more rapid combustion of the fuel in the furnace, and generation of steam in the boiler. The success of the 'Rocket' was complete, and George Stephenson was appointed to build the engines for the company, which he continued successfully to do up to the time of his death in 1848.

The 'Sans Pareil,' although beaten in consequence of a trifling accident in this particular trial, was, nevertheless, a very remarkable engine, and probably but little inferior to the 'Rocket,' notwithstanding that the latter contained the germ of those improvements which afterwards guaranteed the success of the locomotive engine.

The 'Sans Pareil' for many years after the trial did a great deal of excellent work on the 'Bolton and Kenyon Junction Railway,' running as much as 120 miles a day for years.

The successful working of the Liverpool and Manchester Railway led to the immediate construction of the line between London and Birmingham—the parent of the modern 'London and North-Western' system, and let loose a flood of railway enterprise throughout the country, until the present network of railways was gradually built up. It must not be supposed, however, that the early lines of which we have been speaking were in any way comparable with the comfortable and well-equipped railways of the present day. The roads were hard, rough, and uneven, owing to the employment of unyielding stone blocks, instead of the elastic timber and other sleepers now used, and to the lightness of the rails and fastenings. Instead of the luxurious carriages of present railways, passengers had to ride in what were little better than open trucks, exposed to the inclemency of the weather, from which, as we may read, they occasionally overbalanced themselves and fell out, whilst the trains were in motion, or the roughest possible kinds of covered 'coaches' were provided for the higher class of passengers. The station accommodation was of the scantiest kind, and the trains, running at an average speed but little superior to the fastest coaches then on the roads, were few and far between, and started or arrived at their destinations at all sorts of uncertain and irregular intervals. But from the year 1830, every year, and almost every month, witnessed some improvement, either in the road, in the carriages, the engines, or in the service of the railway, until the comforts and security of modern travelling were gradually attained. Nor must it be imagined that the ultimate term in railway improvements has even yet been approached.

In concluding this rapid sketch of the rise of the railway system in England, we cannot refrain from quoting a few words of a speech delivered by George Stephenson in the year 1844, on the occasion of the opening of the 'Newcastle and Darlington Railway,' containing, as it does, so many interesting references to his career. 'Yes,' he said, 'Lord Ravensworth and the Killingworth owners were the first parties that

would intrust me with money to make a locomotive engine. That engine was made 32 years ago. I said to my friends that there was no limit to the speed of an engine, provided the works could be made to stand. In this respect great perfection has been reached, and in consequence a very high velocity has been obtained. In what has been done under my management, the merit is only in part my own. I have been most ably assisted and seconded by my son. In the earlier part of my career, and when he was a little boy, I saw how deficient I was in education, and made up my mind that he should not labour under the same defect, but that I would put him to a good school, and give him a liberal training. I was, however, a poor man; and how do you think I managed? I betook myself to mending my neighbours' clocks and watches at night, after my daily labour was done, and thus I procured the means of educating my son. He became my assistant and my companion. He got an appointment as under reviewer, and at night we worked together at our engineering. I got leave to go to Killingworth to lay down a railway at Hetton, and next to Darlington; and after that I went to Liverpool to plan a line to Manchester. I there pledged myself to attain a speed of 10 miles an hour. I said I had no doubt the locomotive might be made to go much faster; but we had better be moderate in the beginning. The directors said I was quite right; for if when they went to Parliament I talked of going at a greater speed than 10 miles an hour, I would put a cross on the concern. It was not an easy task for me to keep the engine down to 10 miles an hour; but it must be done, and I did my best. I had to place myself in that most unpleasant of all positions, the witness-box of a Parliamentary committee. I could not find words to satisfy either the committee or myself; some one inquired if I were a foreigner, and another hinted that I was mad. I put up with every rebuff, and went on with my plans, determined not to be put down. Assistance gradually increased—improvements were made—and to-day, a train which started from London in the morning, has brought me in the afternoon to my native soil, and enabled me to take my place in this room, and see around me many faces which I have great pleasure in looking upon.'

CHAPTER II

PRINCIPLES OF CONSTRUCTION

Principles of construction of railways—Preliminary—Canals and railroads—The 'idea' of a railway—Expense of reduction to practical form—Embankments—Viaducts and cuttings—Land purchase and compensations—Opinions of engineers in early days of English railways—Choice of route and deviations—Survey and levels—'Formation' and grading lines—Plans and sections—Acquisition of land—Legal regulation of powers of railway promoters—Compensation for damage or injury to property—Parliamentary plans and sections—Alterations—Legal knowledge essential to the Engineer—The Board of Trade—Powers—Maxima and minima dimensions—Superiority of India in uniformity—Important regulations of the Board of Trade.

To understand rightly the principles involved in the application Preliminary. of railways to the purposes of land locomotion, it is necessary to consider for a moment what are the natural resistances which obstruct freedom of movement—and especially rapidity of movement—of any kind. These are three in number, viz., Terrestrial attraction, resistance of the atmosphere, and *friction*. It is beyond any human effort to remove either the first or second, but the last is capable of being so largely reduced as to become practically non-existent. It is therefore principally by the application of human ingenuity to the reduction of the resistance of friction, that the rapidity of motion attained on a line of railway has been rendered possible. On any form of common road the resistance offered by friction to the rapid draft of heavy loads can only be reduced to a certain limit, which is very soon reached. Moreover, the expense of effecting the reduction is incurred over a maximum surface. Hence, before any further advance can be made, something altogether new must be devised. In the history of locomotion this something new first took the form of a yielding and mobile *water-road*, in place of a hard macadamised surface. By the

introduction of navigable canals the resistance of friction to the motion of heavy bodies was greatly reduced, and an important step in advance was made; but the most notable, the most convenient, and on the whole the most economical solution of the problem, was soon found in the tramway, and its rapid subsequent development into the true railway.

The 'idea' of a railway is to furnish two parallel lines of hard, smooth, and unchanging surfaces for wheels to roll upon—no expenditure, so far as concerns reduction of surface friction, being required on any other part of the road, except on those two very narrow surfaces immediately under the rim of the wheels. It is a very simple idea!—but is one of the last that took possession of the human mind—once seized, however, mechanical difficulties only remained, which were soon surmounted, and, accordingly, two lines of strong straight bars of iron— $2\frac{1}{2}$ to 3 inches wide, and 4 to 6 inches deep, laid and firmly supported at a little distance above the general ground surface—were placed at an even distance apart, so as to suit the width of the vehicles; the separate lengths of iron bar were neatly joined together, end to end, and spiked or secured to blocks of wood or stone at short intervals; and, lo! the simple idea was at once embodied in the form of a railway, or iron road, which immediately opened an economical pathway for the introduction of steam, or any other source of power that man might wish to employ for purposes of traction and locomotion.

Simple, however, as the idea of a railway is, its realisation in practical form is often attended with prodigious expense. The natural irregularities of the earth's surface must, in one manner or another, be reduced or removed. Low parts, and often deep valleys, must be filled up by embankments or viaducts. High parts must be cut through by cuttings; or, if the height is too great, must be bored through by tunnelling. Rivers and watercourses, however large or small, must be crossed by bridges—all with the one object of reducing the whole route to one uniform and moderately level surface, so as to reduce friction and prevent loss of tractive power by operating against the action of gravity. The land also on which the railway is constructed has to be purchased, often at great cost, and compensation paid for interference with the

rights of property. The great strength and solidity required in all constructions connected with the road surface of railways, in order to withstand the impact of enormously heavy loads moving at those high velocities which the power of steam and the smoothness and evenness of the rails render possible, is the cause of great outlay, and imposes on the railway engineer works and operations of the greatest magnitude and responsibility.

The general principles of the construction and working of a line of railway are virtually the same in all parts of the world. We will therefore, in the first instance, indicate a few of these general principles, irrespectively of country or locality, so as to familiarise the reader with the various nature and extent of the principal operations undertaken by the railway engineer. We will then briefly glance at the introduction of railways into India, and note some of the special peculiarities of their construction and working in that country, illustrating a few of the more remarkable railway structures which have been carried out, and supplying the reader with such information as to the working results of Indian railways as may be of general interest.

In the early days of English railways, the decision as to the best route for any proposed line was often very summarily disposed of. Given the chief termini, it was said, 'make your line as straight and direct as possible from one point to the other; disregard the smaller centres, because when once the line is open people and trade will flock to it as bees to a honey-pot, and in a few years it will run through a rich and populous district, which it has itself created. If necessary, feeders and branches can be made from any towns of importance, but keep to the shortest and most direct route for your main line. It is the through traffic that will *pay*; the local traffic, which is of less importance, will create itself.' These views, however, were soon modified. Contrary to what was supposed, it was found that the short local traffic paid as well, or even better, than the long through traffic, and that it was more economical to allow extra length to a main line rather than to multiply branches.

The selection of the exact route to be taken by any proposed

line of railway is often one requiring very great skill and judgment, so as fairly to balance economy in construction with commercial advantages and public convenience. Mr. Robert Stephenson, whilst engaged in settling the precise demarcation of the London and Birmingham Railway, is said to have walked over the whole 113 miles of distance between these towns no less than twenty times. After the position of all obligatory points has been determined, the first studies for a line of railway usually result in the alternative of two or three possible routes. Trial shafts and borings are then sunk in order to ascertain the geological formation of the country to be traversed; closer trial levels are run, and approximate sections are made, so as to exhibit on paper the main inequalities of the ground, and to indicate the probable mass of the heavy embankments or cuttings required. The consideration of all merely local deviations, necessary for avoiding expensive properties in the country, if not in the neighbourhood of cities and towns, is for the present postponed; but the crossing-places of the principal rivers and streams are fixed, so that they may be as economically situated as possible. When all the data necessary for forming an accurate judgment has been collected, the engineer responsible for the project balances the evidence in favour of or against the various trial routes, and proceeds to mark out on the ground the exact line which he, or the promoters advised by him, have finally decided upon.

