

lowered, and at a speed of 50 miles an hour upwards of 1000 gallons of water can be easily scooped up and discharged into the tender during its passage over the trough.

Central workshops for the repair or reconstruction of the locomotive engines, and of the carriage and wagon stock of all kinds, are provided on all important railways. These may be located at one of the principal termini, but are generally placed in some central position with reference to the entire system of railways owned and worked by one company or agency.

Every railway station requires to be provided with an outdoor apparatus for signalling, both by day and by night, so contrived that by it instructions may be conveyed from the stations to persons in charge of trains, in order to control the motions of the latter. It would be impossible within the compass of a few pages to discuss in an adequate manner the important matter of railway signalling. We will, however, endeavour to convey to the reader an outline and general idea of the main principles in accordance with which the movements of trains on a line of railway are controlled by the aid of that system of out-door signals, which has been necessitated by the rapid development of railway traffic, and which in many particulars has now reached so high a degree of perfection as to render the safe working of trains, so far as this matter is concerned, almost independent of human error or carelessness.

On the first lines of railway that were constructed, the need of fixed signals was unfelt. So few trains followed each other on the up and down lines nearly always provided, that nothing at first seemed to be required except a code of hand-signals, similar to that still used in station-yards for shunting or other purposes. This code of hand-signals, still almost universally employed, consists of the use of coloured flags, and the various attitudes of the arms of a signalman by day, and of coloured hand-lamps by night. A signal for 'all right' is given by holding out a white flag, or by stretching out the arm horizontally, or at night by showing a steady white light. A signal for 'caution' is given in daylight by a green flag, or by holding *one* arm straight up in the air, and at night by a green light. A danger or 'stop'-signal is given by showing a red flag, by holding up *both* arms vertically, or by waving a cap or some

other object violently. At night a red light is shown, or if no red light is available, by waving violently any other light across the line.

On the original Liverpool and Manchester Railway, when first opened, hand-signals only were employed, and it was not until about the year 1834 that on this line the first fixed signals were introduced for night use, by the simple expedient of fastening an ordinary lamp to the top of a post, showing a red light if it was desired that the train should stop, and a white light if on the contrary it might proceed. Even in the year 1841 the only fixed day-signal employed at stations on this railway was a flag run up and down a mast by means of a rope and pulley. The use of coloured objects, borrowed from the hand-signalling, was soon, however, extended to fixed signals. *White*, whether exhibited in the shape of a flag, a disc, an arm, or a light, came to represent safety or 'all right.' *Green* meant 'caution,' and *red* signified danger or 'stop.' These *colours*, whether by day or by night, for a long period were used simply as *time*-signals. Some description of fixed station-signal—scarcely any two railways using the same—such as a coloured disc, round or square, or a horizontal arm on a post (exchanged after dark for a coloured light), was displayed for both up and down lines. The red colour was shown directly a train had reached or passed a station, and remained exposed for five minutes after its departure, so as to stop any following train. The green signal, often carried on a shorter post, was then exhibited for another five minutes, so as to complete a ten minutes interval, after which either no signal at all, or the white 'all-right' signal was exposed. On some lines the *time*-intervals were varied to suit the special circumstances of the traffic, but before long, and soon after the introduction of the electric telegraph on railways, the main object aimed at in signalling completely changed. It was no longer sought to preserve an interval of *time* between trains, but to ensure an interval of *space*, and it is obvious at first glance that this was a vast improvement: for in case of a train breaking down, or from any cause not running to time between two stations, the time-signal would not prevent the following train from running into it.

Under the present system the colours of the old signals have been retained, but the use of the electric telegraph enables each line of way on a railway to be divided into certain *space-intervals* or 'sections,' and permits the establishment of a rigid rule or regulation, that no train shall be allowed by the ordinary out-door signals, to enter any section until the previous train has been signalled by telegraph to have left it at the other end. This, which is called the 'block' system, ensures, if the regulation is adhered to, that no train can ever overtake or run into another proceeding on the same line of rails.

The form of out-door signal apparatus now employed on all important railways, is that known as the 'semaphore,' which combines the use of colours by night with the relative position of a semaphore *arm* by day. This signal consists of a tall vertical post, which carries near its top a pivoted movable arm—or more than one if signals for several roads have to be given—the arm, projecting from the post in a horizontal position, indicates danger or 'stop.' Lowered to an angle of 45 degrees with the post, it indicates 'proceed cautiously;' or shut down entirely within the post, it signifies 'all right.'

In connection with the 'block' system, however, it is clear that only two signals are really required, viz., one to express the instruction, 'All right, you may go on, for the line is clear in front as far as the next signal-station;' and the other to express, 'Stop at once, for the section of line in front is *not* clear.' In the neighbourhood of towns it is an advantage to be able to discard the use of the white light at night, because it is liable to be confounded with other ordinary white lights, consequently in such situations the green-coloured signal has now almost entirely taken its place, and has practically come to mean 'all right' instead of caution. On the other hand, in the open country, the white light is superior to the green light, inasmuch as it can be clearly seen from a greater distance by the drivers of fast-running trains, and it is, therefore, generally retained under these circumstances. Similarly, the inclined or 'caution' position of the day-signal arm is now almost everywhere used to express 'all right,' the shut-down position within the post being discarded, this position having the objection of being rather the absence of any definite signal than an

affirmative one. The use of the three signals by night is, however, still adhered to on some lines, a purple light being substituted for the white light in the neighbourhood of towns.

As now used, therefore, in connection with the almost universal 'block' system, day-signals consist of a horizontal semaphore arm to indicate danger or 'stop,' and the same arm inclined at an angle of 45 degrees to indicate 'all right.' At night a lamp is lighted near the top of the signal-post, and a spectacle of red and green glass, or one of red only, is interposed in front of the light by the motion of the same rods that work the signal-arms, showing a red light when the arm is in the position indicating danger or 'stop,' and a green or a white light, according to situation, when the arm is in the 'all right' position.

These colours, now used in railway signalling, whether by the exhibition of coloured flags and other objects by day, or of lamps by night, were adopted at a time when that defect in human vision, known as 'colour-blindness,' was little known, or when its accompanying phenomena had been little investigated. Unhappily, moreover, the use of this colour-system of signalling has become so firmly bound up with railway practice all over the world, as to preclude the possibility of any radical change of principle being now thought of.

Modern scientific investigation into the facts of colour-blindness has clearly proved that a considerable and unexpected percentage of persons are unable from birth to interpret correctly one or other of the primary colours, especially 'red' and 'green:' that this defect in visual perception may be induced by excessive tobacco-smoking, either combined with or entirely without, the abuse of alcohol, and moreover that examples exist of persons whose eyesight is normal with respect to the colours of opaque, *non-luminous* objects, but who at the same time are colour-blind to luminous objects, especially of varying intensity (such, for instance, as railway signal lamps). In view of these facts, a duty, the importance of which it is hardly possible to exaggerate, is imposed on those persons responsible for the safe-working of railway trains, to ascertain by the most crucial tests that ophthalmic science may have rendered available, that the vision of engine-drivers and others is not only normal on first engage-

ment, but also by periodical examination to ascertain whether it continues in a healthy condition, seeing that these persons have under daily, and even hourly risk of human life and property, to read correctly the colours of railway signals.

The methods of test hitherto employed, whether by requiring the candidate to name the colours on prepared cards, read the actual outdoor signals, or by requiring him to match together the various colours of skeins of wool, irrespective of shade (known as the 'Holmgreens wool test'), when these tests are unaccompanied by the more stringent trial of correctly matching opaque against the colours of luminous objects of varying degrees of intensity—in a similar manner to the system of testing now adopted by the Admiralty in the case of candidates for the marine service—have been shown to be liable to extreme chances of error, even if they are not actually useless.

In England the subject has attracted great attention in recent years, and railway companies are beginning to be more keenly alive to its real importance. In Indian railway practice, however, really efficient methods of testing the eyesight of engine-drivers, signalmen, and others for colour-blindness are either largely unknown, or their application is singularly lax. It is sometimes urged that too great an importance is attached to the subject, inasmuch as very few cases of railway accident can in practice be attributed to colour-blindness, but in a large number of cases where accidents have arisen from some conflicting interpretation of signals, it has not hitherto been possible, without the aid of the more recently devised scientific methods of test, to prove that such misinterpretation was, or was not, due to this cause. To such of our readers who may desire to have a clearer idea of the theory and facts of colour-blindness, as bearing on railway signalling and the most improved methods of test now employed, a *résumé* of this important question will be found in Appendix J.

During the time of fogs or mist, when neither the arms nor the lights of fixed signals can be seen, *audible* signals are resorted to. At a certain distance beyond the fixed signals in the direction of an approaching train, special signalmen are employed to fasten on the rails by the aid of small leaden clips, percussion or 'fog' signals, which being run over by the engine

explode with a loud report. One such explosion means 'caution,' or proceed slowly, two or more in succession mean danger, or 'stop.'

Having now explained the form and kind of outdoor signals usually employed, it is necessary to indicate their ordinary situations. Every through station is provided with central or 'home' signals, as they are called, and two 'distant' signals, situated far away on either side of it. Terminal stations will of course require the latter on one side only. The main or 'home' signal-post is generally placed adjoining the platform, and either at or close to the main cabin or 'box' provided for the signalman. In consequence of the great speed at which trains travel, it is necessary that engine-drivers should know how the main signals stand some time before they can reach them. This is arranged for by the provisions of auxiliary or distant signal-posts on either side of the home signals, at a distance of a quarter to a half a mile away, the arms of which are worked by wires and rods connected with levers in the signal box. Each of these semaphore signal-posts will often be furnished with arms on both sides of it, or even tiers of arms one above the other, but in *every* case the arm or arms on one side of the post control trains running in one direction, and the arm or arms on the other side control trains running in the other direction. The driver of a train approaching any semaphore signals whatsoever, has only to consider the arm or arms on the *left*-hand side of the signal post; those on the right hand in no way concern him.

In all cases signal arms are counterweighted, so that in case the wires or rods connecting them with the working levers should at any time break, the arms will by their own weight fly to the position of 'danger,' and thus no further harm than some delay will ensue. The normal position of all signal arms is, moreover, horizontal, or at danger, and they are only lowered to the inclined or 'all right' position for the brief time necessary to allow a train to pass clear of it. At complicated junctions, or stations where there are a great number of lines, and consequently where there may be a great many signal arms one above the other on the posts, it is usual to arrange the order of their superposition, so as to correspond with a

numerical or other order in the various lines to which they refer. By the aid of these and numerous other suitable arrangements, which practically provide for all the possible complications that can arise, railway signals are made to convey permission to the driver of any train to proceed, or to command him to stop.

It will be obvious, however, to the most uninitiated person that much more than this is required. Whenever trains have to pass from one line of rails to another by those gates of entrance and exit called 'points' or switches, in doing which they may for a time obstruct communication on, or 'foul' one or several other lines of way, it is clear that the exhibition, and even the exact obeying of signals, will be no safeguard to the traffic, unless the working of these switches or 'points' is conducted in exact correspondence with the signals. If at any time these should be in contradiction the one to the other, conditions favourable to a collision or other accident will be immediately established. It is in order to prevent the possibility of this dangerous contingency that ingenious inventors have devised an interlocking mechanism for the levers of points and signals, so arranged that no signal arm can by any human effort be removed from its normal position of danger, unless all the points situated on the line of way controlled by that signal are previously placed in the proper position for the train to pass, and further, during the whole time that the signal arm is in the lowered position, permitting a train to proceed, by no human effort can the points be moved, nor can any other signal be shown, which will allow another train to proceed on any line of way obstructing or 'fouling' the first. The numerous levers which actuate all the points, as well as those which actuate all the signals, are concentrated and ranged side by side in the signal cabin, and are placed in mechanical connection with an interlocking mechanism, so devised that the *results* of the arrangement are very much the same as if a piano or organ was constructed in such a manner that no combination of notes could possibly be struck which were not in perfect harmony. So far as exact accordance between points and signals are concerned, a blind man might with safety be allowed to enter a signal cabin and pull over any of the levers of an interlocking

apparatus at random. He would probably produce delay in the traffic, but he could not produce discord between the points and the signals.

The main principle of the apparatus is, that so long as all the outside signals are at danger the point levers are free to move, thus permitting any shunting that may be necessary to go on under the protection of the danger signals, but if the signalman desires to lower any signal arm to the 'all right' position he cannot, by the conditions of the mechanism do so, until all the points concerned are *first* set in their proper positions of safety for the train to pass, nor whilst the signal arm is down can he move the points so set, or actuate any other signal concerned with any portion of the same line of way. The *man* and his liability to forgetfulness or error is in fact superseded by the unerring action of the machine. Trains may be derailed, engine-drivers may fail to see, or may disregard the signals, or brakes may refuse to act, but the perfect correspondence between the signals and the safety of the roads to which they refer is practically absolute.

The importance and value of interlocking apparatus will be illustrated when it is stated that at some London terminal stations, at the most crowded time of the day, eighteen or twenty trains may arrive, and eighteen or twenty trains depart within the hour, necessitating perhaps 120 operations of shifting points and signals, or an average of, say one in every 30 seconds, a work which it would be impossible for any unaided human being to carry on without mistake, even for a few minutes.

In addition to the ordinary outdoor signals, of which we have been speaking, platform arrival and departure signals are often used where trains are frequent. Numerous other signals are also employed for conveying instructions from one signal box to another, or between those concerned in the actual working of trains, and even between passengers and the train officials. Most of these are nowadays worked by electricity, and are of too technical a character to be here treated of.

CHAPTER VI

INTRODUCTION OF RAILWAYS INTO INDIA

Introduction of Railways into India—The India of early English occupation—Vivifying power of railways—Influence on the destinies of India—Outline of physical geography of the Continent—Principal divisions—Chief rivers of Hindustan—The table land of the Deccan—Western *ghāts*—Eastern *ghāts*—Principal rivers of the Deccan—Vindhyan mountains—Satpura and Aravalli ranges—Alluvial soil of Hindustan—Characteristics of Indian rivers—Coast line and paucity of sea ports—Madras, Bombay, Karachi, and Calcutta the focus of early railways—The first three main trunk lines—Early projects—The ‘Great Eastern’ Railway from Bombay—The ‘Great India’ or ‘Great Indian Peninsula Railway’—Early history—First suggestion of the guarantee system—Early promotion of the ‘East Indian Railway’—First despatch recognising desirableness of railways for India—Curious assumptions—Deputation of an experienced civil engineer from England—Committee appointed—Proposals for main clauses of contract and Government control—Report of Committee—Experimental line—Discussion of proposals—Views of the Governor-General—Prolonged negotiations—Preliminary agreements signed—Principal contract-terms under the guarantee system.

Introduction
of Railways
into India.

Almost exactly forty years ago—or, more precisely, on the 16th April 1853—the first length of railway in India, viz., the 20 miles between Bombay and Tannah, was opened for public traffic. Thus, only about twenty-two years later than the first introduction of railways into England, was planted on Indian soil the germ of that wonderful subsequent growth of trunk and branch lines of railway, the regenerating and awakening influence of which was there destined to produce more extended and far-reaching results than in any other portion of the globe, and to place in the course of a few years the India of pre-railroad days, and the India of the present, as far asunder as the poles.