This route must now be very carefully adjusted in detail and then surveyed, and a line of close levels must be taken along the centre line—which has been deeply nicked or scored on the ground—on stout pegs driven at intervals of, say, every chain's length. The survey will determine by actual measurement the exact form and dimensions of all the natural or artificial features of the ground to be occupied by the railway, and for some distance beyond it on either side, so that these features can be represented graphically to scale on paper. The levels taken will closely show all the various elevations and depressions of the ground surface above some fixed point or 'datum,' usually the mean level of the sea, and when these levels are plotted in continuous order on a roll of paper, and the surface of the ground is traced through them, the engineer will be enabled to

draw on the 'section' thus formed what are called the 'formation' or 'grading' lines—that is, those lines representing the future surface levels of the railway. Where land for depositing soil, or for excavating material, is very valuable, he will endeavour, as far as possible in drawing these lines, to reduce the necessity of its acquisition by balancing the total amount of cuttings and embankments over given lengths of the section, so that the material from the former will, as nearly as possible, serve to build up the latter; but the high or low level of the formation lines will be principally determined with reference to the amount of earthworks involved, and the necessity for keeping the rate of inclination within that maximum limit which it has been deemed expedient on various grounds to adopt.

This very important matter of 'grading' the line having been finally determined, the engineer proceeds to plan out and design all the works and structures required from one end to the other of the railway, whether large viaducts, smaller bridges, tunnels, or other necessary works, and the exact position, main dimensions, and serial number of all such structures will be carefully marked on the plans and sections. He will determine station accommodation of all kinds, whether for the service of the railway itself or for the public convenience, and will design, or provide for, all matters appertaining to the detailed working of the line, such as signals, telegraphs, engine accommodation, workshops, housing of staff, and all the thousand minor requirements of a working railway. In the meantime the quantities and value of all items of labour and materials that will enter into the construction of any and every part of the line are taken out and scheduled in regular order, until one general 'estimate' is framed, which, according to the skill and experience of the engineer, will represent, with greater or less approximation, the true initial cost to the proprietors of the proposed works.

The construction of a line of railway necessitates the acquisition of a continuous strip of land to be assigned for its exclusive use and occupation; a strip, moreover, which in the majority of cases inconveniently disconnects and severs from free inter-communication the adjoining lands on either side of it. There are consequently but few cases where a railway can be con-

structed without a more or less serious interference with private rights, or without subjecting the owners of adjoining properties to some degree of loss or inconvenience. Hence in all civilised countries it has been found necessary to safeguard the legitimate rights of property, and to regulate and define the powers to be granted to railway promoters by means of legislative enactments.

These enactments proceed on the assumption that the construction of any line of railway is for the public advantage, and—this assumption being proved—that the particular rights of private owners should give way to the general good of the community. In accordance with the provisions of the various railway enactments, companies may obtain legal powers to construct, work, and maintain a line of railway, and authority to acquire compulsorily such lands and other private property, as may be shown necessary for the occupation of the line, stations, or approaches, but these powers and privileges are only conferred under most stringent regulations, framed to protect the rights of private persons which may be interfered with by the construction of the line, and to ensure them adequate compensation. Nor is this compensation only a pecuniary one. Owners are empowered to require from the railway company the construction of all such reasonable works and conveniences which it can be shown will neutralise, or mitigate, the damage or injury sustained.

Before legal powers are granted, a railway company has to satisfy Parliament—or other corresponding Government authority—that the construction of the contemplated railway will really be a benefit to the public, and that it will be constructed and worked in such a manner as to be safe and efficient, both as regards the general public, and the adjoining proprietors or occupiers.

The engineer of a railway has, therefore, in the first place, to prepare for submission to Parliament, accurate land plans and books of reference, showing exactly what lands the railway company propose to acquire, within certain permissible limits of deviation. He has, in addition, to submit sections of the proposed railway, showing all gradients, curves, cuttings, embankments, tunnels, viaducts, bridges, or other works, and in order

to ensure perfect uniformity, all these plans, sections, and documents of every kind are required to be prepared and submitted in one and the same rigidly specified manner, whether with regard to scale of drawings, or in every other particular, instructions for which are laid down in minute detail in the 'standing orders' of Parliament, which must be precisely adhered to, on pain of absolute rejection of any application for powers. Moreover, when powers are at length obtained, no subsequent alterations, whether of route, gauge, gradient, curves, or structures of any kind are admissible, except within the limits of stringent regulations expressly formulated. So greatly, in short, are railway and other engineering works governed and regulated by special legislative enactments, that a very considerable amount of legal knowledge is one of the first necessities of the professional engineer in almost every country.

In England, on the completion of a line of railway, it is necessary that it be found in accordance with the special requirements of the 'Board of Trade,' and if on inspection by the officers appointed by this Board it is found otherwise, the opening of the railway for passenger traffic may be postponed from month to month until such requirements are complied with, or if the line be opened for passengers without the required permission, a legal penalty of £20 a day for every day during which the line remains open without permission may be enforced under the provisions of an Act of Parliament. In England, therefore, if a railway company prefers the alternative of paying the sum of £20 a day, a new passenger line may apparently be opened without any inspection whatever, and the Board of Trade appears to have no power absolutely to order the closing of a line from any cause.

After a line has once been opened the Board of Trade has no further powers, either of inspection, or to order any improvements, or to interfere in any way with the working of a line—except by making suggestions or recommendations—unless additional new works are undertaken, in which case these additions are subject to inspection, and the alteration of such of the old works as are in connection with, and dependent on them, may then be enforced.

According to the present state of English procedure in this particular, it would appear that the Board of Trade may practically enforce on new lines all the latest improvements and best precautions warranted by the most recent scientific advancement, but at the same time an *old* line—on which in course of years an enormous traffic has grown up, far surpassing that likely to be attained on any new line, at least until such time as the new precautions enforced have themselves been superseded—may continue to be worked in the old manner without the use of the new precautions or improvements. In practice, however, although the anomaly in legal powers is great, the evil is of less importance than might be supposed, inasmuch as in nearly all cases railway companies are so strongly interested in the safe working of their lines, as to be willing eagerly to adopt every possible new precaution and improvement that presents itself as practically valuable. The deficiency in the legal powers of the Board of Trade are perhaps most strongly felt in the case of old lines on which—owing to various causes—the older dimensions of fixed structures in relation to changes in rolling stock have in course of time brought about a more or less dangerous state of things, which, as they cannot be altered without incurring heavy expense, are exceedingly liable to be unattended to until some serious accident has resulted. An absolute and rigid uniformity in the relative maxima and minima dimensions of contiguous structures and rolling stock, on every line of a given gauge, is a matter which was greatly neglected in the early days of railroads in England. In India, on the other hand—as we shall see later—this important particular has from the first been carefully attended to, and Indian railways, so far as uniformity in standard dimensions are concerned, are probably the most perfect in the world.

The regulations of the Board of Trade, with respect to the requirements necessary on the opening of new lines, are subject to additions or alterations from time to time, and are issued in circular form for the guidance of its own officers, and for the information of the engineers engaged in the construction of new lines of railway. The inspecting officers have the power of modifying these regulations to meet particular cases, but in

the main the certificate of the Board of Trade will not be given unless the regulations are strictly observed.

The following is a memorandum of some of the more important of these regulations to which English railway companies opening new lines are required to conform, and which—so far as applicable—have also been adopted on all Indian railways—

1. The requisite apparatus to be provided at the period of inspection, for ensuring an adequate interval of space between following trains.

2. Home signals and distant signals for each direction to be supplied at stations and junctions, with extra signals for such sidings as are used either for the arrival or for the departure of trains.

3. The levers and handles of points and signals to be brought close together into the position most convenient for the person working them, and to be interlocked. The points to be provided with double connecting-rods. The levers of the points to be sufficiently long to enable the pointsman to work them without risk or inconvenience, and not to be placed on the ground between the lines of rails. All signals which are worked by wire should be so weighted as to fly to 'danger' on the fracture of the wire.

4. Facing points to be avoided as far as possible.

5. It being necessary that a uniform system of signals should be adopted on all railways, the semaphore arms should, at stations and junctions where there is more than one on one side of a post, be made in future to apply, the first or upper arm to the line on the left, the second arm to the line next in order from the left, and so on. In the case of sidings a low and short arm, distinct from the arm or arms for the passenger lines, may be employed. Clocks should be placed in conspicuous positions for the use of the signalmen.

6. The signal-handles and the levers of the points should be brought together under cover upon a properly constructed stage, with glass sides enclosing the apparatus. They should be so arranged that while the signals are at danger the points shall be free to move; that a signalman shall be unable to lower a signal for the approach of a train until after he has set the points in a proper direction for it to pass: that it shall not be possible for him to exhibit at the same moment any two signals that can lead to a collision between two trains; and that, after having lowered

his signals to allow a train to pass, he shall not be able to move his points so as to cause an accident, or to admit of a collision between any two trains. The facing points should be provided with apparatus which will ensure the points being in their proper positions before the signals are lowered, and which will prevent the signalman from shifting the points whilst a train is passing them. Every signalman should be able to see the arms and lamps of his home, as well as his distant signals, and the working of his points. The fixed lights in the signal-cabins should be screened off, so as not to be mistakable during fogs for the signals exhibited to control the running of trains.

7. The junctions between passenger lines and any sidings should be protected by a home signal and a distant signal in each direction.

8. When a junction is situated near to a passenger station, or is connected with goods or mineral sidings, the platforms and sidings should be so arranged as to prevent as far as possible any necessity for shunting over the junction.

9. When two single lines meet, the junction should, in ordinary cases, be formed as a double-line junction.

10. The lines of railway leading to the passenger platforms to be so arranged that the engines shall always be in front of the passenger trains as they arrive at and depart from the station.

11. Platforms to be continuous, and the descent at the ends to be by ramps, and not by steps. Pillars or columns for the support of roofs, or other fixed works, not to be nearer to the edge of the platform than 6 feet.