Who cannot recall that familiar picture of India of the early British occupation, handed down through so many generations

of Englishmen? Its vast roadless plains, stupendous mountains, and almost impassable rivers. Its gorgeous wealth and abject poverty. Its subtle philosophy and depths of grossest superstition; the singularly unchanged and apparently immovable habits and customs of its dense swarm of dusky inhabitants; the living embodiment of an ancient civilisation extending backwards to the earliest dawn of history. A land where the very names of innovation, progress, energy, and the practical arts of life were unknown, or were abhorred, and which appeared sunk in a lethargic sleep too profound for any possibility of awakening. To arouse this torpid mass, how feeble in action, and how infinitely slow in results, would have been the best efforts of English education, English laws, or even English practical science, as displayed only in the construction of roads and irrigation canals, had not the mighty agency of steam—and more especially of steam locomotion—been called to its assistance. This wonderful vivifying power, scarcely applied, at once commenced its beneficent work, and with a yearly increasing rapidity outstripping imagination, has since continued to quicken the pulse of a whole continent; to infuse a healthy circulation into the stagnant body politic of a vast congeries of peoples; and to urge its rising energies along a new highway of industry, commerce, and material progress, from which it can now never recede.

Nor is it possible to suppose that this mighty upstirring of the various peoples of India will not be accompanied by a general loosening and final casting off of the trammels of superstition, or be unattended with a corresponding moral and religious advancement, in a land from whence, long ages before the infancy of European civilisation, the world had already received some of the most profound conceptions of the human mind; a land which has been the birthplace of an elevated moral and religious philosophy, enriched with many a potent germ, and ready in the more fertile soil of a healthy material progress, and under the influence of an advancing culture, to expand, and assimilate all the ripest products of Western thought. Under the guiding direction of Providence it is from the British nation that the vast continent of India has received the leaven of a new moral

and material regeneration, which can now never cease to operate until it has raised the country to a high level of power and civilisation. The most potent factor in this truly wonderful resurrection of a whole people, so visibly taking place before the eyes of the present generation, is unquestionably the railway system of the country; and there is little reason to doubt that the powerful onward impetus already imparted by railway communication—even if every other instrument of English power were relaxed or removed—would continue to prevail, and that it will ever remain a lasting memorial of the influence of Great Britain on the destinies of India.

It will thus be a matter of no little interest to retrace, even in outline, the main incidents of the rise and early development of Indian railways; but, in order that the reader may intelligently follow the thread of such a narrative, it is first necessary to cast a rapid glance at the principal features of the physical geography of the country. The continent of India is, however, so large and diversified, that in a mere outline description of its physical geography it will only be possible to point out a few of those broad and well-marked features which more specially affect the operations of the railway engineer. India, considered as lying between the mouths of the Ganges and Brahmaputra on the east, the line of the Indus on the west, the Himalayan mountain ranges on the north, and Cape Comorin on the south, has an extreme length of about 1800 miles, an extreme breadth of 1400, and a coast-line of 3600 miles. Geographically, the country is divided into two well-marked natural divisions, differing entirely from each other in physical characteristics, respectively named, 'Hindustan' and the 'Deccan.' Hindustan, comprising the whole northern and north-western portion of the main continent, from the delta of the Ganges to the delta of the Indus, is characteristically a great alluvial plain of only moderate elevation, stretched out immediately at the feet of the Himalayan Mountains. The Deccan, is characteristically an elevated and more or less undulating plateau or tableland, occupying the greater portion of the whole southern extension, below Hindustan, of the Indian peninsula. Hindustan includes a large portion of Bengal

proper, the upper Provinces of the north-west, the Punjab, Scinde, Rajputana, and Guzerat, and extends southwards as far as the main chain of the Vindhyan mountains, a chain stretching from the head of the Bay—or Gulf—of Cambay in a general north-easterly direction, with gradually diminishing altitude, as far as the great southern bend of the Ganges at Rajmahal in Bengal. On the eastern or Bengal side, the great plain country of Hindustan comprises the humid and naturally fertile delta of the Ganges, and its surface is scored with a multitude of river arms, and water-channels, affording easy water communication in almost every direction. The western and north-western side of the great alluvial tract consists for the most part of dry waterless plains, traversed by a comparatively small number of large rivers, some of the most extensive interfluvial regions being practically desert, and all entirely dependent on artificial irrigation for fertility. The principal rivers of Hindustan are the Indus and the Ganges, which, rising in the heart of the Himalayas, and fed by its eternal snows, flow—the first in a general direction, north to south, the second west to east, discharging themselves into the Arabian Sea and the Bay of Bengal respectively at Karachi and Calcutta. Confluent to the Indus are the remaining four great rivers of the Punjab, viz., the Jhelum, the Chenab, the Ravi, and the Sutlej (respectively the ‘Hydaspes,’ the ‘Ascesines,’ the ‘Hydrazotes,’ and the ‘Hysudrus’ of the Greek invasion). The three principal tributaries of the Ganges are the Jumna, the Gogra, and the Sone. Along the whole northern boundary of the low-lying plains of Hindustan, the triple Himalayan chain of lofty mountains present—and will probably for a long time continue to present—a practically impenetrable barrier to railway extension in their direction.

South of the principal Vindhyan range of lesser mountains, which stretch right across India from the Gulf of Cambay to the Ganges at Rajmahal, the main portion of the peninsula is occupied by the high tableland of the ‘Deccan.’ This elevated plateau does not, however, for the most part extend to the actual sea-coast. Along the whole western sea-board, from the Tapti river to Cape Comorin, the high land terminates abruptly in steep precipitous slopes and bold rocky bluffs, leaving a low-

lying maritime plain—seldom more than about 30 miles in width—between them and the sea. The edge of the high land, from the Tapti to a gap which breaks through its wall at Palghât, in the neighbourhood of Coimbatore, is called the ‘Western *ghâts*,’ or ‘Syhadree’ mountains. The general elevation of its ridge-line does not exceed 3000 feet above the sea, and it is nowhere less than about 2200, but it reaches 5000 feet at Mahableshwar, and 6000 feet in Coorg, to the south of which the Neilgherry range of hills trends inland in the direction of Madras, on the opposite coast. Below the gap at Palghât, the range of *ghâts* extends to the extreme southern point of the peninsula at Cape Comorin. The average breadth of the crest of the Western *ghâts*—presenting a more mountainous character than the general tableland to the eastward—is only about 10 miles, although numerous spurs are here and there projected across the plateau for a further distance of 20 or 30 miles. Towards the southern end, however, the mountainous district reaches 40 miles or more in width. In order to make more plain to the reader the extraordinary nature of the obstacle presented by the line of the Western *ghâts* to the progress of any railway in the direct inland line from the coast, it is necessary to point out that these *ghâts* are not to be considered as a range of hills or mountains *through* which a more or less difficult passage might be found by following the direction of the main valleys on either side, with or without tunnels at the summit, but they consist of what is virtually an almost vertical step, forming a kind of retaining wall to the Deccan high lands; so that a railway attacking them from the west has to climb the face of what is practically a line of sheer precipices, from 2000 to 3000 feet in height, broken only along its front by deep rifts or ravines.

The narrow and low-lying maritime plain situated below the *ghâts*, along the western coast, is occasionally broken by low hills, and is intersected by the estuaries of numerous mountain streams, which descend from the rocky channels and gorges of the high land. From the edge or ridge of the Western *ghâts* the elevated plateau dips away to the east, terminating a short distance before reaching the Bay of Bengal in a line of hills of more gentle contour than those on the west, called the

‘Eastern *ghâts*.’ The upper tableland is traversed by a number of great rivers, which, rising on the spurs of the *ghâts* on the western side of the peninsula, flow across the whole extent of the plateau, break through the line of Eastern *ghâts*, and descend into the Bay of Bengal. The chief of these rivers are the Kistna, the Godavery, and the Mahanadi, each having many large and important tributaries.

The Vindhyan mountains forming the northern boundary of the Deccan table lands are composed of three distinct chains, viz., the most northern, or ‘Aravalli’ range of hills—geographically situated in Hindustan—the central or main Vindhyan range, and the southern or Satpura range of lower hills. Between the Aravalli and Vindhyan line of mountains the river Chumbal flows northwards to the Jumna : between the Vindhyan and Satpura ranges the great river Nurbudda flows in a westerly direction to the Gulf of Cambay and the Arabian Sea, whilst rising from neighbouring sources the Sone river flows north and eastwards to the Ganges. The Deccan geographical division of India comprises all the Central Provinces, the greater part of the Bombay Presidency, Hyderabad, Mysore, and the whole of Madras.

Over the vast extent of the great plain country of Northern India or Hindustan, with small exception, the soil is an alluvial deposit of fine sand and clay reaching to an unknown depth. Intermingled with this soil is found immense quantities of *kunka*, a concretion of carbonate of lime and clay, either in the form of hard nodules or in thin beds. This substance, which can be collected with facility, yields when burned an excellent hydraulic lime, admirably adapted for building purposes.

From the points of view of the railway engineer, the most important characteristics of the rivers of Hindustan are their great average size, the immense volumes of water periodically brought down by them during the seasons of flood, the often enormous extent of their inundations, and the erratic and unstable character of their channels. The rivers commonly occupy broad shallow valleys, varying from a mile to 7 or 8 miles in width. These valleys are bounded by low marginal banks of varying breadth, on which the principal towns and

villages are placed. Within the limits of deviation imposed by these more or less permanent banks the rivers at all times wander at will, or sometimes during the season of floods the greater part or the whole of the shallow valley may be filled with turgid water, spilled from the tortuous main channel, which alters its course through the valley from season to season according to the set and wearing action of the current against the light alluvial soil through which it runs. In the lower reaches especially, owing to the heavy annual deposit of silt brought down by the rivers, much of the plain country remote from the banks is at a lower level, and is subject to periodical inundation through the water-courses or *nullas* which intersect the marginal higher ground. The large rivers of the Punjab, flowing through vast level plains of light alluvial deposit are of an exceptionally erratic character; the course taken by their main channels varying over wide limits, so that the works necessary to constrain the body of the stream to preserve a reasonably permanent alignment in the neighbourhood of bridges crossing them, and the net width of waterway to be allowed to such bridges, are among the most difficult problems the railway engineer in Upper India is called upon to solve. Over the higher and more hilly region of the Deccan and south country, with geological formations of greatly diversified character, the more defined catchment basins of the rivers, together with the comparatively fixed and permanent location of their channels, reduces these particular difficulties to more ordinary proportions.

In all countries having free access to the sea, the large commercial ports are among the principal natural centres from which trunk lines of railway will radiate, or the termini towards which they will be directed. This is most markedly illustrated in India, where, notwithstanding its 3600 miles of coast-line, convenient commercial sea-ports are singularly few and scarce. Along the whole extent of the eastern coast, from the head of the Bay of Bengal to Cape Comorin, no really commodious harbour exists. Madras, situated on the eastern coast, is an important railway centre, as the seat of a Presidency Government, but has no natural harbour, and can take but little rank as a commercial seaport. On this side of India the only prac-

ticable port for large ships is Calcutta, situated 100 miles inland on one of the mouths of the Ganges called the Hooghly, through which the navigation is intricate and more or less dangerous. On the western coast the only commercial harbours of any consideration are Bombay and Karachi, of which Bombay is by far the most commodious and extensive. Practically, therefore, the important seaports of India are limited to Calcutta, Bombay, and Karachi, the capabilities of the last being comparatively small, and of recent development.

It was therefore from Bombay, the true commercial capital, and from Calcutta, the political capital of India, that the two first lines of railway, viz., the 'Great Indian Peninsula' and the 'East Indian,' emanated. Both these trunk lines were projected and were commenced at about the same time, although it was a short and easy length of the former that was first opened for public traffic.

It will be obvious, on a first inspection of a map of India, bearing in view the political and commercial importance, and the relative positions of the three Presidency capitals—Calcutta, Bombay, and Madras—that three trunk or main lines of railway will be of primary importance, viz., one from Calcutta, following the general course of the valley of the Ganges, towards Delhi, and onwards to Lahore and the north-western frontier of the Punjab; one from Bombay, meeting the first nearly at right angles somewhere midway between Calcutta and Delhi; and one connecting Madras with Bombay. The two first were, in point of fact, the earliest lines undertaken, and are those which governed the fortunes of the immediately succeeding railways. A rapid sketch of their early history will, therefore, serve to illustrate the story of the introduction of railways into India.

So early as the year 1840 or 1841, projects for extending the benefits of railway communication to India appear to have been discussed by engineers and private capitalists in England, but it was not until two or three years later that the Honourable Court of Directors of the East India Company was approached with any definite proposals. At this time the Government of India was passive, if not actually hostile, to the idea of introducing railways. No doubt the more enlightened minds, both

in India and in England, were fully alive to the advantages certain to accrue to the commerce of the two countries; but it was not conceived possible that the vast amount of capital required could be raised, or that sufficient inducements existed, or could be held out to public investors, which would prevail upon them to embark money upon so visionary and uncertain an enterprise as railways in India. It was assumed that the construction and management of railways could only be undertaken by private enterprise and capital, and that the novelties and unknown difficulties of their introduction into so distant and backward a country, would be sufficient to inspire the general public with certain distrust in the speculation.

In the year 1843, on the invitation—as generally supposed—of the then Governor, Sir George Arthur, Mr. G. T. Clerk, a railway engineer who had been employed on the Great Western Railway in England, went out to Bombay in order to study on the spot the facilities for railway construction from that port to the districts above and beyond the line of Western *ghâts*. In the following year a committee for a railway company was organised in Bombay, having for its object, in the first instance, the construction of a line of railway from the port to the foot of the *ghâts* only, but this inadequate scheme was soon merged in another association having more extended aims, to be named the ‘Great Eastern Railway.’ Mr. Clerk originally advocated the construction of a line branching off into two lines at Callian, the one surmounting the line of Western *ghâts* to the north-east by the Thull *ghât* towards Candeish, the other passing them to the south-east by the Bhore *ghât*, in the direction of Poona and Madras, on a general alignment almost identical with that—after many intermediate vicissitudes—subsequently adopted. This scheme was warmly supported both by the Governor and the Chamber of Commerce of Bombay, but it failed to meet the approval of a committee of military officers appointed to report on it by the Government of India, it being believed that the obstacle presented by that range of steep and lofty precipices, running parallel with the sea-coast at a distance of about 30 miles inland, called the Western *ghâts*, presented a practically insurmountable barrier to any economical railway construction in the direct easterly

line from Bombay. The 'Great Eastern Railway' scheme for the present, therefore, remained in abeyance.

In the meantime a Mr. Chapman had been busily engaged in England in preparing and advocating the formation of a company for a vast scheme of railway enterprise, intended to embrace the whole of India in its scope. This project, which took the ambitious title of the 'Great India,' or 'Great Indian Peninsula Railway,' was to extend a trunk line due east from Bombay, up the *ghâts*, and right across the peninsula to a harbour at the mouth of the Godavery river on the opposite coast, almost half-way between Calcutta and Madras. Lines of rail were to skirt the coasts, and as soon as the main trunk line had surmounted the *ghâts*, branches were to diverge, one north-east to Allahabad on the Ganges, and one south-east to Madras, from which lines other branches were to ramify practically all over India.