12. No station to be constructed on a steeper gradient than 1 in 260. When the gradient at a station is unavoidably steeper, and the line is double, and when danger is to be apprehended from vehicles running back, a catch siding, with points weighted for the siding, should be provided farther down the incline than the passenger platform and goods yard, to intercept runaway vehicles. When the line is single, a second line should be laid down, a second platform constructed, and a catch siding similarly provided.

13. The upper surfaces of the wooden platforms, of bridges, and viaducts, should be protected from fire.

14. No standing work (other than a passenger platform) should be nearer to the side of the widest carriage in use on the line than 2 feet 4 inches at any point between the level of 2 feet 6 inches above the rails, and the level of the upper parts of the highest carriage doors. This applies to all arches, abutments, piers, sup-

ports, girders, tunnels, bridges, roofs, walls, posts, tanks, signals, fences, and other works, and to all projections at the side of a railway constructed to any gauge.

15. The intervals between adjacent lines of rails, or between lines of rails and sidings, should not be less than 6 feet.

16. At all level-crossings of turnpike and public roads the gates should be so constructed as to close across the railway, as well as across the road, at each side of the crossing. They should not be capable of being opened at the same time for the road and the railway. Wooden gates are considered preferable to iron gates for closing across the railway.

17. The fixed signals attached to the gates at the level-crossings should be placed in convenient positions for being seen along the railway, as well as along the road. When a level crossing is so situated that an approaching train cannot be seen from a sufficient distance, distant signals (which may both be worked by one lever) should be supplied.

18. Mile posts, and quarter and half mile posts, and gradient boards, should be provided along the road.

19. Tunnels should in all cases be constructed with recesses for the escape of platelayers.

20. Viaducts of timber and iron should be provided with man-holes and other facilities for inspection, also with hand-rails and with projecting platforms for the protection and escape of the platelayers.

Numerous regulations as to the strength and details of construction of works in iron are also laid down.

CHAPTER III

PRINCIPLES OF CONSTRUCTION

Formation of line—Turning the first sod—Commencement of practical construction—Temporary lines—Main divisions of work—Meaning of the term ‘permanent way’—Construction of earthworks—Gradients—Curves—Elevation of outer rail—Steep gradients and sharp curves on mountain railways—A Welsh engine-driver—Construction of a cutting—Width of formation—Principal difficulties met with in cuttings—Importance of drainage of earthworks—Tunnels and tunnelling—The formation of embankments—Settlement—Viaducts, bridges, and culverts, size of openings—Magnitude of some examples of European and American railway structures—Tunnels and railway bridges—Service bridges and level crossings—Fencing—Indian and American practice.

‘Formation’
of the line. THE actual commencement of the works on an important length of new railway, is generally considered a fitting occasion for some public display of special satisfaction and rejoicing on the part of all friends and promoters of the undertaking who have successfully pioneered the project through its difficult and dangerous periods of incubation and parliamentary contest, and the ‘cutting of the first sod’ is often celebrated with much time-honoured ceremony, followed by that liberal consumption of ‘good cheer,’ without which no true Anglo-Saxon can regard any undertaking as properly inaugurated. The interest of some distinguished personage of high degree is enlisted, or the services of the highest available local magnate are retained. The directors and their friends and guests—probably including all the leading nobility and gentry of the neighbourhood—duly assemble at time and place appointed. A resplendent wheelbarrow and spade of polished wood and shining silver is formally presented by the chairman to the distinguished personage, or local magnate, as the case may be, who is earnestly invited in a flattering speech to convert him-

self—ceremonially—into a navy for a short space. Graciously assenting, the distinguished personage divests himself of his outer garment, and if very enthusiastic rolls up his shirt sleeves, and plunges the elegant and costly spade into the virgin turf; the wheelbarrow is duly filled, is rolled off along the appointed plank-way, and is gravely overturned amidst the cheers of the assembly. The magnate retains the valuable implements as a worthy trophy of the occasion, and the party adjourn to the more substantial features of the celebration. The date of commencement of the new railway is thus for ever marked in the public annals of the country.

The practical construction of the new line, by the contractor or other agency employed, is always commenced at those parts of the route where the greatest quantity of work has to be done, and the operations throughout are taken up in such order that the whole of the works, or those on a certain defined portion, may be completed simultaneously. The lighter portions of the road connecting the heaviest cuttings and embankments are, however, at once brought to proper level, and temporary lines of rails are laid down to facilitate the transport of material from the former to the latter. Labour and working plant is collected at the sites of all the larger viaducts, bridges, tunnels, or other heavy works, and arrangements for getting in the deepest and most troublesome bridge or other foundations are rapidly pushed forward, until in a very short time the greater part of the route of the new line presents a busy scene of life and activity.

The works on a line of railway are apportioned into three main divisions, respectively called, the 'formation' of the line, the 'ballast and permanent way,' and 'station buildings and machinery.' The 'formation' level of a railway is the finished top of the line of embankments, the bottom of cuttings or tunnels, and the floor level of viaducts or bridges. Above this level is placed the 'ballast,' and in and on the ballast is laid the 'permanent way,' consisting of the sleepers, chairs, rails, fastenings, points, and crossings, in short, all those materials which form the actual road on which the engines and vehicles run. The term 'permanent' way serves to distinguish the completed road from the 'temporary' lines of way used by

contractors or others merely for carrying materials or facilitating construction. It is obvious that the main mass of labour and materials is comprised in the first of these three divisions, viz., the 'formation' of the railway, and of this division 'earthworks' form a very large item (the removal of all material, whether earth, gravel, or rock, being included in this term). In a vertical direction the construction of the 'earthworks' involves the formation of that uniform top surface which has been planned by the engineer to take the place of the irregular and uneven natural surface of the ground. This uniform surface will sometimes lie above the natural ground; sometimes below it, necessitating here an embankment or viaduct, there a cutting or tunnel. When completed, it will either be a *level* surface, or will have a certain degree of regular slope called a 'gradient.'

The traveller by railway by observing and reading the 'gradient boards' affixed at intervals along the side of the line can always discover whether he is going up hill or down hill, or along a level. Thus he may see an arm projecting forwards from a low post, in the direction he is travelling, having a slightly upward angle, and bearing, perhaps, a sign 1—350, meaning that the surface of the road is now rising uniformly at the rate of one foot in every 350 feet of distance. Presently he will arrive at another post, with arm projecting downwards in a reverse or backward direction, and marked in the same terms, but on the other or forward side of the post he will see another arm in a horizontal position, indicating that beginning from that point the road is now horizontal or level, and so on at every place where the slope of the artificial surface or 'gradient' changes he will find it duly recorded by the posts and arms. The object of these gradient posts is to inform the engine-driver of the nature and degree of the road inclination against him or in his favour.

Horizontally, or in plan, the construction of railway earthworks will always proceed in a straight line except at certain definite places where two straight lines will be joined together by a *curve* or curves. There are, therefore, two important matters to be carefully regarded by the engineer immediately engaged on the works, viz., the correct formation of the surface 'gradients,' and the accurate tracing and preserving the align-

ment of the various straight lengths and curves as exhibited on the plans. For a long time after the first introduction of railways it was held as the very first principle of construction that the running surface should be everywhere made as nearly level as possible—original outlay being held of secondary consideration as compared with the supposed subsequent economy of working. The original London and Birmingham Railway, and in some degree the Great Western, are examples of this mode of construction. On the former line no gradient exceeded 1 in 330, with the exception of the Camden Hill incline, which it was intended to work, and which for some years was actually worked, by a stationary engine.

It was conceded, however, after some experience had been gained, that a series of moderate undulations, or up-and-down gradients, although enormously cheapening original construction, do not result in any serious increase in working expenses; the power saved in the descending portions of the road compensating in great measure for the excess on the rising gradients. Moreover, the enormous improvements in the capabilities and power of modern locomotives, permits gradients to be now adopted which a few years ago would have been prohibitory, and have enabled engineers to carry lines of railway over districts which in earlier days would have been regarded as economically impassable.

In an ordinary plain country the total length of curves on a line of railway will generally be very small as compared with the total length of the straight portion, the average degree of curvature will also be very much less than in a hilly district. In the infancy of railways, curves, unless of very large radius—that is, of very gentle curvature—were regarded with very much alarm. Under Parliamentary standing orders the necessity for curves of less than a mile radius (5280 feet) was required to be separately inquired into. It was supposed that the resistance offered by curvature of the line would be exceedingly great, and that the tendency of trains travelling at high speeds to continue their motion in a straight line, instead of following the curved track, would cause them to leave the rails, and lead to inevitable disaster. Experiments, however, did not confirm these apprehensions. It was found that the resistance offered

by curves having a radius down to 2500 feet, or even less, was hardly appreciable at any practicable rate of speed. By slightly raising the level of the outer rail on curved portions of the line an inward inclination was given to the moving vehicles, which largely counteracted the centrifugal force tending to cause them to leave the rails—just as the body of a circus horse galloping round a ring will, in proportion to his speed, be strongly inclined inwards towards the centre of the curvature. The amount of elevation given to the outer rail is found by calculation, and is dependent on the radius of the curve, the gauge of the railway, and the maximum speed of the trains. This expedient, combined with the lateral play or side movement allowed to the coned wheels—which will be more specially referred to when we are speaking of the permanent way—imparts to the vehicles travelling on a curve a certain degree of natural tendency to move in a circle, just as a cone placed on its side will roll in a circular path, and thus the amount of resistance and danger of leaving the track was reduced to a minimum, and the employment of curves of much smaller radius than those formerly allowed was rendered possible.

It is obvious that there are some situations, such, for example, as the approach to a terminus, or to important stations, over which the starting or arriving trains will always be moving at a very low rate of speed—where much sharper curves may with safety be introduced, than on middle sections of the line, travelled over with great velocity. The danger of very sharp curves is moreover increased in proportion as the inclination or ‘gradient’ is also great. Nevertheless, in mountainous districts the combination of exceedingly steep gradients and very sharp curves is commonly obligatory, and such lines can be safely worked with special precautions as to limitations of speed, or by the help of auxiliary appliances, such, for instance, as the cogged rail employed on the Righi mountain, near Lucerne. On Alpine railways, and in many of the mountain lines in America, the extent and degree of curvature now safely worked over without the use of extraordinary appliances and at ordinary speeds, would startle the timid and inexperienced first projectors of railways. In many of the more hilly districts of Wales mineral and passenger lines of narrow gauge have been

carried in and out of the intricate valleys of the country in a manner truly surprising. The long trains sometimes double round on themselves in such a manner that passengers from a window in a foremost part of a train will see the hindermost portion pass by them, moving in a direction contrary to their own motion. Series of sharp double reverse curves impart such a snake-like and winding aspect to these trains as almost to warrant the bold hyperbole of a certain Welsh engine-driver, who is asserted to have said that, one dark night, when he was new to the road, he was pulled up by the tail danger-lights of his own train.

Having now given our readers some particulars of railway 'gradients' and 'curves,' we may return to the earthworks of our new line in course of construction. As soon as the temporary line of rails in those lighter portions of the road lying between the heaviest cuttings and embankments has been laid, so that the material from the one may be trained to the other, gangs of workmen attack the face of the hill through which the cutting is to be carried, and soon a narrow passage or 'gullet,' just wide enough to receive a row of tip-wagons is formed and projected into the body of the hill, and into this gullet the temporary line is prolonged. The 'stuff' from the walls of the gullet is showered into the wagons, now lying just alongside, and as soon as they are filled they are led away, or are allowed to run down by their own impetus, if the inclination of the road is favourable, to the 'tip' of the neighbouring embankment.

Near the embankment end of the temporary road the line forks into two or more lines, forming 'sidings,' and the wagons descending or led from the cutting are run into one or other of these, and are made to discharge themselves singly over the embankment 'tip,' or it may be simultaneously over the sides. In the meantime a train of empty wagons is hauled by horses or engine-power, or is allowed to run back to the cutting; is filled in its turn, and is again sent off and emptied at the embankment. By constantly repeating this process the 'gullet' of the cutting is daily carried farther and farther into the hill, and the head or 'tip' of the embankment is advanced farther and farther into the valley.

The 'formation' approaches on either side of a cutting, and

in the greater part of a cutting itself, are, in order to minimise excavation, nearly always on some gradient, either in one direction only, or in both directions. If there is an inclination in both directions there will generally be a small intervening length of *level*, situated somewhere about the middle of the cutting. In this very common state of matters work can conveniently proceed from both sides of the hill at the same time, and the two gullets are prolonged until they meet in the centre. As the gullet is gradually widened out the temporary rails are pushed over so as to bring the wagons close to the wall of earth, and soon there is room for a second line of rails, enabling *two* trains of wagons to be loaded up simultaneously. Before long the gullet—now of the full bottom width of the cutting, but with vertical, or nearly vertical, sides—will be carried right through the hill, and the work of forming the side slopes will be commenced. Lines of planks and trestles will be formed, along which the crowd of navvies trundle their wheelbarrows, and discharge the contents into the wagons, or if the amount of ‘stuff’ from the cutting is more than sufficient to form the neighbouring embankment, the surplus material has to be ‘put to spoil.’ In this case, if the cutting is very deep, ‘runs’ of planks are sometimes formed up the sloping sides, and the men and barrows are hauled up the inclined planes by ropes, worked by horses from the ground-level above, and the surplus material is deposited on land specially provided for it, clear of the cutting. If, on the other hand, the quantity of material furnished by the cutting is insufficient to complete the embankment, the balance will either be run from other cuttings situated farther away along the line, or it will be obtained from side-cuttings, sometimes called ‘borrow-pits,’ dug on separate land alongside the unfinished portion of the embankment. Cases will often occur, when the distance and cost of transporting material from a cutting to the site of the nearest embankment, or the small size of the banks and cuttings themselves will, in relation to the value of land, render it more economical to procure *all* the earth for a bank from side-cuttings, and to place *all* the material from a cutting to ‘spoil.’ Every case will be decided by the engineer according to considerations of expense and rapidity of execution.

The *width* of the earthworks on a line of railway on the top, or 'formation' level, will depend upon varying circumstances, such as the number of lines of way, the gauge of the railway, and the length of the sleepers. To allow ample space for side drains or ditches, the width is always greater in cuttings than on embankments, the extra width depending on the size and particular kind of side-drains necessitated by local conditions of soil and quantity of water to be drained away.

The principal difficulties met with in heavy cuttings are due to the nature and inclination of the strata cut through, the behaviour of the material under the influence of exposure to weather and the presence of springs. Some materials will not be secure from all danger of slipping at almost any angle of slope, and the heavy expense of retaining-walls may have to be resorted to. Other materials require very flat slopes and expensive drainage-works before stability can be secured. Alternate strata of sand and clay, or shale, are especially dangerous or troublesome, particularly if heavily inclined and full of water. Other materials stand firmly at slopes of $1\frac{1}{2}$ or 2 to 1. Hard clean rocky strata, although expensive to cut through in the first instance, are often the most economical in the long run as the slope will stand almost vertical, imposing a smaller quantity of initial excavation, and little or no subsequent outlay.

The bottom or 'formation' level of cuttings is generally made with a fall towards each end, and side ditches, either excavated or constructed of masonry, are formed along the foot of the slopes, by means of which water is allowed to drain away. Catch-water drains, especially on sloping ground, will also be necessary along the summit level of cuttings to cut off flood water from the upper slope. *Water*, in fact, is the one great enemy of completed earthworks, and thorough and efficient drainage is everywhere imperative to prevent them from being slowly worn away and dissolved. No expense is spared by the judicious engineer in order to get rid as quickly as possible of all water from the neighbourhood of his earthworks.

The cost of cuttings increases in proportion to their depth, hence there is always a certain limit at which it becomes more economical to burrow, or tunnel underground, than to continue

the open cutting. This limit, although it will vary somewhat according to the nature of the material to be excavated, is in ordinary cases found to lie somewhere between 60 or 70 feet of depth. In very hilly or mountainous country—unless it so happens that a very great deal of material is required for high embankments, which cannot be obtained except from the cuttings—this economical depth is usually soon reached, and tunnelling will be resorted to with more or less frequency. Short tunnels commonly present little difficulty, and can be bored or ‘driven’ through a hill from end to end without intermediate shafts. Beyond a certain length, however, and in cases where the depth of the tunnel below the natural surface of the ground is moderate, it becomes economical to sink one or more shafts, or wells, along the centre line of the tunnel, from the bottom of which boring or driving the tunnel can be carried on in two directions. By this means the work is prosecuted with greater rapidity from more numerous points of departure.

Simple tunnelling through hard rocky materials is generally carried on by blasting, either by gunpowder, dynamite, or other explosive. A small opening or ‘heading’ is first pierced by the miners working in front, and others following them gradually enlarge the opening to the full section of the tunnel. In the softer kinds of material, however, the difficulty and expense of tunnelling is often greatly increased, especially if considerable quantities of water are met with. The whole of the sides and roof of the tunnel excavation as it advances will be shored up, or supported by temporary timber work, and a permanent lining of stone or brick masonry of a strength sufficient to withstand the pressure of the surrounding material will be necessary, every part of which will be set in durable cement, to prevent the percolation of water. Very heavy and expensive pumping operations may also be necessary.

In the formation of an embankment, the loose vegetable soil on its seat is first removed in order that a good and solid ‘bottom’ may be obtained for the load to be placed upon it, and all roots of trees, stumps, brushwood, and other matter which might by decay cause ultimate subsidence, are carefully cleared away. The earth, from the commencement, is deposited over the whole width of the intended bank, in order to avoid

the necessity of any subsequent lateral additions; always difficult to connect with the original mass. Wherever such additions are unavoidable the older work is cut into deep trenches, or steps, to prevent the newer work from slipping. The proper elevation and alignment of embankments is guaranteed by the previous erection of posts or brick pillars erected at convenient intervals along the centre line, and the correct level of the top of the finished earthwork is marked on these posts or pillars; but in actual construction an additional height, which will vary according to the nature of the material, is always allowed for the subsequent settlement or subsidence of the mass. As soon as the rough embankment is completed to full height, and has been allowed sufficient time for settlement under the influence of weather and of its own weight, the side slopes are neatly trimmed off, or made up to correct section. It is usual to leave the upper surface somewhat above the true 'formation' level, to allow for any further subsidence that may take place under the weight and vibration of the traffic. Wherever possible, the completed slopes of both cuttings and embankments are covered with good soil and are sown with grass seed, or turfed.

When deep valleys, rivers, large streams, or minor water-courses intersect the alignment of an embankment, the construction of great viaducts, bridges, or culverts becomes necessary, either to avoid the building up of enormous earthworks, or to provide a free passage for the water. Where embankments are high the smaller culverts are usually arched over at a low level, the line of earthworks being continued above them. In other cases the bridges or culverts are carried up nearly to formation level, and the openings are then either arched over, or are spanned by beams or 'girders' of wrought iron or steel, which carry the rails. In this case a break occurs in the continuity of the embankment, and the adjoining ends of the earthwork are protected and supported by masonry wing walls, projecting from the abutments of the bridge or culvert. Ample time for the setting of the mortar or cement used in these masonry structures is always allowed before the full weight of the earthwork is placed upon or against them.

The carrying of a line of railway over deep gorges or valleys,

large rivers, or it may be arms of the sea, is usually effected, either by continuous and often lofty viaducts of masonry, or by means of a succession of iron or steel girders, sometimes of great stretch from one support to another. The girders of bridges are supported on masonry or iron abutments, and a line of intermediate piers, so disposed as to cover the entire waterway of the river. The size of the individual openings is not a matter of arbitrary selection, but will in each case be decided by the engineer on grounds of economy or necessity. The most economical size of span will primarily depend on the cost of the piers including their foundations, and the greater the estimated cost of constructing these, the larger in ordinary cases will be the size of the girder spans which it will be economical to adopt.