Mr. Chapman, on learning what was being done in Bombay, proposed an amalgamation with the 'Great Eastern Railway' promoters, and eventually the latter association was merged into the 'Great Indian Peninsula' Company, Mr. Clerk being appointed engineer in India. The Bombay committee were, however, naturally adverse to the proposal of a trunk line across the peninsula to the opposite coast, chiefly on the ground that it would be of minimum benefit to Bombay, and that one-half would be a competing line to the other half. In the meantime other promoters, both on the side of Calcutta and Madras, taking the field, the 'Great Indian Peninsula' project, although still adhering to its ambitious name, gradually, by the year 1845, came to restrict its scope to a system designed only to connect with Bombay the principal producing districts situated at a reasonable distance beyond the *ghâts*. These producing districts lay to the north-east and south-east of the port, and any direct lines to them must necessarily bifurcate below the *ghâts*, and mount them by two separate ascents, but these *ghât* ascents involved stupendous engineering difficulties, and the great body of the promoters were prepared to sacrifice directness in favour of one central ascent, to be situated at the Malsej *ghât*, with a bifurcation somewhere above instead of below the line of *ghâts*. Later and more detailed investigation,

however, led to an abandonment of this idea, and a reversion to the original design of the 'Great Eastern' scheme, viz., two separate *ghât* ascents, one to the north-east and one to the south-east of Bombay, which, as we shall see in the following chapter, was the course eventually adopted and carried out.

It was from the early 'Great India' or 'Great Indian Peninsula' Company—the promoters of the visionary scheme of constructing a main trunk line of railway right across the peninsula from Bombay to Caringah, at the mouth of the Godavery river—that the first suggestion for a Government guarantee appears to have emanated. In November of the year 1844, through their agents in India, these promoters proposed that, in order to stimulate the ardour of those persons seeking safe investments at moderate rates of interest, the Government of India should offer a guarantee of 4 per cent. from the date of opening the railway, or any portion of it, with a proviso that if the profits exceeded 10 per cent. the surplus should be devoted to a fund expressly appropriated to a further extension of the lines under the company—extensions subject in their turn to a similar guarantee. The duration of the arrangement was to be limited to some term of years to be agreed upon. It is needless to say that these proposals did not meet with acceptance, but among the numerous railway promoters, who had by this time begun to turn their attention to an Indian field of operations, it was very early seen that there would be little probability of raising in the public market any capital adequate for the purposes of railway enterprise in India, unless the Honourable East India Company were willing to offer some kind of security for the money advanced. Among the lines mooted at the very earliest date was one which took the name of the 'East Indian Railway,' having for its object the construction of a line starting from Calcutta and following the Mirzapore road for a distance of 140 miles towards Allahabad—Mr., afterwards Sir Donald, Stephenson, being the principal promoter. At the end of the year 1844 the managing director of this proposed Company suggested that, in order to encourage the introduction of railways into India, the Government should adopt a plan then working successfully in France, and guarantee a minimum dividend to the railway shareholders from the date of opening the line for

traffic. Negotiations were opened on this basis. The company proposed a guarantee of 4, subsequently lowered to 3, per cent. on a capital expenditure which was not to exceed one million sterling, or an annual bonus of £30,000 until the profits should reach 3 per cent. Soon, however, the important modification was introduced, that the interest should be guaranteed from the commencement of operations, instead of from the date of opening for traffic. The Honourable Court of Directors, after due consideration of these, together with the various proposals made by other nascent companies, addressed an important despatch to the Governor-General in India, calling attention to the whole question of the introduction of railways into that country.

This despatch, dated 7th May 1845, is interesting as being the first official recognition of the desirableness of railways for India. It contains, moreover, some curious assumptions which have been signally falsified by the event, and apprehensions of peculiar difficulties in railway construction which have not in practice been seriously experienced. It was assumed, on grounds which probably few at that time could have called in question, that, contrary to the experience which had been already gained in England and Europe, the 'remuneration from railroads in India must for the present be drawn chiefly from the conveyance of merchandise, and not from passengers.' It was apprehended that, in addition to the ordinary difficulties common to railroads in all countries, there were others peculiar to India which would be almost insuperable, such as the violence of the periodical rains and inundations, the continued action of violent winds, and the influences of extreme heat; the ravages of insects and vermin, and the destructive effects of spontaneous vegetation on timber, earthworks, and masonry; the unenclosed and unprotected nature of the tracts of country traversed, and the difficulty and expense of securing the services of competent engineers and engine-drivers. In view of these considerations—of no small weight in the year 1845—the despatch from the Court of Directors was soon followed by the deputation from England of an experienced civil engineer, who was selected as especially conversant with railway questions and requirements. The gentleman selected was Mr. Simms, C.E., who arrived in

Calcutta in September 1845. He was instructed to examine into the whole question of the applicability of railways for India in all its bearings, and it was directed that two competent military engineer officers, to be appointed by the Government of India, should be associated with him, and the committee thus formed were to investigate and report on the whole matter, and to suggest some moderate and convenient length of line which might be undertaken as a sort of experiment. The directors also made certain general suggestions with regard to the nature of the control to be exercised by Government over any railways that might be intrusted to the agency of private capitalists, or companies, and recommended these suggestions for consideration and comment.

In February 1846, Mr. Simms drew up a set of proposed stipulations for the main clauses of contract between the Government and private railway companies. In return for certain concessions to be made by the former, the principal of which was the very moderate one of a free grant of land, companies were to be subject to a most complete and minute government regulation and control, and at the expiration of a lease of certain definite duration, the railway, in perfect order and repair, was to be handed over to the Government without payment. In addition Mr. Simms suggested that, if thought advisable, a small percentage might be guaranteed on the actual capital cost of the works from the date of opening for traffic.

In the same month the committee of engineers submitted their report on the general applicability of railroads to the conditions and circumstances of India, and on the apprehended peculiar climatic and other difficulties, which they had been invited to consider. On the general question, the committee was of opinion that railways, far from being inapplicable, were, on the contrary, quite capable of being constructed and maintained in India, as perfectly as in any part of Europe, and, moreover, that their introduction was a great desideratum. With regard to the apprehended peculiar difficulties enumerated by the Court of Directors, they admit their existence in some degree, but regard them as easily surmountable. Seriatim, each item is gravely discussed, and it is quietly enunciated, possibly with some satire, that suitable arrangements in the

construction of the works will overcome any difficulty likely to arise from these causes to the line itself, nor do they consider them to be of a nature to prevent an immediate prosecution of railway enterprise.

The committee in a long and—considering the extreme paucity of data existent at that time—very able report, recommend the introduction of railways into India by the agency of private companies, and advocate the construction of a line following a direct route from Calcutta to Mirzapore, and thence to Delhi, with various lateral branches. If a short experimental line is considered necessary, they advise one between two important centres, such as Cawnpore and Allahabad, or a shorter line between Calcutta and Barrackpore. The committee in their report did not enter into the question of the cost of construction of railways, or the probable remuneration, but somewhat later, on being pressed for their opinion on these points, reported £14,000 to £15,000 per mile, without rolling stock, as the probable initial outlay—an estimate not very far from the truth for the earlier broad-gauge lines; but they declined to give an opinion on the probable returns, being entirely without data on which to base an estimate.

Mr. Simms' suggestions for contract with railway companies, and the report of the engineering committee, were then taken into consideration by the Government of India. Lord Hardinge, the Governor-General, was at the time absent from Calcutta, the question was, therefore, discussed by the president (Sir Herbert Mallock) and members of council. The proposal that Government should provide land free of cost was unanimously approved. In view of this concession it was not considered necessary that any guarantee of interest should be offered, but all the members were, nevertheless, agreed in the opinion that the fullest powers of directing the construction, and controlling the management, of all railways should remain with the Government. Mr. Simms' proposal that railway companies should deliver over at the termination of their lease the whole railway, free of cost, was objected to on the obvious ground that it was highly improbable that any projectors would agree to such an arrangement; it was considered quite sufficient to secure to Government the option of purchase on settled terms at the end

of a certain period. Finally, as the conclusion of an elaborate and forcible minute on the whole question, the president and council considered that a long length of line from Calcutta to Delhi should be chosen as the first line to be encouraged, and that if an experimental length of railway was deemed necessary at all, it should be one between Calcutta and Burdwan, with a branch to Rajmahal on the Ganges.

In July 1846 the Governor-General recorded his own views in a brief but statesmanlike minute. Lord Hardinge was disposed to grant far more substantial encouragement to railway enterprise than were the president and members of his council. He pointed out that a lease of land representing a contribution roughly estimated at £200 a mile, to a work calculated to cost £14,000 a mile, was totally inadequate, and he expressed his conviction that 'the speculation of the railway company (*i.e.* the proposed "East Indian") will entirely fail, unless it be largely and liberally encouraged by the East India Company.' Enumerating the advantages and economy to Government of a daily mail service between Calcutta and Delhi, and the important military aspects of the question, he gave, in conclusion, his opinion that 'on military considerations alone the grant of one million sterling, or an annual contribution of five lakhs of rupees, may be contributed to the great line when completed from Calcutta to Delhi, and a pecuniary saving be effected by a diminution of military establishments.' The Governor-General, in fact, thoroughly realised that, without some really large and substantial assistance, it would be impossible for joint-stock companies to raise the capital necessary to construct the great railroads of India, although he was rightly opposed to the principle of granting such aid until the period of completion of the works.

The various opinions and reports of the authorities in India were now referred to England, and from that date commenced a long and weary triangular duel of negotiation between the promoters of the companies and the Honourable Court of Directors in London, and between the latter and the Commissioners for the affairs of India, or Board of Control. These negotiations and discussions were protracted over a period of about three years, a delay which appears to have been almost entirely

chargeable to the parsimonious views and difficulties raised by the Board of Control. In the final result of the struggle, during which, on more than one occasion, the negotiations almost completely collapsed, the companies practically obtained all the concessions for which they had so long contended, viz., an absolute guarantee of 5 per cent. on all sums authorised to be paid into the treasury of the East India Company, so long as they held ownership of the railways, and repayment of the actual capital expended on the lines, plant, and rolling stock, at any time they pleased, on giving six months' notice of surrender. A general understanding having been at length arrived at, preliminary legal agreements were signed with the 'East Indian' and 'Great Indian Peninsula' Railway Companies on the 17th August 1849. The final terms of the contracts some time subsequently entered into under the much abused 'guarantee system,' between the Government of India and the railway companies, may be thus briefly summarised.

1. 'The design and execution of certain railroads in India are intrusted to joint-stock companies.'

2. 'The Indian Government guarantee interest on moneys duly raised by companies and paid over to Government, controlling at the same time their expenditure and operations.'

The interest guaranteed was from $4\frac{1}{2}$ to 5 per cent. for ninety-nine years, on all money paid with authority into the Government Treasury. An option was given to the railway companies to demand repayment, on six months' notice of their intention to surrender the railway, of the whole capital duly expended by them. The Government also agreed to 'leave to the railway company, free of cost for ninety-nine years, all land required for the permanent works of the railway, and further to provide all other land temporarily needed for its construction.' In return for these important and valuable concessions, the Government retained power to supervise and control the whole of the affairs, operations, and expenditure of the companies, whether in India or in England; they obtained the free carriage of mails, and the carriage of troops and military stores on favourable terms, and the power of appointing a Government director to sit at the boards of railway companies in England, having a veto on all their proceedings, except certain privileged

communication with legal advisers. All receipts from traffic were to be paid into the Government treasury, and all profits above the guaranteed interest were to be divided equally between the Government and the shareholders, until the debt of the railway company for guaranteed interest was repaid, after which all profits were to accrue to the shareholders. Powers to surrender by the Company, and powers of purchase by the Government, or to take possession in case of failure of agreement, were also given, and the money transactions between the contracting parties were to be calculated at the rate of 1s. 10d. per rupee.¹

These terms, highly favourable as they undoubtedly were to the companies, naturally removed all difficulty in obtaining almost unlimited funds for the purposes of railway construction; and in spite of much that can be urged against them under the results of practical working, they have had the effect of conferring on India the inestimable indirect benefits of railway communication, and inaugurating her career of material prosperity from a much earlier date than could have been effected by any other means.

¹ The rate was varied in other contracts.

CHAPTER VII

INTRODUCTION OF RAILWAYS INTO INDIA

Introduction of railways into India (*continued*)—Commencement of railway construction—Slow progress—Causes of delays—Discussions on fundamental principles—Novel theories—Report and proposals by Colonel Kennedy, R.E.—Proposed regulations—Ruling gradients and limitation of cost—Coast and valley lines—Long discussions—Suspended system of railways—Lord Dalhousie's exhaustive minute—Sanction accorded to line from Calcutta to Delhi—Western *ghât* surveys ordered—Era of Indian railways begun—Studies for the *ghât* ascents from Bombay—Final approval of the Bhoire and Thul *ghât* proposals—Main route followed by the Great Indian Peninsula Railway—The East Indian Railway—Experimental length of line—Position of Calcutta—The Hooghly—Determination of the question of standard gauge—Principal standard dimensions fixed—Government control—Consulting engineers appointed—Large powers exercised—Vexatious delays—Parliamentary committee—Beneficial effect of report—Principal features of the Government control—East Indian Railway—Early proposals and particulars—The Madras Railway Company—Early history and initiation.

We have seen that the 'East Indian Railway' emanating from Calcutta, and the 'Great Indian Peninsula Railway' from Bombay were projected and organised at about the same time. Construction work on the section from Bombay to Callian—33 miles in length—was commenced in February 1851 as an 'experimental' line; and a portion of this section, 20 miles in length, from Bombay to Tanna, was opened on the 16th April 1853, about a year and a half before the opening of the first 37-mile 'experimental' section of the 'East Indian Railway' from Calcutta to Pandua.

Rapidity, in the early construction of railways in a new country situated as India was forty years ago, was hardly to be expected. Practically nothing in the way of manufactured materials or working plant was purchasable in the country; and the engineers or contractors had to manufacture, prepare

or collect—often from great distances—everything required, such as bricks, stone, lime, timber, iron-work, or plant of all kinds. At the commencement of operations, and for some time subsequently, no trained subordinate staff existed, and inspectors imported from England—then a vastly more distant country than at present—were almost useless until they had acquired some knowledge of the language, and had learned and unlearned much new and old experience; and lastly, skilled labour of almost every description did not exist, until in course of time it could be trained and educated, and even ordinary unskilled labour was difficult to secure, until full confidence in the new employers had been gained.

Much delay was also entailed by the natural hesitation of the chief Government authorities amidst the conflicting views of responsible advisers, and the opening up anew of lengthy discussions on fundamental principles, whether as guiding the choice of route for the railways, or the actual details of construction; principles, the greater number of which had already been threshed out in the twenty years' experience of practical railway engineers in Europe, but which were more or less unfamiliar to many of the military engineer officers in high authority in India, who necessarily approached the subject from an almost purely theoretical standpoint.

That some mistakes should have been made was only what might have been anticipated; but that errors of judgment should have been on the whole so few, and that they should have entailed so little ultimate loss beyond some unnecessary delays, is a remarkable evidence of the care and skill with which the many large-scaled problems presented by Indian railways, were from the commencement met and overcome. Amongst the most prominent of the many elaborate and startling theories broached on the eve of Indian railway construction, was one which emanated from Colonel Kennedy, R.E., for a short time Consulting Engineer to the Government of India for Railways, and subsequently Consulting Engineer to the Bombay and Baroda Railway Company. In a report or memorandum written at the close of the year 1851, addressed to the Honourable Court of Directors, Colonel Kennedy drew up a kind of code of rules and regulations for the

proposed guidance of railway authorities in India, containing some essentially novel views and opinions, which, coming from a man in his prominent position, necessarily demanded attention and careful consideration. Dealing first with the military and economical aspects of the question of railways in India, Colonel Kennedy proceeded, in twelve proposed regulations, to lay down the broad general principles on which the whole railway system of the country ought, in his opinion, to be guided, and, in unsparing language, he condemned all that had hitherto been done by railway engineers.