Tunnels, viaducts, and bridges of enormous magnitude have in recent years been carried out in various parts of the world in connection with railways. Excluding a few examples of exceptional dimensions, some of the most important of these are to be found on Indian railways, and will be specially referred to in some detail in subsequent chapters. In the meantime it will be of interest to note the magnitude of a few of the most prominent examples, both of tunnels and railway bridges, which have been constructed by the science and skill of railway engineers.

The tunnel carried through the main part of the Alpine range at St. Gothard is $9\frac{1}{4}$ miles long. It is situated 4000 feet above the level of the sea, a level reached only by a series of massive and stupendous works, and is situated from a mile to two miles below the surface of the mountain.

The Mount Cenis Alpine tunnel is nearly $7\frac{1}{2}$ miles long, and is more than a mile in depth, within the bowels of the earth. The tunnel carried beneath the Severn, between Bristol and South Wales, is $4\frac{1}{2}$ miles long, including approaches. The river or arm of the sea lying above the tunnel is more than $2\frac{1}{4}$ miles wide. Owing to special difficulties from influx of water, seven years were occupied in driving the heading of this tunnel. It is made for a double line, and is lined throughout with brickwork in cement, from 60 to 70 millions of bricks having been used for the purpose.

The tunnel at Stand Edge, on the London and North-Western Railway is 15,705 feet, or nearly 3 miles long. The Khojack tunnel, on the north-west frontier of India, is nearly $2\frac{1}{2}$ miles long. The tunnel at Bramhope, near Leeds, is 11,010 feet, or rather over 2 miles long. The above examples comprise the most important railway tunnels in the world.

The largest existing railway bridge is that over the Firth of Forth. This extraordinary structure has two enormous openings, each of 1700 feet; two of 675 feet; fourteen of 168 feet, and six of 50 feet, and has a clear headway for navigation above high-water of 150 feet. The total length of the bridge is over $1\frac{1}{2}$ miles. The Lansdowne Bridge over the Indus at Sukkur has one magnificent span of 820 feet, and three of smaller dimensions. In America the Great International Railway suspension bridge, spans the Niagara River by a single opening of 800 feet from tower to tower, and the rails are 250 feet above the surface of the river. The Cincinnati Bridge has a clear opening of 515 feet.

The central pier of the Britannia tubular bridge over the Menai Straits is 230 feet high, the shore abutments being each over 160 feet. It has four large openings, those in the centre being of 460 feet clear span.

The new viaduct over the Firth of Tay is probably the longest railway viaduct in the world over continuous water. It is no less than 2 miles in length, consisting of 86 openings of various kinds, from 50 to 245 feet, of which thirteen are large spans of 245 and 227 feet each, carried at a height of $141\frac{1}{2}$ feet above the lowest foundation, and 77 feet above high-water in the Firth. The Saltash Bridge over the Tamar, near Plymouth, consists of nineteen spans, seventeen of which are small, but the remaining two, span the main river in two openings of 455 feet each. The height from the foundation to summit being 260 feet. The Hawkesbury Bridge in New South Wales has seven spans, each of 416 feet.

Such are the formidable dimensions attained by a few of the principal structures that have been required to reduce the natural inequalities of the earth's surface, and create that uniform 'formation'-level requisite for the purposes of a line of railway.

Along its course, especially in thickly-populated districts, it becomes necessary to provide for frequent cross-communication from one side to the other of that enclosed strip of land occupied by a railway. Public and private roads of all kinds will be carried across the line by means of service-bridges, passing either over it or under it, and these works are often very numerous and costly. In very flat country, where the level of the rails and the surface of the roads will commonly be more or less coincident, the construction of such bridges involves an extensive series of embankments, or cuttings, either for the road or the railway, in order that one may be made to pass over or under the other. In such cases, unless the road be of an important character, 'level-crossings' are resorted to. Gates are provided, which close alternatively across the road, or across the railway, as required, and an attendant or gate-keeper is maintained in constant charge of these gates; a small house being built alongside for his accommodation. The ordinary position of the gates is across the line of railway, leaving the ordinary road free for public traffic, but when any train is due their position is reversed until the train has passed. Sometimes the gates of a level-crossing are mechanically connected with signals which, actuated by the movement of the gates themselves, either remain at danger or allow the train to proceed, according as the gates are either closed or open for the passage of the train. In some cases, especially in the neighbourhood of stations, the movements of the gates are controlled by a lever worked from a 'signal-box,' and are mechanically connected, or as it is called, 'locked,' with the ordinary station, or special signals.

Both sides of a line of railway, unless very exceptionally circumstanced, are commonly provided with some form of fencing, in order to prevent accidents from the straying of cattle on the line of rails, and to reduce the danger and opportunities of trespass offered to the general public. Fences are of all kinds, such as an ordinary ditch and bank, the latter sometimes planted. Posts and rails of wood, thick live hedges; fences of iron wire, and stone-walls laid dry or otherwise. In India, but more especially in America, railway lines are, however, sometimes more or less completely unfenced, and in the latter

country not only in thinly-populated districts, but also in the neighbourhood of towns and villages. The people are warned to keep out of the way of the trains by the continuous clanging of the engine-bell, and stray cattle are promptly removed from the track by the peremptory action of the 'cow-catcher,' placed at the head of the engine.

CHAPTER IV

CONSTRUCTION OF LINE—‘PERMANENT WAY’

Permanent way—Ballast—Gauge of railways—English ‘standard’ gauge—Examples of gauges of different countries—Wheel flanges—‘Clearance’ and coning of wheels—Design of permanent way—Rigidity and elasticity—Early use of stone blocks—Sleepers and their object—Kinds of sleepers—Cross and longitudinal—Preservation of wood sleepers—Metal sleepers—Sectional forms of rails—Double-headed and flat-footed—Bull-headed irreversible rail—Increase of weight of rails—Railway chairs and keys—Spikes and trenails—Design of railway chairs—Tread of vehicle wheels—Inclination of rails—Flat-footed rails and fastenings—Length of rails—Fish-joints—Contraction and expansion—Check rails—Sidings—Cross-over roads—Switches and crossings—Facing and trailing points—Locking of switches.

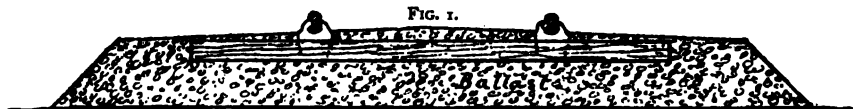
Permanent
way.

As soon as the whole, or any sufficient length of a new line of railway has been completed to ‘formation’ level, and the earth-works have been allowed sufficient time to settle and become firm, the laying of the ‘permanent way’—or the actual road on which the trains run—commences. This road, or line of way, consists of continuous pairs of end-connected rails, secured at a certain distance apart from each other by suitable fastenings to some form of ‘sleepers’ placed at close intervals, and imbedded in a mass of ‘ballast’ laid on the formation surface of the railway. ‘Ballast,’ which is usually considered part of the permanent way, and is, in fact, its foundation, is composed of a variety of hard unfriable materials, such as broken stone, clean gravel, sea shingle or pebbles, and slag from blast furnaces. Hard-burnt brick and sand are also in cases of necessity sometimes used for ballast, but are inferior. The main desiderata of good ballast are, that it should be entirely free from all substances which are soluble and liable to disintegrate under the action of water, that the particles of which it is composed should be of such size and hardness as not to crush or break up under the weight and impact of heavy blows, and that at

the same time they should not be light enough to be moved or lifted by the vibration or wind created by passing trains.

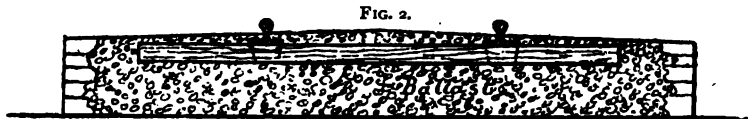
The height from formation level to the top of the rails on embankments is usually two feet. In cuttings it is sometimes more, in order to allow a greater depth of ballast below the sleepers for efficient drainage. The thickness of the ballast below the bottom of the sleepers is commonly one foot, and it is especially important that this portion of it should be of the *hardest* material. It is also considered better that it should be broken or screened to a larger general size than that used for the upper portion, so that it may allow rain-water to rapidly drain away from it. A medium and uniform size both for the upper and lower ballast is, however, often employed. The upper ballast reaches the level of the under side of the rails, and it is usually thickened towards the centre between them, so as to lightly cover the top surface of the sleepers, which if of wood are thereby protected from fire, which is sometimes dropped from the engine furnaces. In cases where the rails are supported on chairs, and are fixed by keys—especially of wood—the top ballast is also packed round the latter, and serves to protect them from shrinking and loosening under the heat of the sun. The width of the ballast on the upper surface generally extends about 18 inches beyond the ends of the

FIG. 1.



PERMANENT WAY ON EMBANKMENT.

FIG. 2.



PERMANENT WAY IN CUTTING.

sleepers—which may vary in length according to gauge—on each side, and the sides terminate in slopes of 1 to 1. In cuttings, to save width, the sides of the ballast are often retained within two vertical walls of dry packed stone. Figs. 1 and 2 represent sections of railway permanent way of English standard gauge, and will be useful to refer to.

The 'gauge' of a railway is the exact distance apart at which the inside edges of the top platform of rails are set by an iron instrument, commonly employed for the purpose, called a 'gauge,' and a variety of such gauges have been adopted in various parts of the world. Some uniform width between the rails, however, is almost universally adhered to over large systems of connected lines, so as to avoid the many inconveniences resulting from a break in continuity. The standard gauge of railways in England is 4 feet 8½ inches, but a few lines of narrower gauge occur in the hilly districts of Wales, or have been employed in other places under special local conditions. A large portion of one important railway system, viz., the 'Great Western,' was originally constructed at the broad gauge of 7 feet, but this has now been changed to the standard width. The English standard gauge of 4 feet 8½ inches is used to a greater or less extent almost all over the world. The most important exceptions are India and Ceylon, where the principal gauges employed are 5 feet 6 inches and 1 metre (or 3 feet 3⅞ inches). Spain, Portugal, Brazil, and Chili also employ almost entirely the 5 feet 6 inch gauge. Ireland, New Zealand, Victoria, and South Australia have decided in favour of 5 feet 3 inches; and Russia is practically the exclusive possessor of a 5-foot gauge. The United States of America have indulged in a great variety, from 8 feet down to 3 feet—the English standard gauge being included amongst them; Japan, Tasmania, Cape Colonies, Queensland, and to a great extent Norway, have remained constant to a 3 feet 6 inches gauge.

Each pair of vehicle wheels are provided with projecting flanges running inside the rails, so as to keep the vehicles from leaving the track; but the distance apart of these flanges is not made so as to exactly or tightly fit the gauge, but is usually about one inch less, allowing what is called a 'clearance.' On curves also the gauge itself is, in practice, made somewhat full, so as to permit a still greater lateral play or side movement of the wheels. The wheels of railway vehicles are rigidly attached to their axles, which revolve with them, and moreover all the axles of one vehicle are usually fixed rigidly parallel to each other. The outer rail of a curve is obviously longer than the

inner rail, hence, to avoid an excessive dragging and grinding action of the wheels against the rails, it is desirable that some provision should be made to enable the outer wheels on curves to travel over the greater distance in the same time as the inner wheels take to travel over the lesser distance. It is attempted to effect this by slightly coning the treads of the wheels from the flanges towards the outer edges. To a certain extent, in consequence of this coning and the tendency of the vehicles to proceed in a straight line and press against the outer rail, the exterior wheels on curved portions of the road do run on a slightly larger diameter than do the inner wheels, and thus advance a greater distance at each revolution of the axle; but the object in view is very imperfectly realised in practice, and the inner edges of the rails on curves are always subject to much abrasion. Nevertheless, a pair of wheels, one of which is in any degree larger than the other, if rigidly joined by an axle, will tend to roll in a circular path, hence the coning of the wheels is of some value in reducing resistance on curves, and in neutralising the tendency of the vehicles to leave the track.

In designing the permanent way of a line of railway, it is necessary to ascertain what are the severest ordinary and extraordinary strains, both vertical and lateral, to which each of the component parts of the line of way may be subjected, and to impart to each of these a strength and solidity more than sufficient to withstand such strains. At the same time, a certain degree of flexibility and elasticity must be permitted to the whole permanent way, so that it may yield a little to the stresses, in order to secure freedom from jar and hardness, and allow the vehicles to run with ease and pleasantness of motion.

It will not be necessary to detain the reader with any minute account of the various component parts of the permanent way, which, in addition to the ballast already spoken of, consist of the sleepers, the rails, with attachments and fastenings, and the points and crossings. In the early days of railways it was supposed that the permanent way could not be made too rigid, and in order to secure this rigidity heavy blocks of stone were employed in place of the elastic

wood or iron sleepers now universally used. These blocks were about two feet square and one foot thick; on each of them a cast-iron chair or seat for the rail, was attached by wooden trenails, driven into holes previously prepared in the stones. They were placed under each rail at a distance apart of about three feet. On the original London and Birmingham Railway upwards of 150,000 tons weight of stone blocks were laid down, all of which had to be removed, owing to the hardness and want of elasticity in the road, and the consequent severe wear and tear imposed on the vehicles. The object of a sleeper is to support the rails and distribute the load carried over a considerable surface of the ballast. Except in countries where wood is either very expensive or is especially liable to rapid decay, or other injury, wooden sleepers are now almost universally employed. For the standard English gauge they are made 9 feet long and rectangular in section, viz., 10 inches wide and 5 inches thick, although half round, and other sections are occasionally used. In Europe, sleepers are commonly made from Dantzic or Memel fir, pitch pine, and occasionally oak. In India, for the 5 foot 6 inch gauge, the sleepers are 10 feet long and 12 inches by 6 inches in section, and teak, oak, sal, and other hard woods are more generally employed, as well as a large proportion of metal sleepers, either of cast-iron, wrought-iron, or steel. In the case of metal sleepers, the chairs or seats on which the rails rest nearly always form a part of the main body of sleeper.

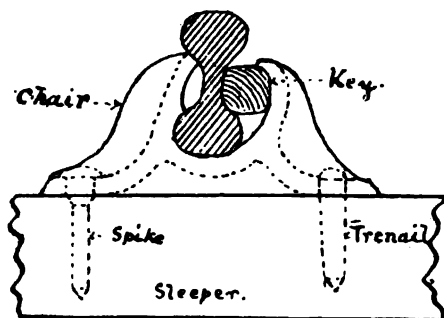
Sleepers are of two principal varieties, viz., either 'cross,' that is, placed at a certain distance apart, at right angles to the rails, in which case they also serve to keep the rails in gauge; or 'longitudinal'—that is, placed in a continuous line under the rails, when, in order to preserve the gauge, transoms and bolts, connecting at intervals each line of sleeper, are necessary. Longitudinal sleepers require to be of larger section than cross sleepers, and necessitate the use, economically speaking, of the flat-footed form of rail. Owing to the rail-foot lying parallel with the fibre of the wood, continuous packing pieces of wood, with the fibre at right angles to the rail and sleeper, are required. Longitudinal sleepers are also only economical on lines of very wide gauge. Rails laid on

them make a very easy and smooth road ; but the arrangement is attended with some inconveniences in maintenance, besides having other disadvantages, and notwithstanding that a lighter rail can be used to do the same work, is—for the narrower gauges—expensive ; hence longitudinal sleepers have practically been almost abandoned. ‘Cross’ sleepers are placed at right angles to the axis of the road, at a distance apart varying according to the weight and strength of the rails. A common distance is about 3 feet from centre to centre, and 2 feet at the places where rail-joints occur. If placed much closer than this it becomes difficult to properly pack the ballast under them. In order to preserve sleepers made from the softer kinds of wood from premature decay, they are often subjected to chemical treatment, the preservative composition employed being forced into the pores of the wood by enormous pressure. Cast-iron bowl or, as they are called, ‘pot’ sleepers, consist of a pair of round or oval bowls, or ‘pots’ of cast-iron, connected together by a bar of wrought-iron passing through them, and secured at a proper distance apart by keys. Jaws forming a seat or ‘chair’ for the rail are cast on the top of the rounded bowls, into which the rails are fixed by wood or metal taper wedges. Most forms of metal sleepers are much the same in general features, although varying in detail to suit the nature of the metal employed.

The sectional forms of rails and the details of fastenings of permanent way, have exercised the ingenuity of more inventors, and have been the cause of more controversy among practical engineers than any other subject that could be named. So great are the multitudinous varieties which have been introduced, that it would not now appear possible to devise any untried arrangement. The eliminative selection of experience has however resulted in the ‘survival of the fittest,’ and, practically speaking, rails as now used are confined to two general types, viz., the I or double-headed rail, and the solid flat-footed rail. As regards material, the cast-iron rails used on the early tramroads were soon exchanged for those of wrought-iron, which in their turn have since given place to the more durable steel.

The I, or double-head section of rail was originally made—

and is still often used—with two equal bulbs, above and below, the intention being when one head was worn out by the traffic to reverse the rail and utilise the other head. This form of rail however, having no foot, requires both vertical and horizontal support. To supply this support, seats, or as they are



CHAIR RAIL.

appropriately called, 'chairs,' to hold the rail were introduced, but it was found that the under-side of the rails were apt to be worn into hollows or indentures at the points where they rested on the chairs, and were thus rendered more or less unsuitable for reversing. The chairs were in consequence gradually increased in size and area so as to afford a larger bearing surface to the rail; but owing to this increase of weight it soon became cheaper to give up the idea of reversing the rails altogether. The surplus material in the lower bulb of the rail was therefore reduced, and transferred to the upper or wearing bulb, which was thus greatly enlarged, resulting in the economical, and now common form of the 'bull' or bulb-headed irreversible rail.

The continuous increase in the power and weight of locomotives has gradually led to a corresponding increase in the size and weight of rails necessary to withstand the increased loads, and wear and tear to which they are subjected. On the original Liverpool and Manchester Railway the rails weighed only 35 lbs. per yard of length, but the increasing weight of the engines soon obliged the directors to renew the road with rails weighing 60 lbs. per yard, and at the present day steel rails weighing 75 and up to 100 lbs. per yard are frequently used.

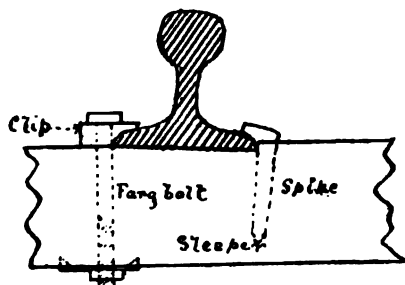
'Chairs' for supporting the I or double-headed form of rails are usually made of cast-iron, and have gradually increased in weight from 20 lbs. to 50 lbs. each. The jaws and seat of a chair are made of a form to fit the outlines of the rail, with a space left on one side—generally the *inside*—for the insertion of a taper wedge of wood or metal called a 'key,' which, driven firmly in between the rail and the jaw of the chair, prevents all lateral or vertical movement under the action of the traffic. The chairs are provided with two or four holes, through which iron spikes and hard-wood trenails are driven to secure them to the upper surface of the sleepers.