In opposition to the contemplated direct route of the 'East Indian Railway' from Calcutta to Mirzapore, passing through the Shergotty range of hills, and the ascent of the line of Western *ghâts* by the proposed 'Great Indian Peninsula Railway' from Bombay, he argued in favour of a sort of Median and Persian Government decree, that no trunk line of railway in India should have a ruling gradient of more than 1 foot in every 2000 feet, or 1 in 330 on secondary or branch lines; that no line should be undertaken which was estimated to cost more than £5000 a mile, exclusive of bridging the larger rivers; and in order to secure the necessary flat gradients, and on the hasty assumption that the rivers of the country were everywhere the main arteries of commerce, he proposed that lines of railway should be constructed skirting the whole coast line of India, and thence be carried all over the interior of the country by closely following the lines of the great river valleys. Thus the line of the 'East Indian Railway' should closely follow the course of the Ganges from Calcutta, *viâ* the great bend at Rajmahal; and the line of the 'Great Indian Peninsula Railway' from Bombay, instead of recklessly ascending the Western *ghâts* on a necessarily steep and most expensive alignment, should follow the natural routes to the interior—on the north, *viâ* the coast line and the Tapti and Nerbudda valleys; and on the south to Madras, *viâ* the coast, the gap in the *ghâts* near Coimbatore, and the Kaveri valley to the eastern coast line.

In the long discussions which followed this celebrated memorandum it was ultimately agreed that no such gradients as those proposed for the trunk lines were economically feasible,

even by following the course of the river valleys; that it was better, in most cases, to construct a line with steep gradients than no railway at all; that the cost of the increased length of line necessary to secure such flat gradients would be greater than the cost of working the steeper grades, *i.e.* that a short line with steep grades might in the majority of cases be a cheaper line to work as well as to construct, than a longer one with easier gradients. It was also seen, that to limit the estimated cost of railways per mile to any rigidly fixed sum, and that a sum altogether inadequate, would be not only impracticable but extremely injudicious. With regard to the recommended coast and river valley scheme of railways for all India, it was opposed, that not only would the coast lines cross the whole drainage of the country at its largest point, and be the most expensive to construct, but would also commercially and politically be the most useless, and everywhere in direct competition with sea-borne traffic. It was shown that in every country it is necessary that railways should be laid out with reference to the distribution of population, and to the general resources and necessities of the people, rather than to the mere physical characteristics of its geography, and with reference to the greatest political and commercial advantages, than with a mere view to easy gradients, however desirable these might be when readily obtainable. Moreover, the idea that the great river valleys were necessarily the main arteries of commerce, was in India—except in a few instances—shown to be peculiarly erroneous, and that an attempt to lay down *any* inflexible and rigid system of railways to cover the whole face of the continent was both premature and unpractical.

Belonging to an entirely different category, and as a mere curiosity, may also be mentioned the appearance—shortly after Colonel Kennedy's noted memorandum—of a book written by a Colonel Grant, of the Bombay Engineers, to prove that the idea of laying down the permanent way of railways on the surface of the ground was utterly inapplicable under the conditions and circumstances of India. He recommended, with all seriousness, that every Indian railway should be suspended throughout its entire length by a regular series of suspension chains, at a minimum height of 8 feet above the ground, which

he considered would be ample to place it above the reach of animals. Costly models of this unique system of railways were even prepared and exhibited. Several other theories of equally ingenious and erratic character had to be combated by the infant railway system of India, much as the human child has to undergo its regular course of infantile maladies.

The twelve general rules and principles advocated by Colonel Kennedy, although in their most essential features not adopted, had nevertheless, the advantageous result of compelling the close attention of the Government authorities to many matters of the highest importance in connection with the first location and construction of railways on a new and virgin soil, and in this manner may possibly have hastened the arrival at precise and definite conclusions respecting them. In the early part of the year 1853, Lord Dalhousie, then Governor-General of India, after having received the reports and opinions of all the various consulting engineers and railway experts in the country, reviewed in a masterly minute, at once clear and exhaustive, the whole question of railway routes for the earlier trunk lines, and the guiding principles to be adopted on all the main points of controversy which had been so long under discussion. The recommendations formulated in this peculiarly lucid statement, which have rendered it a justly celebrated document in the history of Indian railways, were at once fully concurred in by the Honourable Court of Directors in London, who were now thoroughly alive to the vast benefits certain to ensue from the construction of an extensive and well-planned system of railway communication in India, carried out in a large and liberal spirit. They accordingly, without hesitation, gave their assent to the immediate commencement of a line from Calcutta by the Ganges valley to Delhi. With regard to the railway from Bombay, they directed that surveys for the several *ghât* routes proposed should be at once undertaken, and they expressed their willingness to sanction the prosecution of a line from Madras to Bombay *viâ* Cuddapah and Bellary, as well as certain other proposed lines, should the result of the surveys prove satisfactory.

From this date, viz., the latter end of the year 1853, the era of Indian railways may be considered as really begun. The

line of the 'East Indian,' from Calcutta towards the Upper Provinces, was fairly launched on its long journey. The 'Great Indian Peninsula' had opened its first section of iron-road to Tannah, in the direction of Callian and the *ghâts*, and the minds of all those responsible for the interests and well-being of India had now fully recognised the importance as well as the practicability of an extended system of railways in that country, and were actively engaged in the solution of its many initial problems. The infant line from Bombay had, however, stopped short at the foot of stupendous difficulties, and had yet to pass through some period of painful struggle before the path of its further progress could be cleared.

Mr. Clerk, who, as we have seen, ten years before, when working in connection with the then-called 'Great Eastern Railway,' had advocated the surmounting of the Western *ghâts* by two routes, in the main identical with those subsequently adopted, appears, on detailed investigation, to have been daunted by the formidable character of the difficulties his proposals would involve. In the year 1847, we find him arrived at the conclusion that the Thull and Bhore *ghâts* were virtually impracticable for railway purposes, and advocating in their stead a single passage at a point situated about mid-way between the two, by a route known as the Malsej *ghât*, with a bifurcation of the line at some point *above*, instead of *below* the line of *ghâts*. This route was the one at first contemplated by the 'Great Indian Peninsula Railway' Company, into which the 'Great Eastern' had in the meantime merged, and was, moreover, the one generally agreed to by Government, and was incorporated in the first agreement entered into with the company in 1849.

In the year 1850, Mr. James Berkeley, C.E., who was appointed chief engineer to the company, entered upon a detailed examination of the Malsej *ghât* route, and soon came to the conclusion that the difficulties of carrying a railway by that line were practically insuperable, and that on commercial grounds it would be injudicious; he, therefore, turned his attention to the abandoned routes *viâ* the Thull and Bhore *ghâts*. These *ghâts*—the first to the north-east, the second to the south-east of Bombay—were each already occupied by

ordinary roads. In the early part of the century, under the orders of the great Duke of Wellington, a track, passable by artillery, had been formed up the Bhore *ghât*, leading towards Poona, and in the year 1830 this track had been re-made, and improved into a cart-road, which was still in use as a trade route to the Deccan. Under the orders of the Bombay Government, a few years before the era of railways, an excellent road for wheeled vehicles had also been carried up the Thull *ghât*, and this road was now used for the mails, and formed the only serviceable trade route to the districts of Candeish. By the year 1852, Mr. Berkeley had traced and laid out a series of inclines by both these *ghâts*, which promised an eventual alignment for the railway, which, although severe, would be suitable for locomotives. In view, however, of the enormous difficulties that would in any case be involved, and more especially owing to the whole question of economical railway construction having been opened up by Colonel Kennedy's memorandum, the Government of India hesitated to commit itself to a definite decision as to the best north-eastern route to be followed by the Great Indian Peninsula trunk line, until further exhaustive studies and surveys were made, or until it was clearly proved that the route *viâ* the coast and the Tapti valley to Candeish—enabling the *ghât* ascent to be avoided altogether—was economically undesirable. With regard to the south-eastern route towards Poona and Madras, it was acknowledged that some *ghât* ascent was inevitable, but it was directed that further search should be made to discover, if possible, an easier route than that by the Bhore *ghât*. These instructions having been received, active steps to prosecute the surveys ordered were at once taken.

During their prosecution, however, the chief engineer of the Great Indian Peninsula Railway continued with unremitting care and industry his study of the Thull and Bhore *ghât* inclines. His survey of the proposed Tapti valley route enabled him to demonstrate, first, that it would, to the same fixed point in Candeish, require 131 miles of additional railway, and that it would cost over a million sterling more to execute than that *viâ* the Thull *ghât*, besides the saving in time, working expenses, and the additional profits ensured by the shorter

alignment, which, moreover, had the advantage of following the existing and natural trade route. He showed, also, that a perfectly practicable series of inclines suitable for locomotives was obtainable both by the Thull and Bhore *ghāts*, and that as all the heavy goods traffic from the Deccan districts would be in the downward direction towards Bombay, the *ghāt* inclines would be in favour, rather than adverse, to the working of the line.

It was not, however, until the end of the year 1854 that all objection to the Bhore *ghāt* route was withdrawn, and until the following year that the Thull *ghāt* proposals were agreed to, the approval of the Honourable Court of Directors to the latter not being recorded until the 31st January 1856, by which time it was finally decided to proceed with both these prodigious engineering undertakings. It will thus be seen that a very considerable period of time was expended in a thorough examination and investigation of the Syhadree range. Whatever portion of this long delay may be fairly debited to the hesitation of the Government, Bombay at least had the satisfaction of knowing that no exertions had been spared to prove that the earlier decisions arrived at by the company's engineers were thoroughly sound and practical.

The ultimate main line routes followed by the Great Indian Peninsula Railway are as follows. Proceeding across the marsh separating the island of Bombay from the island of Salsette, and across the arm of the sea separating the latter from the mainland of the Concan, the early experimental line, 33½ miles in length, which was completed and opened for traffic in 1854, arrives at Callian. From Callian two lines diverge—one north-east, surmounts the Thull *ghāt*, and proceeds to Bhusaval, from whence again two lines diverge, one extending to Jubbulpore, where it joins a branch of the East Indian Railway from Allahabad, and one to Nagpur, the capital of the Central Provinces. The second line diverging from Callian, mounts to the Deccan high lands by the Bhore *ghāt*, and proceeds to Poona, Sholapore, and Raichore, where it joins the Madras Railway. The total length of the Great Indian Peninsula system is 1288½ miles. In the year 1863, or ten years after the opening of the first section to Tanna,

552 miles were open for traffic, and by the year 1870 the system was complete approximately to its present dimensions.

It is now necessary to turn our attention to the fortunes of the 'East Indian' Railway, starting from Calcutta. We have seen that a preliminary agreement was entered into with this company on the 17th August 1849, but that it was not until the latter part of the year 1853—after Lord Dalhousie's celebrated minute—that the Honourable Court of Directors gave their final and unhesitating assent to the construction of the line the whole way to Delhi. In accordance with the early idea that it would be desirable, in the first instance, to construct a short length of railway in Bengal for the purposes of experiment (an idea also extended to each of the other Presidencies), the length from Calcutta to Burdwan, with a branch to Rajmahal on the Ganges, had been recommended as a suitable one for the purpose. On the signing of the agreement in 1849, it was proposed to construct a single line to Raneegunge, a point about 120 miles from Calcutta, situated near the coal-fields a short distance beyond Burdwan, and on the line of direct route towards Mirzapore and Delhi; the object being the opening up of this rich mineral district. In July 1850, Lord Dalhousie sanctioned the construction of the experimental line as far as Pandua, 37 miles in length, with works for a double line of rails, and recommended its extension to the Raneegunge coal-fields. In the same year the detailed surveys were put in hand, and the first section of land was made over in January 1851, when construction work on the experimental line actually commenced.

The capital city of India is situated on the *left* bank of the Hooghly tidal-channel, and any line of railway starting from it in the direction of Burdwan and Delhi would immediately have to cross this channel, an obstacle of considerable magnitude. Opposite Calcutta the Hooghly has a stream some 1700 feet broad, with a maximum depth of 40 feet below low-water, a tidal rise of 20 feet, with a very rapid flood velocity, and unusual difficulties in the formation of convenient railway approaches. It is probable that if capital had from the beginning been raised for the construction of the whole long length of 1017 miles to Delhi, the advantages of locating the terminus

of the line on the Calcutta side of the Hooghly would have overweighed the large, although in this case relatively small, expense of erecting a bridge over that channel, but for the purposes of a short experimental length of line with a capital of a million pounds only, it was plainly inadmissible; so that after some discussion of alternative proposals it was decided to commence the railway at Howrah, a suburb of Calcutta, situated on the right bank of the Hooghly opposite the city, communication being maintained by means of a steam ferry.

It became necessary somewhat before this time to finally decide upon the important question of standard gauge to be adopted for Indian railways. Mr. Simms, the consulting engineer to the Government of India, sent out by the Court of Directors in 1845, is said to have been the author of the 5 feet 6-inch gauge actually adopted, and it is probable that this particular width was selected merely as a convenient mean between the ordinary 4 feet 8½-inch and the 7 feet gauges then in use in England, and as a dimension giving more space for locomotive machinery and admitting more comfort in passenger carriages, than it was thought could be conveniently attained on the ordinary narrow gauge. The full bearings of the question of width of gauge for railways was at this early period imperfectly apprehended, and the decision arrived at was undoubtedly an unfortunate one, since there can be little question that, had the now fixed English standard been at first adopted, the railway system of India would have been spared whatever disadvantages have arisen from its present want of uniformity of gauge.

In the year 1856 the principal standard dimensions of road-way and rolling stock to be henceforth adopted, and strictly adhered to on Indian railway lines of the 5 feet 6-inch gauge, was definitely fixed by mutual agreement among the consulting engineers to each of the Indian railway companies, and was approved by Government. The extreme importance of a rigid uniformity in this respect, the want of proper attention to which had already occasioned, and still continues to occasion, much inconvenience on English railways, was thus early recognised in India, and the same principle of strict adherence to well-formulated standard dimensions, was also observed in the

case of the narrow-gauge lines subsequently introduced. As a consequence of this timely forethought, there is now probably no large system of railways in the world superior to that of India in respect of this important matter. The leading dimensions for railways of the 5 feet 6-inch gauge, fixed in the year 1856, were as follows :—

	Ft.	Ins.
Minimum clear width between two tracks, . . .	6	0
Minimum distance of platform-wall from rail, . . .	2	6
Projection of nosing not to exceed . . .	0	3
Minimum clear height for all openings above rail in centre of each line, . . .	14	6
Breadth from centre to centre of buffers, . . .	6	5
Height of centre of buffers above rail-surface, . . .	3	6
Extreme width of body of passenger-carriage, . . .	8	6
" " roof " " . . .	8	10
" " steps " " . . .	10	0
Maximum length between centres of wheels (all vehicles)	11	0
Minimum diameter of turn-tables, . . .	15	0
" " of engine-tables, . . .	40	0

Detailed lists and diagrams of maximum and minimum dimensions for all fixed structures, both inside and outside station limits, and of rolling stock, were also elaborated at a very early period, and have since been strictly enforced by the consulting engineers to Government for railways.

It has been shown, that from the earliest inception of railways for India, both the Honourable Court of Directors and the Indian authorities were thoroughly alive, not only to the importance but to the absolute necessity of retaining in the hands of the Government of the country, the fullest powers of control over all the proceedings and operations of the joint-stock companies proposing to undertake the construction of railways. Under the contracts entered into with the companies, and in exchange for the liberal terms offered, the Government, in fact, secured this control to an almost unlimited extent, whether as regards the supervision, expenditure, and staff of the companies during the construction of the lines, or after their opening for traffic. In England, as we have seen, a Government director was appointed to sit on the board of guaranteed railway companies, having a veto on all their proceedings, except certain

privileged communications with legal advisers. In India, the large powers of control, admitted by the contracts were at first exercised directly by the Government acting on the advice of a specially appointed consulting engineer conversant with railway practice, but as the multitudinous business connected with the early lines increased, and the constant reference of matters of detail to the supreme government became needlessly cumbersome, separate consulting engineers were appointed to each local government, and subsequently to special railway divisions, intrusted with large discretionary powers, which, however, they exercised under general rules and regulations laid down for their guidance. These rules and regulations were supplemented as need arose from time to time, and it was laid down that certain matters of general importance were to be specially referred to the Government of India for decision.

The officers appointed for the discharge of these important functions, requiring in their dealings with the officials of the companies, great tact, judgment, and professional ability, were for the most part, or entirely, selected from the corps of Royal Engineers. The system when at first established seems, as might be expected, to have worked with some degree of friction. Relative responsibility was, in fact, very ill defined. In constructional matters all initiation, both of design and estimate of works, was in the hands of the engineers of the railway; but these could execute nothing without the express approval of the Government officers, on whom, without any powers of origination of their own, was thrown a very large responsibility. The consulting engineers, themselves the agents of a higher authority, could obviously act only on reasonably full and detailed information, not always forthcoming in the particular shape demanded, and it could hardly be otherwise but that the procedure at starting should in some cases have led to vexations and delays, responsibility for which both sides considered themselves in a position to repudiate. The Government consulting officers in the early days of railways, although often men of great judgment and administrative ability, were rarely equal to the companies' engineers in practical experience of constructional details, whilst the latter were probably unduly impatient of a control and criticism, and of opinions which,

rightly or wrongly, they supposed to be frequently based on too purely theoretical grounds.

In the year 1857-58, a parliamentary committee was appointed to inquire into the causes of some delays which were alleged to have occurred in the prosecution of railway enterprise in India, and the whole subject of the special machinery for the exercise of the large powers of Government control given by the contracts was incidentally, but most carefully, at the same time, gone into. With regard to this particular detail of the inquiry, the substance of the report of the committee was, *that* up to that time the progress of railways under construction in India bore favourable comparison with that of English lines, *that* willing testimony had been given by many of the railway authorities themselves to the value of the Government control to the interests of the companies, when rationally and temperately used, and that 'if due care was taken to intrust discretionary power only to men who are to be relied on as competent to distinguish an effective general control, from too great an interference in details, by a judicious adherence to the spirit rather than the letter of the contracts,' the committee was assured 'that the arrangements might be simplified, united action for one common object secured, and railway enterprise in India may before long assume proportions commensurate with the vast commercial, agricultural, and mineral resources of that country.'

This report had an immediate beneficial effect, and brought about not only a more patient acceptance by the companies of the conditions imposed by the contract terms, but helped to promote a greater mutual confidence and respect for opinion on both sides. The companies' officers, as time went on, were led to comply more strictly with the reasonable requirements of the consulting engineers in respect of the fuller and more detailed preparation of designs and estimates prior to submission for approval, and the latter, soon gaining a wider practical experience of the detailed construction and working of railways, were induced to exercise their large powers in a broad and liberal spirit.

The control exercised in India by the consulting engineers to Government for railways over the whole expenditure and

operations of the guaranteed companies, has undoubtedly had the most beneficial results in safeguarding the general interests of the Indian public, and securing, at the same time, the ultimate interests of the railway shareholders themselves ; and in consequence of the almost absolute nature of the control exercised from the commencement by one central governing authority, the Indian railway system, considered as a whole, has been spared many of the now almost incurable evils which, especially in England and America, has resulted from the enormous powers which have been allowed to fall into the hands of the great railway corporations.

In relation to the construction of the guaranteed lines of railway, the principal features of the control exercised by the Indian Government, either directly or through their consulting engineers, may be thus briefly summarised : The final decision as to the direction and course to be taken by the railways, the position of all the more important stations, and other large works. The preliminary approval of all designs, estimates, and indents whatsoever, whether for works or establishments. In the case of completed lines, the absolute control over all capital expenditure, and powers of supervision and regulation of every detail of engineering expenditure or traffic-working of the railway. Special powers are also conferred on the consulting engineers for Indian railways to examine into and report on all cases of accident and injury, whether to life or property, within the railway boundaries. To minutely inspect in the closest detail, every half year, the working condition of every line of railway in their special circle of authority, and report on all matters requiring attention, whether as regards the safety of the line or passengers, the convenience of the public, or the well-being of the company's staff. To inspect, prior to opening for passenger traffic, every new line of railway, or additions to older lines, and to subject at any time to such tests as may be deemed necessary the strength and stability of all bridges, whether permanent or temporary, whether new or old.

It is now necessary to return to the East Indian Railway. The construction of the experimental line, 120 miles long, through Burdwan to the Raneegunge coal-fields, encountered to the full all those ordinary difficulties and delays inseparable

from the initiation of large and novel engineering operations in a new country ; but in addition, the rapid prosecution of the works was greatly affected by the refusal of large and competent contractors to undertake contracts on the terms at that time held reasonable by the governing authorities. The works were therefore, for the most part, let to a number of small and inexperienced local contractors, under agreements which were also, perhaps, somewhat hastily entered into. It was not, consequently, until September 1854, or at the end of 3 years and 9 months from the commencement of the works, that the first section of the experimental line from Howrah to Pandua, 37 miles in length, was opened for public traffic, or until February 1855 that the whole 120 miles to a point near Raneegeunge coal-fields was completed and opened.

During the course of this interval the original contract with the ' East Indian Railway Company ' for the experimental line, had been superseded by a larger one for the construction of a railroad the whole way to Delhi. The original proposal of the company had been to construct a main line from Calcutta by the direct route to Mirzapore, passing through the Shergotty hills and on to Delhi, with branches to Rajmahal, Patna, and Benares, thus avoiding altogether the Ganges valley east of Mirzapore. Owing principally, however, to Colonel Kennedy's powerful advocacy of river valley routes and flat gradients at this time, and partly on local commercial considerations, the alignment eventually chosen for the main line was that *viâ* the Ganges valley, from Burdwan, through Rajmahal and Patna, a decision which, when later it became a question of doubling the track on this route, led to the construction, as a preferable alternative, of a chord line, with double line of rails passing over a part of the hilly districts, in order to shorten by 64 miles the total length of the through route to the Upper Provinces, and to traverse a valuable coal district. It is probable also that, to still further shorten the through route, the originally projected alignment through the Shergotty hills will eventually be constructed.

The length of the extension from Burdwan to Delhi by the Ganges valley, or loop line, first decided upon, was 930 miles, and the contract with the company for its construction was

signed on the 15th February 1854; but some time before this date preliminary sanction to the acquisition of land, and the commencement of the works, had been accorded. From the year 1853, therefore, the construction of the railway along the extension to Delhi continued in active progress for many years, interrupted only for a short time by the Sepoy mutiny; until the last remaining link of the magnificent trunk line extending over 1000 miles in length, from the new to the old capital of India, viz. the fine bridge over the Jumna at Delhi, was completed in the year 1866.

The East Indian Railway system of lines and branches has now grown to a total length of 1525½ miles. Besides the chord-line with double line of rails, constructed to avoid passing the through traffic by the great loop of the Ganges valley at Rajmahal, and numerous short branches, a long branch of 225 miles, starting from Allahabad, effects a junction with the 'Great Indian Peninsula Railway' at Jubbulpore, and thus links the important Presidency capitals of Bombay and Calcutta in continuous railway communication.

As early as the year 1845 the 'Madras Railway Company' was formed in London, with the object of constructing a railway almost due west from Madras, to an important commercial centre at Arcot, but being unable to obtain any pecuniary concession, the company was shortly afterwards dissolved. In the year 1849 the project was again revived, and application was made for a concession on terms similar to that granted to the 'East Indian' and 'Great Indian Peninsula' Railways; the proposal was, however, rejected at that time, and the project was consequently again shelved.

Soon afterwards, however, surveys and projects for various alternative lines of railway in the Madras Presidency were made, and in 1852 a preliminary contract, with guarantee, was entered into with the 'Madras Railway Company.' The first portion of line sanctioned as an 'experiment' was one from Madras to Menil, a distance of 50 miles, a line which it was considered would be common to other railways leading towards Madras from the north-west and west. This length was commenced in the year 1853, but before much progress had been effected, an extension of the line to Beypore, a small port on the

opposite western coast, was sanctioned ; the contract with the Company being signed in December 1855. The first section of the Madras-Beyport railway, 64 miles in length, was opened on the 1st July 1856, and from Arcot, a point situated 42 miles from Madras, a trunk railway was afterwards constructed in a north-westerly direction through Cuddapah to Raichore, effecting a junction at that place with the Great Indian Peninsula line coming from Bombay. The complete connection by railway of the Presidency towns of Bombay and Madras, although it had been early recognised as of Imperial importance, was, however, delayed for some years, partly owing to financial exigencies arising from the Mutiny, and partly to prolonged discussions and surveys of the various alternative routes proposed for the connecting line.

CHAPTER VIII

' EAST INDIAN ' RAILWAY AND HOOGHLY BRIDGE

Progress of Railways—Peculiarities of construction in India—Relative value of land—Labour facilities—Manual labour—Small number of over and under bridges—Level crossings, and employment of small bridges and culverts for cross traffic—The large use of iron on Indian railways—India the country of large girder bridges—Methods of founding piers and abutments—Foundation well-sinking of native origin—Description of well-sinking—Erection of iron girder superstructures—Outline description of works on the East Indian Railway—Flood-openings and bridges on the first section—Monghyr tunnel—Route followed by line—Bridge over the Sone river—Description of works—Interruption by mutineers—Tonse bridge—Jumna bridge at Allahabad—Delhi Jumna bridge—Detailed description of recent bridge over the Hooghly near Calcutta—Sinking the pier caissons—Accident—Erection of superstructure—Completion—General particulars of East Indian railway.

East Indian
Railway and
Hooghly
Bridge.

WE have now traced in outline the history and fortunes of the three earliest trunk lines of railway projected and constructed in India. Inaugurated by the opening of the first 20 miles of the Great Indian Peninsula line in the year 1853, the railway system of the country has since steadily expanded, until 40 years later, in 1893, the total length of railways opened for public traffic has reached little short of 17,000 miles, constructed at a capital expenditure amounting to some 227 millions sterling.

The practical construction of railways in India varies little in general methods from those practised in other countries. The leading principles of ordinary railway construction have been already sketched in previous chapters, it will not, therefore, be now necessary to do more than indicate such minor points of difference in constructive details as may be more or less peculiar to the circumstances of India. First then, owing to the generally level character of the country—especially in the

northern plains of Hindustan—the permanent way of railways is carried for the most part on embankment of moderate height, cuttings being of generally rare occurrence. In the construction of ‘earthworks,’ which form so large an item in the ‘formation’ of a railway, it is seldom economical or necessary in India to transport soil from one part of the line to another, such as leading or carrying by mechanical means material from cuttings for the building up of embankments. The relative value of land is so small, and labour facilities so great, that, as a rule, the cheapest manner of throwing up embankments is to employ manual labour in obtaining the necessary material from side-cuttings excavated along the sides of the railway, and in the few cases where cuttings occur to place most of the excavated material to ‘spoil.’ The side-cuttings are shallow detached pits dug parallel with the course of the line, outside the boundary of the permanent land occupied by it. In the more hilly portions of the country through which a railway may be carried, and where more numerous cuttings will necessarily occur, the method of forming the earthworks will still be dependent on economy as governed by the values of land and labour. For the most part, therefore, in India the formation earthworks of a line of railway are carried out by direct manual methods without, as a rule, the intervention of such aids as ‘tip’ wagons and other mechanical appliances, all the earth or material being brought or removed by large bodies of men, women, and children, in small baskets carried on their heads. This manner of working, however primitive in appearance, is in practice found to be speedy and efficient, as well as economical, wherever a large quantity of labour can be engaged, as is commonly the case.

The generally level character of the country—combined with the comparative rarity of ordinary cross-country roads, and the relatively small number of trains run, prevents also in India the necessity for those numerous over and under bridges intersecting a line of railway so common on European lines. Such bridges—except in the immediate neighbourhood of large towns—are accordingly of rare occurrence, and cross-country roads or tracks are for the most part passed over the lines of rail by means of crossings on the level, gates and a hut or lodge for the

gatekeeper being provided at all vehicle crossings. The railways, as we have seen, are largely carried on embankment, and the numerous drainage under bridges crossing the smaller water-courses, being usually dry for a considerable portion of the year, can be and are, largely utilised as cross-passages for foot-passengers, cattle, and even for the ordinary vehicular traffic of the country districts.

The use of iron in the construction of railways is probably more largely resorted to in India than in many countries. 'Sleepers' of cast-iron, wrought-iron, or steel are greatly used as a substitute for wood, owing to climatic conditions rendering the softer kinds of wood sleepers liable to rapid decay, and to the difficulty of procuring seasoned hard-wood sleepers in sufficient quantity. Although the advantage and economy of masonry structures is fully recognised, iron and steel is also used to a very large extent for the superstructure of railway bridges, not only in those cases where the unavoidable size of opening renders its use imperative, but to a considerable degree in cases where in other countries stone or brick archwork would be preferred. In many parts of India either stone cannot be economically procured, or good brick-earth is difficult to obtain, or it may otherwise be that the conditions of sub-soil for foundation purposes are not suitable for arched structures. Iron or steel bridges of large average size are imposed by the magnitude and conditions of the numerous great rivers of the country, and India is consequently, in a pre-eminent degree, the land of heavy iron bridgework for railway purposes. The foundations of many of these large iron structures present some peculiarities which may be here noted.

The most usual method of founding the abutments and piers of large bridges in the sandy beds—extending often to unknown depths—of the great rivers of the Indian plains is by sinking cylinders, or wells, of brickwork, either singly or in groups, on which the pier superstructures are built; or by sinking the whole pier of an elliptical or other form by means of well-openings or chambers provided in the mass of the masonry. This system is one which is an improved and highly-developed adaptation of old native methods practised in India for centuries in the past. Nearly all the ancient bridges of

Upper India, and even in the more remote regions beyond its boundary, were founded on brick cylinders sunk into the sandy beds of the rivers. English engineers, recognising its suitability, have reduced the practice of foundation well-sinking to a highly-developed art, and have introduced numerous mechanical contrivances and expedients for rapidly sinking the cylinders to great depths, but the *principle* is one entirely derived from native sources. In these wells the brickwork is commenced on timber, or more usually on wrought-iron, curbs of great strength, suspended by vertical tie-rods, passing through iron rings inserted at intervals in the masonry. In the case of circular wells the internal diameter is generally about half the external diameter, so that the thickness of the brickwork will be a quarter of the whole width. The sand or other material met with in sinking is gradually withdrawn through the central hollow of the well by means of suitable mechanical dredgers of various kinds, assisted on occasion by divers working under the water; and after the sinking has been carried to a certain depth—usually about one to two diameters—the wells are loaded with a heavy weight, such as iron rails or bricks stacked upon them, in order to overcome the side friction of the cylinders. These foundation-wells are frequently forced down to great depths, such as 80 to 100 feet, and reaching even 140 feet. When the sinking to the desired depth is complete, the interior space (or spaces) is sealed at the bottom with a certain thickness of cement concrete deposited in the water; the latter is then removed, and the remaining hollow portion is plugged with ordinary concrete or brickwork. Undue scour at the site of the piers is checked by the deposition of large masses of rough stone of great size and weight thrown round them. As the rivers, especially in Upper India, contain little water in the dry season, it is at this period that most of the well-sinking is carried on, and the protective stone is deposited; the latter work being often continued for several seasons, or for such time as may be necessary to replace the rough stone which gradually sinks below the bed during the seasons of flood. During the dry months of the year bridge foundation-wells can largely be pitched directly in position on the exposed surface of the river-bed, but where the operation has to be executed in water of

more or less considerable depth, the foundation blocks are commenced in iron caissons, of varying height to suit the depth of the water, and numerous variations may occur in the special means employed for forcing the wells through the sand or soil of the bed below.