In every mile of single line, allowing 9 sleepers to every rail of 30 feet in length, there will be 3168 chairs, and the difference of *one ounce* in the weight of a single chair will mean about *one ton* in every 11 miles of road, or nearly 18 tons in every 100 miles of double track. It is, therefore, of some consequence that a railway chair should not contain in any detail of its structure, even a single ounce of metal more than sufficient for its exact necessary strength. Successive designers of railway chairs have therefore keenly and narrowly scrutinised every feature of their outline, and wherever a particle of metal more than sufficient for the exact necessary strength could be spared, it has been ruthlessly shorn off and suppressed. They had nothing in their minds but rigid economy and the strictest utility, but the altogether unintended result has been the production of a very graceful and pleasing outline, especially in the case of single chairs for the lighter forms of rail, where the principle of strict serviceableness and economy of material has been permitted to assume its fullest expression: so true it is that pure art outlines are ever the result of the severest simplicity and the absence of all redundancy. There are probably few objects that serve better to illustrate this important truth than the common railway chair of our permanent way.

We have already mentioned that the flat portion or 'tread' of the wheels of railway vehicles are not horizontal cylinders, but are slightly coned outwards. In order that such wheel-treads may bear evenly on the upper surface of the rails it is obvious that the latter ought not to be horizontal either, but should be slightly inclined inwards. It is found convenient to

effect this by tilting the whole rail, which is readily done by inclining that portion of the chair-seats on which the rails rest, and in this manner the upper surface of the rail-head is made to lie true to the inclination of the coned wheels.

The flat-footed form of rail is made with the usual rounded top bulb, but with a broad base or foot, 5 inches or $5\frac{1}{2}$ inches



FLAT-FOOTED RAIL.

wide. It is, of course, not intended to be reversible, and as these rails do not require lateral support, chairs are not strictly required. The London, Chatham, and Dover Railway adopted a flat-footed form of rail, supported on low cast-iron chairs, the object in this case being to distribute the weight over a larger area of the sleepers. The arrangement in the case of this line has been since superseded by the employment of the double-headed rail and ordinary chairs. Generally speaking, however, flat-footed rails are seated directly on the sleepers, and to give them the necessary inward inclination the upper surfaces of the cross-sleepers are adzed to the extent required. This form of rail has great lateral stiffness, enabling it to resist the outward thrust of the wheels, and has, moreover, no deficiency of vertical strength. The bearing area on a cross-sleeper 10 inches wide will be as much as 50 to 60 square inches, and the rail-foot lies across it at right angles to the fibre of the wood. Although this bearing area is less than that of the larger chairs now used—principally to prevent the under side of double-headed rails from being damaged—it is found sufficient in ordinary cases to prevent any crushing of the harder woods, whilst in the case of the softer kinds of sleepers, 'bearing plates' of wrought-iron are often introduced between the foot of the rail and the sleeper.

The chief defect of the flat-footed form of rail—used, as it generally is, without chairs—as compared with the double-headed chaired rail, is found in the relative insecurity of the fastenings. Where first employed these rails were spiked or bolted to the sleepers through holes bored through the foot of the rail, but this was found inconvenient, not only as too rigidly determining the distance apart of the sleepers (the holes being bored at the time of manufacture of the rails), but the rails themselves were unduly weakened. To avoid the necessity of passing the spikes or bolts through the foot of the rail, the bolts are now provided with iron ‘clips’ projecting over the rail foot. Where the traffic is not heavy, spikes with projecting heads are alone used, but in other cases ‘fang bolts’ (see Fig.), passing completely through the sleeper, with a claw or fang on the under side and a clip above, are employed, either at every sleeper, or at the extremity of each pair of rails only, the intermediate points being secured by spikes. The severe side-pressures exerted against the rails by the blows of the wheel flanges under the swaying motion of rapidly running trains, have a tendency to thrust the rails over outwards, and either to partially draw out the spikes, or to put a severe strain on the fang bolts and clips. Nevertheless, the flat-footed pattern of permanent way possesses many economical advantages, and is very largely used.

Rails, of whatever pattern, are made in lengths of 20 to upwards of 30 feet, and it is plain that where the ends of two rails come together it is necessary to firmly join them. When a sailor wishes to mend a broken spar he often lays a piece of timber on one or on both sides of the fracture, and lashes the whole round with rope. This in nautical phraseology is called ‘to fish’ the joint. The joints of rails are also ‘fished.’ Two



pieces of iron called ‘fish plates’ are made to fit the sides of the rails, and are bolted across the joints by bolts passing through holes in the web of the rail. Four bolts, *i.e.* two on each side of the joint, are usually employed, and the section of iron given

to the fish-plates is such that when they are securely bolted up to the sides of the rail the combined strength of the plates, and also that of the joint itself, is at least equal to that of the solid rail. Rails, like all other objects, contract and expand under the influence of changes of temperature, and in order to prevent distortion of the road resulting from these movements it is necessary to allow a little space between the abutting ends of each pair of rails. The fish-bolts passing tightly through the web of the rails would, however, prevent their elongation or contraction were it not that the bolt-holes are made slightly oval in a longitudinal direction, and the necessary movements are thus duly provided for. In practice it is necessary, moreover, that the fish-bolts should not be screwed up too tightly, otherwise the friction between the fish-plates and the sides of the rails would be so great as to prevent the movements taking place, and the road would in consequence be forced out of shape, and distorted into a wavy line, instead of preserving that perfectly straight and even alignment which is so essential in the permanent way, and the absence of which is always so uncomfortably felt by the railway traveller.

On very sharp curves it is sometimes necessary to lay down close to the inner rail what is called a 'check-rail.' This check-rail allows only an easy play to the wheel flanges, and its object is to check the tendency of the outer wheel to mount the rail on curves. Double check-rails are also sometimes used over long lofty bridges, even where the road is straight, or in other situations where any derailment would be exceptionally disastrous. The check-rail when used with the flat-footed form of permanent road is often only a stout angle iron, bolted firmly down to the sleepers, and as an additional precaution it sometimes projects to a slightly higher level than the top of the running rail.

On every line of railway, besides the main line or lines forming the traffic road, numerous side lines of way are required at fixed places or stations, so that trains or detached engines and vehicles may be passed on and off the main tracks. These various 'sidings,' as they are called, are connected with the main lines, and with each other, by diagonal connecting, or 'cross-over' roads, laid with long easy reverse curves. At

either end of the cross-over roads the junction is effected by means of a pair of pivoted movable rails called 'points' or 'switches,' so constructed that, placed in one position, the flanged wheels of the moving vehicles will continue to move along the principal track; but placed in a reverse position, the wheels will be constrained to enter the cross-over or diverging road. At the places where one rail has to pass across another, a gap in the rail to be passed over is introduced by laying down a grooved table of steel, called a 'crossing,' which admits the passage of the wheel flanges along the grooves, and allows the tread of the wheels to roll smoothly along the upper surface without interruption.

Points or switches are of two kinds, respectively called 'facing-points' and 'trailing-points,' but these terms do not denote any difference in mechanical construction, but refer merely to their position with reference to a moving train. When an engine approaches, and first comes in contact with switches at their free movable end, the points are called 'facing,' but when the heel or pivot end of a pair of movable rails is first touched by an engine—moving in this case in a contrary direction—the points are called 'trailing.' Facing-points cause the vehicles to diverge from a main track or siding into a branch or cross-over road. Trailing-points cause the vehicles to converge into a main track or sidings. Points and crossings may thus be regarded as gates of entrance and exit, admitting the passage of trains or vehicles from one line of way to another, and as such, are always more or less dangerous portals, unless the traffic through them is maintained under perfect control.

Switches are usually kept locked so as to restrict the traffic to one road only, and are only unlocked for the time necessary to admit the passage of vehicles into or out of that road, as may be required. The working as well as the locking and unlocking of points is sometimes in country districts where the traffic is small, directly effected at the switches themselves by a pointsman in charge, but where the traffic is at all heavy the manipulation of all the switches in a station yard is concentrated and carried on from one signal station or box, from whence all the signals are also worked. The various adjustments of the

switches, and the movement of the signals are, moreover, effected in unison by means of a special mechanism. This interlocking of switches and signals will be further alluded to in the next chapter, when we are dealing with the signalling arrangements on a line of railway

CHAPTER V

CONSTRUCTION OF LINE—‘STATION BUILDINGS AND MACHINERY’

Station buildings and machinery—Provision for growth and expansion—
Passenger roadside stations—Height of platforms—Goods accommodation—
Large terminal passenger stations—Principal varieties and relative advantages
—Buffer stops—Large terminal goods stations—Varieties of plan—London
goods stations—Locomotive depôt—Running sheds, pits, and watering—Turn-
tables, triangles, carriage turntables, and traversers—Water cranes, tanks,
and ashpits—Pick-up watering—Central workshops—Outdoor apparatus for
signalling—Early history of railway signalling—Colours—Time signals
superseded by space signals—Block system—Forms of outdoor signals—
Colour blindness—Fog signals—Situation and details of signals—Corre-
spondence of signals with points or switches—Interlocking of signals and
outline of apparatus—Value of the system—Platform and other signals.

RAILWAY stations, whether passenger or goods, are of largely varying size and importance, from the smallest roadside pick-up station, at which only a few trains may stop, to the often gigantic terminal stations required in a capital city, into and out of which flows, night and day, a continuous and never-ceasing stream of busy traffic. Accommodation and conveniences for the receipt and despatch of goods—according to the commercial importance of the locality—will either be combined with, or be altogether distinct from the passenger arrangements.

The growth and development of traffic on almost every line of new railway is commonly so steady—even if not always immediately great and rapid—that a judicious engineer will, from the very commencement, in designing all station accommodation, make ample provision in his plans for a large and economical possibility of extension. He will, however, *actually* provide in the first instance for the minimum requirements only, and this provision will be based upon the best judgment he can form as to the smallest immediate necessities of the case. It is on

the engineer's forethought and wisdom in this matter of initial economy, combined with initial arrangements for growth and expansion, that much of the future economical working of the railway will depend.