The particular methods adopted for erecting the iron girder superstructures of large bridges have little or no distinctive features in India; these methods, there as elsewhere, are dependent on numerous special or local conditions. Where the height of the work and circumstances of the river admit, the most usual arrangement is to construct between the piers a timber staging of sufficient strength to carry temporarily the weight of the ironwork until it is erected in place piece by piece. In cases where the erection of staging in the river-bed is inadmissible, various other expedients have to be adopted, some of which will be detailed in the examples of particular bridges which follow.

With the exception of a remarkable bridge erected in recent years over the Hooghly channel of the Ganges, the East Indian Railway from Calcutta to Delhi contains no example of engineering construction of the first order of magnitude, but probably few lines can exhibit a greater aggregate number of difficult undertakings, such as in any other country but India would be considered works of a large and important character. The first division of the railway from Howrah to Burdwan, and northwards to Rajmahal and the Ganges valley, traverses a low portion of deltaic land, subject to extreme inundation from the water-system of the country, where the drainage problems to be encountered and solved by the engineers of the railway were of exceptional and extraordinary magnitude. Over this wide expanse of level country, subject to an excessive tropical rainfall, inundations from the flood-spill of the enormous channel of the Ganges and other great rivers, are often spread as a vast sheet over miles of country, converting the whole district into the semblance of an inland sea, from which only the inhabited villages along the higher marginal levels emerge. The formation of long lines of railway embankment, checking the free movement of this expanse of waters, necessitated the provision of an extraordinary number of flood-openings, built

in a peculiarly treacherous soil—having a total area of waterway sufficient to allow the free passage, concentrated at certain definite lower levels, of huge volumes of flood-water, which formerly wandered unrestricted over many miles of country. In addition to these numerous flood-openings, entirely confined to the disposal of the inundations from the main rivers, the course of the East Indian Railway along the low-lying portions of the Ganges valley necessitated the crossing at their widest points of an unusually large number of important channels and broad deep rivers, requiring bridges or viaducts of heavy dimensions: such were the viaducts over the rivers Adjai and Mor, the first spanned by 32 brick arches, each of 50 feet, and the second by 24 arches of the same size; the Dwarka and Brahmini bridges of 7 and 9 girder spans of 60 feet; the latter having 7 masonry arches of 24 feet in prolongation, and the Pugla bridge of 25 spans of 28 feet, and 4 of 60 feet girders, together with a succession of others of scarcely inferior opening. The total length and area of waterway in viaducts, bridges, culverts, and flood-openings along this portion of the East Indian Railway is probably greater than on any equal length of line in existence. The foundations of these structures, and generally of all similar constructions on this side of India, were formed by sinking blocks of masonry perforated with holes or wells, through which the soft alluvial soil and sand below the blocks was withdrawn by means of dredging instruments, the sinking being continued until a bed of clay was met with; or failing this, until a depth was reached considered sufficient to place the foundation beyond the reach of scour.

After passing the bend of the Ganges at Rajmahal the railway is carried on the higher marginal land between the river and the inundated districts situated on a lower level than the river-bed, crossing all the numerous intersecting channels, and requiring much heavy earthworks and bridge and flood-arch construction; the larger bridges here consisting of from 3 to 7 openings of 60 feet girders. Near Monghyr occurs the only example of a tunnel on the East Indian Railway. This tunnel, through the last spurs of the Kymore hills, is of short length; being only 900 feet long, pierced through 600 feet of clay slate, about 500 feet of which required brick-lining, and 300 feet of

quartz rock of exceptional hardness. A short distance beyond Monghyr the line encounters severe obstacles. Here a large portion of the accumulated flood-spill of the Ganges passes through a gap in the marginal bank of the river, and during the season of floods the whole country is often under water to a depth of 8 or 10 feet. Through the opening two rivers of considerable magnitude also pass, viz., the Keeul and the Hulohar. In order to carry the line onwards, no less than 630 flood arches, each 15 feet span, were required. The Keeul river was spanned by 9 girder openings of 150 feet, and the Hulohar by 4 spans of similar size, the piers and abutments being founded on brick-wells of 10 feet and 20 feet diameter, sunk from 25 to 45 feet into the river-bed. Altogether—including flood-openings—to pass this gap no less than 11,400 lineal feet, or over two miles, of waterway was provided. The original Bengal section of the East Indian Railway, from Burdwan *viâ* Rajmahal to the border of the Bengal province at the Kurumassa river, is $416\frac{1}{2}$ miles long. The construction of this difficult length involved not far short of 1000 millions of cubic feet, or 37 million cubic yards, of earthworks, and nearly 40 millions of cubic feet, or a million and a half of cubic yards, of brickwork, of which latter $8\frac{1}{2}$ millions of cubic feet were situated in one short length of 21 miles.

The above examples, out of a large number that might have been quoted, will serve as an illustration of the extraordinary character and nature of the drainage difficulties encountered by the East Indian Railway along the lower portion of the Ganges valley. It was hardly to be expected that, nearly forty years ago, railway engineers, fresh from England, and working under an entirely novel set of conditions, should at once have fully grasped the exceptional nature of the problems presented, in providing for the efficient drainage of a line of railway in such a district as Bengal. The experience of the first few years corrected numerous initial mistakes, and supplemented insufficient precautions. In many cases bridges as at first designed proved far too small, and had to be extensively enlarged, a quantity of additional flood-openings had to be provided, and foundations injured or undermined by the force and volume of the pent-up floods had to be strengthened and secured. The

treacherous nature of the subsoil of the Ganges valley as a foundation for arched structures was moreover at first imperfectly realised, and much reconstruction and replacement of brick arches by iron girders, was from time to time rendered necessary.

Leaving the Province of Bengal, the line of the East Indian Railway proceeds to Moghul Serai, a junction station for Benares, and to Allahabad, where it crosses the Jumna river by a magnificent bridge, and throws off a long branch to the Jubbulpore terminus of the line from Bombay. From Allahabad the main road is carried in nearly a straight line to Cawnpore (finally leaving the neighbourhood of the Ganges at that place) and across the Ganges Jumna Doab to a point within thirteen miles of Agra, to which town a branch line now extends. Hence by the left bank of the Jumna the line is carried to Delhi, where it crosses to the right bank of the river and enters the city. Excluding the recently erected bridge over the Hooghly channel near Calcutta, the four principal bridges on the original main line of the East Indian Railway are those over the Sone river, the Tonse, the Jumna at Allahabad, and the same river again at Delhi. The first and last two of these bridges are remarkably fine structures, and are only dwarfed by a few more modern examples of bridgework situated on other lines.

The bridge over the Sone river merits somewhat detailed notice, as the first example of those large iron railway bridges now so numerous in India. It was begun in the year 1856, and was finished at the close of the year 1862, its progress having been seriously interrupted by the Sepoy Mutiny of 1857. The total length of this fine structure is 4731 feet or $\frac{7}{8}$ ths of a mile, and it consists of 28 decked spans of 150 feet, or 162 feet from centre to centre of piers, which are each 12 feet thick, carried on three brick wells of 18 feet diameter, sunk to a depth of 32 feet below low-water into a stiff bed of yellow clay. The following account of this interesting bridge is much abridged from a work on the railways of India, compiled from the Records of the India Office, and published in the year 1868 by Captain Davidson, R.E.—a work to which this volume is greatly indebted for much information on the earlier railway

lines in India. The Sone river, rising in the elevated districts of Central India, traverses the plains of South Behar, and discharges itself into the Ganges, near Patna, after draining an area of nearly 23,000 square miles. Its extreme discharge in floods is said to be about $1\frac{1}{2}$ million of cubic feet per second. The chief peculiarity of the river is the great width of its channel in the lower reaches. For the greater part of 100 miles it is over 2 miles wide, and reaches as much as 3 miles. This wide expanse of bed, through which during eight or nine months of the year only a narrow stream meanders, consists entirely of fine sand, appearing to the traveller like the surface of a great sandy desert. During the season of floods, the depth of water carried averages barely 20 feet, and it seldom exceeds 30 feet in the deepest parts. The whole width of the immense channel is, moreover, rarely completely covered. After careful examination of this formidable obstacle to the railway, a narrow point not far removed from the natural direction of the line was selected. Here the river was only about 4000 feet in width; and the banks were high and composed of clay, a bed of clay was also found by borings to underlie the sand across the whole width of the bed. It was at first proposed to construct a bridge of brick arches; but after some discussion, it was finally decided to adopt brick foundation-wells, with piers of similar material, used to support a superstructure of wrought-iron girders, each of 150 feet span, carrying the rails on the top, and having an ordinary roadway below. The foundation of the first pier sunk in the year 1856 was composed of a group of twelve brick wells, each 10 feet in diameter, laid close together in two rows of five, with additional wells at either end for the cutwaters. Initial work on the bridge was well in hand, when in July 1857 the native regiments at Dinapore mutinied, and marching towards the west, overran the works. 'The resident engineers, their wives and children, together with inspectors and overseers and their families, escaped in the iron boats belonging to the railway company to Dinapore, and the mutineers left nothing untouched that was destructable; then continuing their march along the line they came to Arrah, where Mr. Boyle, the resident engineer, had fortified a house. To it the European

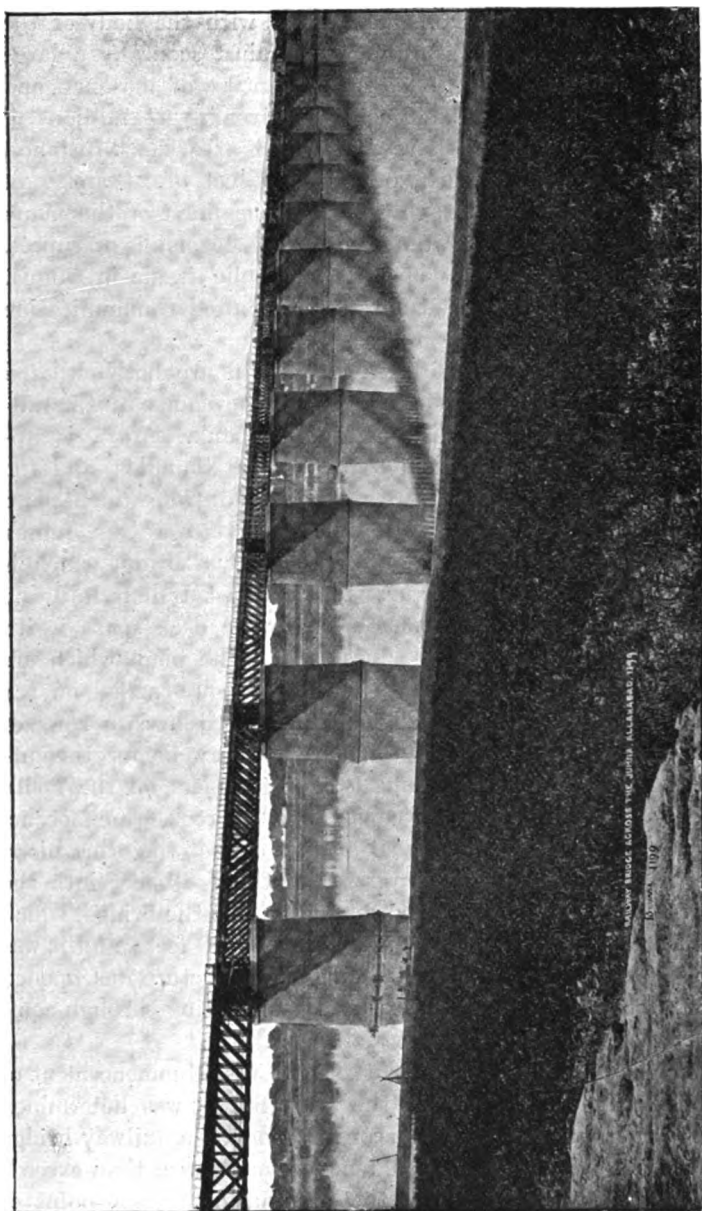
residents, 16 in number, with 45 Sikhs, retreated, and bravely defended themselves for a week against immense odds. The mutineers after crossing the Sone had been joined by a chief called "Koor Singh," and numbering about 2500, had invested the house occupied by the residents of the civil station of Arrah, against which they fired a field-gun which was in their possession. The little garrison, however, bravely held the place until relieved by a force under Major Eyre, Bengal Artillery, who, marching from Buxar, defeated the rebels in an action near the town of Arrah.'

It has been estimated that the value of property destroyed in 1857-58 by the mutineers at the Sone bridge alone was £42,000; and that the total loss from the mutiny, on all heads of account suffered by the East Indian Railway Company, over the whole line, amounted to an equivalent of three millions sterling.

Work at the bridge site was of course suspended, and could not be resumed until November 1858, when operations had practically to be commenced *de novo*. The design for the pier foundations was now modified, and in place of the cluster of small 10-foot wells originally intended, the piers were founded on three wells, each 18 feet in diameter, built on very strong wrought-iron curbs, having vertical iron rods attached to them connected with horizontal rings of iron built at intervals into the brickwork. The foundation-wells were sunk into the river-bed to an average depth of 32 feet below low-water, entering into a bed of stiff clay, and by the year 1860 construction work on all the piers was in full progress. As soon as the piers were completed, the girders were rapidly erected by the aid of a timber staging; and the bridge was virtually finished by the end of the year 1861, its final completion being unfortunately delayed by the loss of certain portions of the iron work in transit, so that it was not ready for traffic until the end of 1862. The section of main line as far as Moghul Serai, was soon afterwards officially opened by Lord Elgin, Viceroy and Governor-General, viz. in February 1863. The initial cost of constructing the Sone Bridge, which was completed for a double line of rails—including protective works—is given as 33 lakhs of rupees or £330,000 at par.

The bridge over the Tonse river, situated in the Mirzapore district, about 21 miles east of Allahabad, was completed in the year 1864, and enabled the line to be opened as far as that city on the 1st April of the same year. The bridge has seven spans of latticed iron girders of 150 feet clear opening, and the piers and abutments are constructed of brickwork, the cutwaters, being faced with dressed stone, they are carried on groups of brick wells, each 12 feet in diameter, sunk into clay at about 15 feet below the river-bed. The girders are deck-spans, similar to those of the Sone, carrying an ordinary roadway below. The advantage of utilising the larger railway bridges for the double purpose of carrying an ordinary cart or foot-road, as well as the railway, has been everywhere fully recognised in India, and a small toll levied on the traffic, probably in the majority of cases, amply repays the slight extra cost of the provision.

At Allahabad, the East Indian Railway crosses the Jumna river just before its junction with the Ganges, by a handsome bridge of larger openings, and of much greater height than that over the Sone, but of somewhat shorter total length. The site for the bridge was fixed so early as the year 1855; but owing to various causes, the design was not finally decided upon until after the Mutiny, and actual work on it was not commenced until the summer of 1859. The first design was for a bridge of 15 openings, each 200 feet long; but on a further investigation of the maximum flood discharge of the river, one span was suppressed. The bridge, therefore, as constructed, consists of 14 deck spans—carrying a cart-road below—of 200 feet each, and three small openings of 30 feet. The piers, which are 60 feet high above low-water, are founded on groups of twelve brick wells, each $13\frac{1}{2}$ feet in diameter, sunk to an average depth below low-water of 42 feet. The average height, therefore, of the pier masonry, from the well curbs to the under side of the girders, is 102 feet. The total length of the bridge, from end to end, is 3235 feet. The girders, which are of wrought iron, and constructed for a single line only, are of the open lattice tubular form. During the sinking of the wells, the up-stream end of No. 11 pier was undermined by a flood and overthrown; the overthrown portion was, however,



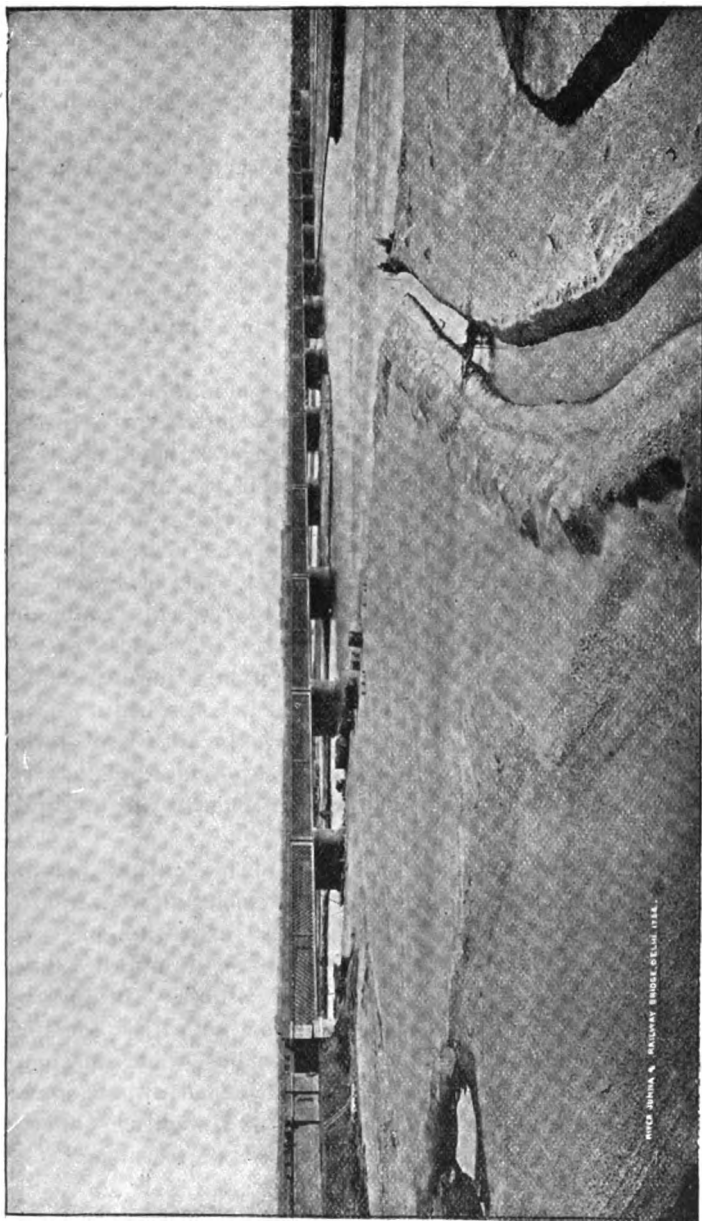
JUNNA BRIDGE, ALLAHABAD

Y

by the aid of a cofferdam, reconnected with the body of the pier, and the whole was protected against scour by a large mass of rough stone. The total quantity of masonry and brickwork in piers and abutments is given as $2\frac{1}{2}$ millions of cubic feet (or 92,600 cubic yards); whilst at a short distance, on the northern approach, occurs a viaduct of 24 arches of 30 feet each. The initial cost of this, the finest of the many railway bridges over the Jumna river, was $44\frac{1}{2}$ lakhs of rupees, or £445,000, and it was opened for public traffic in August 1865, permitting from that date uninterrupted communication between Calcutta and Agra.

The important cities of Agra and Delhi are both situated on the right bank of the Jumna, whilst the course of the railway beyond Allahabad is on the left bank. Agra is approached by a branch from a junction at Tundla; and the main line proceeds northwards to Ghazibad, from which place it turns sharply to the west, and again crosses the Jumna before entering the ancient city of Delhi by a bridge which is the last of the large structures on the East Indian Railway. The Delhi Jumna Bridge consists of twelve deck spans—with cart-roadway below—of $211\frac{1}{2}$ feet each. The piers, which are $23\frac{1}{2}$ feet high above low-water in the river, are carried on ten brick wells, each 12 feet in diameter, disposed in two rows of four each, with single up and down-stream wells for the cutwaters. Both abutments and two of the piers on the Delhi side of the river are, however, founded on rock, which occurs at a few feet below the surface. In the case of the other piers, the wells are carried for an average depth of 39 feet into the river-bed into stiff clay. The total length of the bridge, which has been constructed for a single line, is 2640 feet; and it was constructed at a cost of £166,000. The structure was opened for traffic at the end of 1866, finally completing through communication between Calcutta and Delhi.

It has been mentioned that on the first commencement of the East Indian Railway in the year 1851, it was determined—in order to postpone the construction of a railway bridge over the Hooghly, which could not be otherwise than exceedingly expensive—to establish the terminus or starting-point of the line at Howrah, a suburb situated opposite Calcutta on



JUMA BRIDGE, DELHI

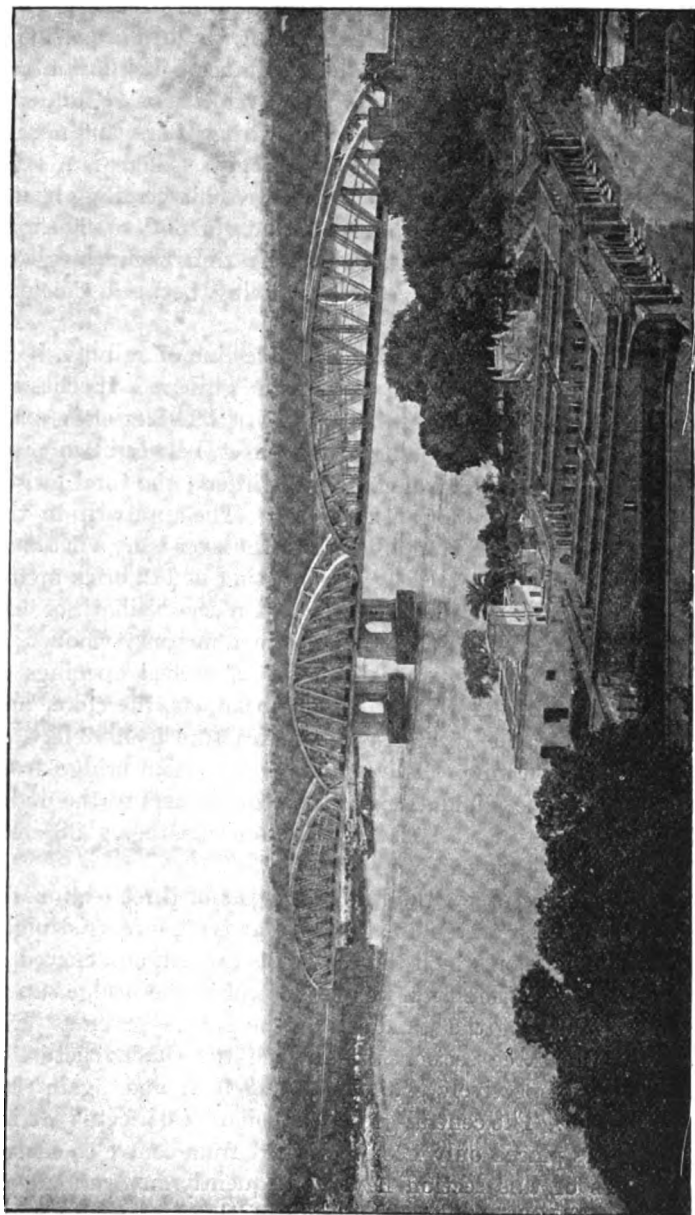
PHOTO JUMA & RAILWAY BRIDGE CLUB 1934.

the right bank of the Hooghly tidal channel; communication between the city and Howrah being in the meantime maintained by means of a steam-ferry.

In the year 1875—to meet the growing necessities of the Calcutta traffic—an ingeniously constructed pontoon bridge, to carry an ordinary carriage-way, supported at an unusual elevation above the level of the pontoons, was constructed across the Hooghly, and this means of communication has since continued in use, to the great convenience of the town. The urgent need, however, of a bridge over the Hooghly capable of sustaining a railway, remained unsatisfied until so recently as the year 1887.

The remarkable railway bridge commenced in the year 1883-4, and opened in the year 1887, has been constructed over the Hooghly tidal channel at a point of the river situated 28 miles above the pontoon bridge, which connects Calcutta with the Howrah terminus, and by its means a junction is now effected between the East Indian main line and the Eastern Bengal Railway, leading into the heart of Calcutta. The bridge crosses the river at the town of 'Hooghly,' a place which, a couple of hundred years ago, was the principal port and factory of the British Company of Merchants in Bengal, and from which the whole channel has taken its name. As a consequence of the year in which the bridge was opened, viz., the 50th year of the reign of her Majesty, Queen Victoria, Empress of India, the structure itself has been appropriately named the 'Jubilee Bridge.'

The particulars embodied in the following outline-description of this fine engineering work, are chiefly derived from a paper on its erection read before the Institution of Civil Engineers on the 24th January 1888, by Sir Bradford Leslie, K.C.I.E., M.I.C.E. At the site of the 'Jubilee' Bridge the Hooghly channel is 1200 feet wide at low water, the selection of the precise point of crossing having, among other considerations, been largely influenced by the relative narrowness of the river immediately opposite the town of Hooghly. On the town- or right side of the river, the bed is 66 feet deep below mean sea-level, and the bank is defined and well above the highest floods. On the left side the water is comparatively



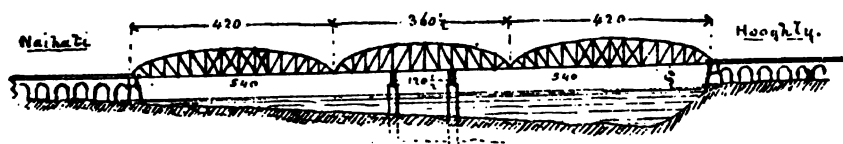
JUBILEE BRIDGE OVER THE HOOGHLY NEAR CALCUTTA

shallow, and there is a low bank, with a wide stretch of low-lying ground beyond, inundated during high floods. The height of the tide varies from a short distance below mean sea-level to 20 feet above, with a maximum velocity of $4\frac{1}{2}$ miles an hour when the flood-tide enters with a strong bore, and nearly 6 miles an hour on the ebb-tide in freshets. There is a very large navigation, consisting of unwieldy country sailing-boats, little under control, and steamers and flats of 500 to 600 tons burden belonging to the Inland Navigation Companies, together with the passenger steamers plying between Calcutta and Kulna.

The bridge is constructed for a double line of railway, both lines being carried between the main girders. It consists essentially of two large openings, each of 524 feet clear span, with a central smaller opening of $106\frac{1}{2}$ feet, between two piers supporting a pair of central cantilever girders; the total length of the bridge proper being $1213\frac{1}{4}$ feet. The approach to the main structure on the Hooghly side of the river is by a masonry viaduct 3278 feet in total length, consisting of 112 brick arches of spans varying from $10\frac{3}{4}$ to 48 feet. On the Naihati, or left side of the river, the approach is also by a masonry viaduct, in this case 441 feet long, consisting of 29 arched openings of $10\frac{3}{4}$ feet. From end to end of the viaducts, therefore, and across the river, the total length of structure is 4932 feet, or not far short of a mile. The height of the main bridge from the bottom of the foundations of the central piers to the under side of the girders is $153\frac{1}{2}$ feet, the foundations being $98\frac{1}{2}$ feet below the lowest water.

The superstructure of the bridge consists of three sections of steel girders, each of the open triangular type, having straight bottom members on which the railway is carried, and curved in bow-form above. The total weight of steel in the bridge superstructure, including the standards on the piers, is given as 3876 tons, and the three sections into which the superstructure is divided are respectively 420 feet, $360\frac{1}{2}$ feet, and again 420 feet in length. The central-girder section of $360\frac{1}{2}$ feet is carried on two piers placed only $120\frac{1}{2}$ feet apart from centre to centre, the girders of this section have consequently an overhang or projection of 120 feet on either side of the supporting piers.

Resting on the overhanging or projecting ends of the central cantilever girders, the two land-girders, each 420 feet long, stretch to the bank abutments. The object of this somewhat unusual arrangement, giving two very wide land-spans, and a smaller one in the centre (lying between the two piers supporting the central cantilevers) was partly in order to locate the piers in comparatively shallow water. If a bridge of three equal openings, say of 400 feet, had been adopted, the pier on the Hooghly side of the river would have fallen in 40 feet of water at low tides, and the cost of foundation construction would have been greatly enhanced. There were, moreover, other advantages in the design. The position chosen for the two piers leaves the widest openings on each land-side of them for navigation, that on the shallower side, where the current is more moderate, for the native craft, and that on the deep side



SKETCH DIAGRAM OF HOOGLY BRIDGE.

of the channel for the use of steam vessels and flats. The founding of the two piers and the erection of the superstructure steel-work of the girders by the particular methods employed, which were virtually imposed by the conditions of the river, as well as by considerations of labour and rapid execution, was also at the same time facilitated by the design. The general form of the bridge will be best understood from the sketch-diagram above, from which also it will be seen that the structure is far from being graceful in outline.

The two piers are each 66 feet long, up and down stream, and 25 feet wide, with semicircular ends and flat sides, and the average depth of the water at the place where they are pitched is about 27 to 30 feet at low spring-tides in the dry season. The main body of each pier is enclosed by a wrought-iron caisson, 108 feet high by 66 feet long, and 25 feet in width, weighing 453 tons. Each caisson was divided into three exca-

vating chambers (open from top to bottom), by two buoyancy chambers extending its full width, and 15 feet wide. The lower portions of the caissons, which were provided with tapered curbs or cutting edges, were floated into position and sunk through the water and soft silt of the river bed by the aid of a pair of floating pontoons moored between them, the pontoons being furnished with suitable stagings and powerful tackle, commanding the site of both piers simultaneously. As the sinking progressed, additional sections were built on the top of the caissons, until at length the bed of stiff clay selected for the foundation was reached, and into this clay the lower edge was forced, some 10 or 12 feet, to a depth of 98½ feet below the lowest water in the river. The whole interior of the caissons was filled in solid with concrete and brick-work, brought up to the necessary level to carry the steel standards on which the cantilever girders rest.