In the case of every passenger station, even one intended for the accommodation of a village or very small town, the length of the platform will be made at least equal to that of the longest trains which are required to stop at it. This length will depend on the gauge and importance of the railway, but will in ordinary cases reach 600 to 800 feet on main lines. Unless land is exceptionally expensive, or the station has to be built on a high embankment, or in a deep cutting, or other difficult situation, the *width* of the platform will be liberal and spacious, 25 to 30 feet being now frequently allowed. The height of platforms for passenger traffic has been, in practice, subject to great variations, chiefly on grounds of economy of materials. Probably, however, the most convenient height, both for the work of the station staff in crossing the lines and in handling luggage, as well as for the ease and comfort of passengers, is about 6 or 8 inches below the floor-level of the carriages.

The booking-office is most conveniently placed on that side of the line nearest to the town or village; but if there are up and down lines a second platform and a waiting shed will be provided on the opposite side. It is important that booking-offices and waiting-rooms should, whenever possible, be on the same level with the platforms and the outside approaches to the station, and this requirement is always kept in mind, both in the original grading of the line and in the selection of the precise spot for the station. Where the arrangement is impossible, easy inclined planes will be better than steps or stairs between the approaches and the platform. The minimum amount of accommodation provided in station offices, whether for the public or for the staff, will indefinitely vary according to the circumstances of the traffic in each particular case, but the smallest station will always include, in addition to the platform, a public booking or ticket-office, a clerk or station-master's office adjoining, a general waiting-room, store-room, urinal, and some portion of covered platform or outside shelter, either on one or on both sides of the line. The ordinary home

and distant signals, a clock, supply of water, and arrangements for lighting will be among the necessary provisions.

If the roadside station is important enough to require separate goods accommodation, goods sidings and a separate platform will be provided somewhere near the main offices, so as to be under the convenient inspection of the station-master at all times. The goods platform will be made of such a height as to be level with the floor of the wagons brought up alongside of it. Shed room will also be constructed in proportion to the requirements of the case, arranged so that perishable goods may be loaded or unloaded under cover, and that carts or vans may be able to approach the loading platform. It is usual to make the doors of goods sheds sliding instead of hinged to economise space and promote convenience. The principal fittings necessary for the goods side of a roadside station will be a small crane for lifting heavy weights, a weighing machine, and perhaps a weigh bridge, a loading gauge, a lock-up store, and small office with clock for the booking-clerk, together with a supply of water and lighting arrangements. Intermediate stations for large and important towns or junctions, whether for passengers, for goods, or both combined, will of course be greatly enlarged to suit the amount of traffic expected to be dealt with.

The arrangement and disposition of a large terminal passenger station—usually situated within the limits of a great city—depend not only on the traffic, but is often greatly determined by the cost and shape of the site that may be available. There are, however, three principal varieties of terminal stations, important examples of which are to be found, and against, or in favour of each of which, certain advantages, and other corresponding disadvantages may be urged. The three varieties are distinguished by the relative position of the main station offices, with reference to the departure and arrival platforms. These offices may be situated, either along one *side* of the station; they may be placed in a *central* position, or they may be situated at the *end* or extremity of the terminus. When the main station offices—comprising booking, luggage, telegraph, station-master's, and parcels offices, cloak-room, waiting-rooms, refreshment-rooms, lavatories, etc.—are placed

along the *side* of a terminal station, a long main departure platform is very conveniently situated immediately opposite to them, and passengers reach this platform near its middle. The arrangement is also convenient where large quantities of luggage have to be dealt with, as the luggage office and weighing apparatus is located close to the departing trains. On the other hand, access to a second, or to other departure platforms is difficult, and is only to be effected, either by an inconvenient and distant end-passage, by an over-bridge, an under-passage, or by a movable crossing platform, which can be put into position, or removed as required ; so that where a large number of trains are required to be despatched from several departure platforms, the inconvenience of this want of easy access to all except the first, is a disadvantage. The plan of placing the general booking and station offices in a *central* position is commodious in many respects, but is less usual. The arrangement admits of two long departure platforms, one on each side of the buildings, to which easy access is gained near the middle portion of the trains. It is said, however, that this arrangement disperses the staff, and requires a large number of station hands to carry on the work. However this may be, there is little question that where a very heavy and frequent passenger service has to be dealt with, the third arrangement, or that where the main station offices are situated at the *end* or extremity of the terminus, is on the whole preferable to the other two.

The principal advantages of this last arrangement are, that there are no difficulties in the way of using any of the platforms, as occasion may require, either for departure or arrival of trains ; a very important desideratum. A discharged train which has just arrived, can thus be used as a fresh departure train from the same platform, and generally much shunting and moving of trains and vehicles will be avoided. The arrangement is also very economical in space ; a highly important matter where land is valuable, as each platform will have a line on either side of it, requiring to be but very little wider for the use of two trains than for one only. In this form of terminus a wide space is provided between the end of the lines of rail, and the station offices, to which the public

may be freely admitted without interference with the service of the trains. Travellers and their friends can be prevented by barriers from entering on the train-platforms, except by ticket, and can be admitted only a short time before the train departures, an arrangement which is hardly possible in the case of the other two plans. From a railed-off portion of this end platform, luggage also can be weighed, carried to the trains, and loaded into the train luggage-vans, with more freedom from press and intermixture with the passengers; the whole work of the station is more concentrated, and can be carried on with fewer hands; the porters passing from one platform to the other inside the barriers as trains depart or arrive. Perhaps the only disadvantage of this plan of terminal station is, that passengers approach the trains from their ends, instead of about their middle, and consequently have to walk, and luggage has to be taken a longer distance than when the general offices are situated either at the side, or in the central portion of the station premises.

In all three arrangements, roads for the approach and departure of cabs are provided—on one side—or it may be also between two of the principal arrival platforms. The entrance to the main cab road is, wherever possible, made at the end farthest away from the exit, so that empty vehicles may enter by a different road from the loaded ones leaving the station.

At the points where the several lines of way suddenly come to an end at all terminal stations, it is necessary to provide some means of arresting the motion of vehicles which may overrun the point at which they should have stopped. This is done by fixing at the end of each line of rails a strong massive buffer-stop of timber and iron, provided with spring buffers fixed at the same height, and similar in character to those on the vehicles.

The planning out and arrangement of a large terminal goods station, so as to combine the greatest facility in marshalling the incoming and outgoing trains, and working them into and out of the various platform sidings, whether for loading and despatch, or for receipt and unloading, together with the utmost convenience for the rapid entrance and exit, loading and unloading of the ordinary road vans or carts, for the

receipt and delivery of goods, is one that taxes the skill of the designer more than any other detail of railway accommodation, and perhaps in no particular does the practice of the great railway companies differ more than in the ground plan and general arrangement of their terminal goods stations. The ultimate object in every case, however, is to carry on with a maximum of convenience and rapidity the enormous operations frequently involved.

At some of the larger London goods stations, 1500 or 2000 men may be nightly employed in loading and unloading goods, over an area of 15 to 20 acres, containing perhaps 20 miles of sidings, and disposing in a few hours of perhaps 1000 or 1200 wagons, comprising 3000 to 4000 tons of merchandise, exclusive of minerals. The 'outwards' or despatch work is largely carried out in the early part of the night, in readiness for the 'inwards' or receipt traffic usually dealt with in the early hours of the morning, and so great is the perfection in the arrangements now commonly attained, and the order and rapidity with which the work is carried on, that often hardly more than an hour will elapse between the consignment of goods and their despatch by train to their various destinations.

At all terminal stations, and at varying intervals along a line of railway—intervals dependent on the conditions of the traffic—locomotive depôts will be established, to provide for the proper grooming and victualling of the ponderous iron horses. These depôts will be furnished with 'running' or shelter-sheds for housing the engines. Inside the sheds will be continuous pits between the gauge of the rails, to allow free passage beneath the locomotives for examination of the machinery, and a plentiful supply of pure water, supplied at considerable pressure from an elevated tank, for washing out the boilers and general cleansing purposes. The sheds will also usually contain some workshop accommodation for executing minor repairs. Near the running sheds, 'ashpits' between the rails for receiving discharged ashes from the engines, hollow water-cranes, by means of which the engines may be furnished with water, and stages for conveniently taking in supplies of fuel, will be provided.

Terminal stations will also invariably contain some provision

for turning, or reversing the running position of the engines. In most cases this is done by means of what is called a 'turn-table;' but in country localities, where the expedient may be admissible or convenient, the engines can be turned on a short length of railroad laid down in the form of a triangle, of size sufficient to enable the engines to pass round it. Points and crossings are, of course, provided at the apex of the triangle and at its points of junction with the main road. A 'turn-table' is a centrally pivoted revolving platform, of a diameter and strength sufficient to carry an engine with its tender, having a line of rails on it coincident and level with the adjoining line of way. The engine being run on to the platform and stopped, the whole by suitable mechanism is revolved a half turn, when the position of the engine will be reversed, and it can then be run off the platform on to the line of way by which it came. In crowded terminal or other station yards, turntables for carriages enabling them to be quarter turned, and pushed on cross lines from one line of rails to another, instead of passing by cross-over roads, are also sometimes employed; but it is generally more convenient in such places to use a 'carriage traverser,' or low dwarf frame running on cross lines, on which the carriage or vehicle is first mounted, to effect this purpose. When these are used, at least one carriage turntable will be provided, in order to reverse the running position of the carriage and waggon stock when desired.

At sundry intermediate stations along the line, water-tanks and cranes for refilling the engine-tanks with water, and 'ash-pits' for receiving the discharged ashes from the engines, will also be necessary. The distance apart of these watering or ashpit stations will depend upon the varying conditions of the traffic as affecting the consumption of water, the capacity of the engine tanks; or the kind of fuel used. In cases where it is desirable that trains should run exceptionally long distances without the necessity of stopping to take in water, 'pick-up' water-troughs are employed on many railways. A long open trough of very considerable length, and kept filled with water, is constructed between the gauge of the rails, at convenient watering-places. Into this trough a 'dip-pipe' or scoop, attached to the bottom of the tender of the running train is