The many difficult operations connected with the sinking of these pier-caissons were successfully carried out, but not entirely without mishap. On the 16th April 1884, the lower portion of one of them, drawing 32 feet of water, and weighing with load some 750 tons, had been floated ready for placing in position, when it was caught by a strong bore in the river. The chain lashings by which the top had been secured to the pontoons, and the chain tackle of the up- and down-stream moorings, were broken by the violent strains to which they were subjected, and the caisson being released, was carried away by the current, and floated nearly half a mile up the river, where it grounded. By the aid of extraordinary exertions it was, however, secured, lightened of 40 tons or so of cement brick-work, and at length refloated by the evening of the following day, being fortunately found to have sustained no serious injury, so that before very long it was again ready for deposition on its permanent site.

The foundations of the two abutments of the bridge presented no unusual difficulties, and were sunk on two iron curbs 65 feet long, 28 feet wide, and 8 feet deep, divided into three excavating chambers. On the Hooghly side the curb was sunk about 40 feet, and on the Naihati side about 84 feet below the river bank. The steel standards placed on the piers for carry-

ing the cantilever girders are vertical cellular structures 20 feet high, built up of plate and angle bars riveted together, and secured to the brick-work of the piers by holding-down bolts and anchor-castings. The standards each contain 205 tons of steel.

The central portion of the cantilever girders, or that portion lying between the piers, was erected by means of a platform supported by raking struts from the pier-sides, and the overhanging portions were then built out, piece by piece, by the aid of overhead tackle until completed. The girders for the land-spans were each erected on lines of rails carried on the surface of the two approach-viaducts, which were designed and strengthened in the necessary manner to bear them. A complete span, composed of two connected girders weighing 1000 tons, was then mounted on rollers, and the whole mass was run forward by the aid of steam tackle, until the outer end of the girders projected over the water for some distance beyond the face-line of the abutment; the portion so projected having been previously temporarily strengthened. At this stage of the operation the two floating pontoons which had been employed for sinking the pier caissons, and which were now fitted with a suitable staging, were brought into position beneath, and the projecting ends of the girders were wedged-up and supported on the pontoon staging. The whole was then once more moved forward; the pontoon carrying the outer ends of the girders being now warped across the current, until these ends were brought into position, and deposited on the projecting extremities of the cantilever girders.

These operations, of extraordinary magnitude and difficulty, requiring the most exact calculation, and adaptation of means to ends, were carried out with the utmost precision. The girders on the Hooghly side of the river were launched on the 8th November 1886, and those on the Naihati side on the 20th of the following month, the operation in each case occupying about five hours only. The actual construction of the Jubilee Bridge was commenced in the year 1884, it was practically completed by the end of 1886, and was formally opened for public traffic on the 25th March 1887. The total cost of the bridge, including the two long approach viaducts, is given as

£261,178, or, stated in rupees, after deducting the cost of plant and supervision, the total expenditure incurred on the whole work is officially shown as Rs. 30,95,388.

The length of the main line of the East Indian Railway, including the chord line of $186\frac{1}{2}$ miles, is 1205 miles. In addition, the main line has fifteen branches, aggregating $320\frac{1}{2}$ miles, most of which are short, except that from Allahabad to Jubbulpore, which is 224 miles in length. The total length of main-line and branches amounts, therefore, to $1525\frac{1}{2}$ miles. Of this, the distance from Howrah to Moghal Serai (the junction for Benares) is laid double, which, together with some other short lengths, brings up the total length of double-line to 474 miles. The earthworks and bridges are generally everywhere constructed for a double line, except the bridge superstructures.

The permanent way is laid with rails varying from 74 lbs. to 82 lbs. per yard. Originally the line was laid almost entirely with wooden sleepers, but cast-iron plate sleepers have since been largely introduced, and are now mostly used for renewals. About 1200 miles have also been relaid with steel rails in place of iron. On the Jubbulpore branch wooden sleepers of creasoted pine and sal are the most numerous. The East Indian Railway was acquired by the State from the late Guaranteed Company on the 1st January 1880. The working and management is still, however, carried on by a company under contract with Government.

CHAPTER IX

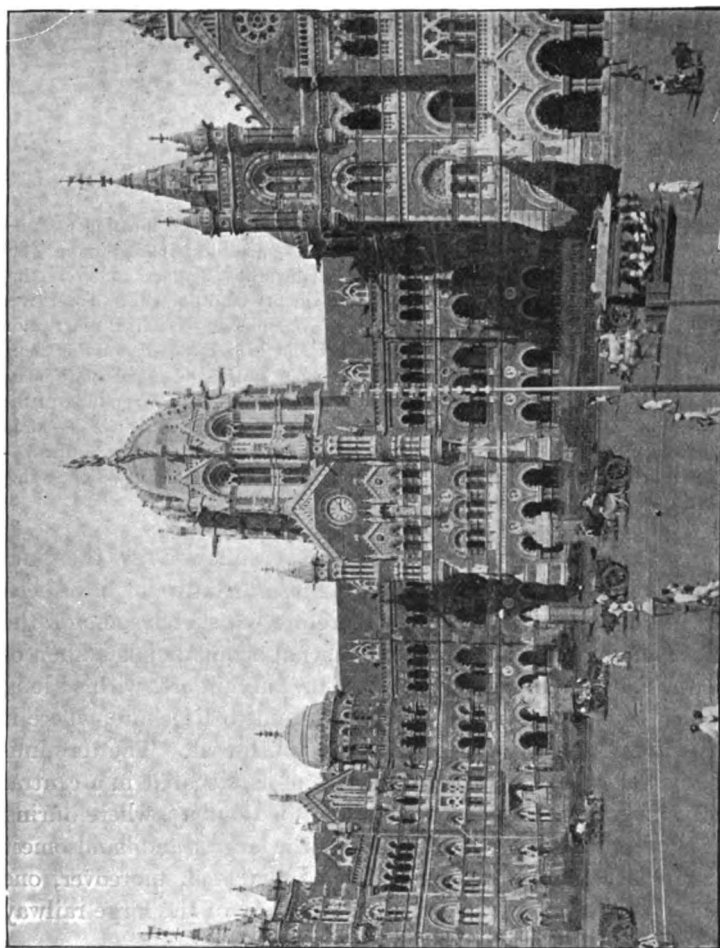
' GREAT INDIAN PENINSULA ' AND ' MADRAS ' RAILWAYS

The Great Indian Peninsula Railway—Sketch of principal engineering works—Bombay to Callian—The Western *ghāts*—Detailed description of the Thul *ghāt* incline—Gradients and curves—Earthworks—Viaducts and reversing station—Tunnels—Route followed by main line and branches—Tapti river viaduct—Nerbudda bridge—The Bhore *ghāt* incline—Detailed description—Difficulties of undertaking—Gradients and curves—Works on the Bhore *ghāts*—Stations on the incline—Reversing station—General particulars of viaducts and tunnels—Peculiar difficulties—Surprising magnitude of the works—Route of railway from Lanowlee, and principal works—Main particulars of Great Indian Peninsula Railway—The Madras Railway—Routes and outline of principal bridges—General particulars—Concluding observations.

THE early history and general course followed by the lines belonging to the ' Great Indian Peninsula Railway ' have been already outlined. It remains, therefore, to sketch some of the principal engineering works on this important trunk system of railways, extending from Bombay to Jubbulpore, with a long branch to Nagpur on the north-east, and to Raichore, where it joins the ' Madras Railway,' on the south-east. The terminus of the Great Indian Peninsula system is situated in a central and convenient position on the island of Bombay, where during recent years has been built, certainly the largest and handsomest terminal station to be met with in India, and, moreover, one which will enter into comparison with any of the large railway stations of the world.

A short distance from the terminus, viz., at Byculla and Parel, are situated the extensive goods depôt and locomotive work-shops of the railway. At Sion, the extreme north-eastern point of Bombay island, a short branch was originally

Great Indian
Peninsula
Railway.



BOMBAY TERMINAL STATION

constructed to the old town of Mahim, situated at the western extremity of the island, once the principal seat of the commerce of Bombay, though now of relatively small importance. The railway crosses the wide Sion marsh to the island of Salsette by a long embankment, and near Tannah, at 22 miles from the terminus, it crosses the arm of the sea which divides Salsette from the mainland of the Concan and of India by two arched masonry viaducts, 333 and 579 feet long respectively, in the latter of which is an iron girder opening for passing the navigation. Traversing a portion of the Concan, the line reaches the junction station of Callian at 33 miles from Bombay. This point marks the end of the original 'experimental' line, opened on the 1st May 1854 (the first 20 miles to Tannah having been opened about a year earlier), and is the point from which the two trunk lines to Jubbulpore and Raichore bifurcate, each climbing by separate passes, situated respectively to the north-east and south-east, the rugged line of the Western *ghâts*, in order to gain the upper table land of the Deccan.

It has already been pointed out that the line of the Western *ghâts*, as approached from Bombay, is not to be regarded as a chain of mountains or hills, but as a precipitous line of cliffs, some 2000 to 3000 feet high, forming the vertical wall of the Deccan high land; this line of precipices being only broken by deep ravines, or rifts along its face, with occasionally projecting spurs running down to the Concan. The first section of the railway from Callian to the north-east, and in the direction of the Thul *ghât*, is one of 26 miles, extending from Callian to Kasora. On this length the line gradually climbs by steep gradients of principally 1 in 100, and by sharp curves down to a radius of 30 chains, the south side of a long irregular spur which descends westwards from the main *ghât* precipices, and separates the ravines or valleys of the Basta on the south from the Wyturnee on the north. The works on this section are of a heavy character. The earthwork formation contains over half a million of cubic yards of cutting through hard trap and basaltic rocks, and over $1\frac{1}{2}$ million cubic yards of embankment. Rifts, or ravines, are crossed by four important viaducts of which the two longest are 372 and 429 feet long, and no less than 127 and 122 feet high. There are also forty-four bridges

up to 30 feet span, and 117 minor culverts. The level of Kasora, placed 1040 feet above the sea, is 849 feet higher than Callian, and as the level of the summit of the Thul *ghât* incline is 2012 feet above sea-level the height now gained by the railway leaves 972 feet still to be surmounted before the upper tableland is reached.

The actual Thul *ghât* incline is considered to commence at the Rotunda *nulla*, or stream, at Kasora, and extends from thence to Egutpura, on the summit of the pass. The preliminary surveys and studies for this remarkable example of railway engineering occupied 4 years, and its actual construction was commenced in October 1857. The total length of the incline, which has been constructed for a double line throughout, is $9\frac{1}{2}$ miles, having a rise of 972 feet in this short distance, or an average ascent of 102.21 feet per mile, or about 1 foot rise in every 58 feet of length. The actual gradients, however, vary, the steepest being an incline of 1 in 37 for a length of 4 miles 30 chains—that is, for about one-half of the whole ascent. Other gradients are 1 in 45 for 838 feet, and 1 in 50 to 1 in 148, and in the total length there is only 3036 feet of level line.

Of the $9\frac{1}{2}$ miles comprising the *ghât* section from Kasora to Egutpura, close upon 6 miles are curved, the remaining $3\frac{1}{2}$ miles being straight. The radius of the curves varies from the sharpest, which is 17 chains (1122 feet) up to 100 chains. The sharpest curve has a length of 2178 feet, another of 20 chains radius has a length of 3000 feet. The total length of curves of 20 to 50 chains radius is over $4\frac{1}{2}$ miles, those from 50 to 100 aggregating 3168 feet only.

The quantity of earthworks, consisting for the most part of hard rocky materials, on this short length of line, is no less than 67 millions of cubic feet, or 2,486,000 cubic yards, the quantity in cuttings and in embankments respectively being about equal. At the commencement of the Thul *ghât* incline the Rotunda *nulla* and ravine is crossed by a viaduct 90 feet high, and 198 feet long. Passing through a rock tunnel of about 400 feet, the railway reaches the Manda Sheyt ravines, which are crossed by two lofty viaducts, the first 84 feet high, and 429 feet long, the second 87 feet in height and 198 feet

long, adjoining which are two tunnels 240 and 1625 feet long respectively. At $3\frac{1}{2}$ miles from Kasora the line reaches a short level length, or station, situated for the most part on high embankment, where the direction of the railway is suddenly altered, the engines being here turned and transferred by means of a turn-table and sidings, from one end of the trains to the other. Hitherto the line has ascended the south, or river Basta side of the great projecting spur. After leaving the reversing station, however, it passes through a gap in the ridge and gains the northern, or Wyturnee valley side. Passing through three tunnels, the longest of which is 705 feet in length, and over a viaduct 90 feet in height and 198 feet long, the railway encounters in the sixth mile some of the most formidable difficulties on the *ghât*. Over the Ehegaum ravine is thrown a magnificent viaduct, 750 feet long, and of the great height of 182 feet, whilst the sides of the hill are pierced by four tunnels, the two longest of which are 1461 and 1247 feet respectively. The railway now creeps painfully up the steep side of the cliffs, and, before reaching the summit-level at Egutpura, traverses three other tunnels of 783, 420, and 174 feet, and passes over another viaduct 450 feet long and 60 feet in height.

The tunnels on the *ghât* incline are for the most part pierced through greenstone or basalt rock of the hardest description. With the exception of the Ehegaum ravine viaduct, the superstructure of which consists of three spans of triangulated iron girders placed 182 feet above the stream below, and having semicircular arches of 40 feet at either end—all the viaducts and smaller bridges are arched structures, built chiefly of basalt masonry. Altogether on the $9\frac{1}{2}$ miles of the Thul *ghât* ascent there are thirteen tunnels, having an aggregate length of 7956 feet, six lofty viaducts, having a total length of 2223 feet, and ranging from 82 to 182 feet high, fifteen bridges of spans varying from 7 to 30 feet, and between sixty and seventy culverts.

Leaving Egutpura, on the summit of the *ghât*, the line, encountering only ordinary obstacles, crosses the fertile valley of the Upper Godavery, and passing by an easy gap the Indyahadree range of hills at Munmar, enters the rich districts of Candeish; traversing which, the railway reaches the junction and locomotive station of Bhasavul, 276 miles from Bombay.

The works along this section, although numerous, are of secondary character. At Bhasavul, a long branch of 245 miles extends to Nagpur, the capital city of the Central Provinces, traversing and connecting with Bombay one of the best cotton-producing districts in India. The country is generally favourable, and no individual works require detailed mention. The principal viaducts are those over the rivers Mund and Wardha, the former consisting of fifteen openings of 60 feet, with piers 70 feet high, and the latter of twelve openings of 60 feet each.

Soon after leaving the junction station of Bhasavul, the main line sharply curves to the northwards, and crosses the important Tapti river by a handsome viaduct, carried at a height of 60 feet above low water. This viaduct, which is 2556 feet long and constructed for a double line, consists of twenty-eight openings of 60 feet, and five larger spans of 138 feet each. The piers are formed of a pair of iron cylinders filled with concrete, resting on the solid rock, which forms the bed of the river, and nowhere located at a greater depth than 16 feet below the lowest water. The cost of the structure is given as £163,000. The present Tapti viaduct is a reconstruction, the original one erected with masonry piers having failed, partly from faulty construction, and partly from the sudden and violent floods—rising sometimes to a height of nearly 70 feet above the lowest bed—to which the river is liable.

The section of line from Bhasavul to Jubbulpore, 339 miles in length, passes, a short distance beyond the Tapti, through a gap in the Satpura range of hills, with gradients nowhere steeper than 1 in 100, and enters the valley of the Nerbudda, continuing along the left bank of that river for about 200 miles. The country is for the most part flat, and favourable for railway construction, but the line necessarily encounters a large amount of cross drainage falling into the main river, requiring a series of heavy and expensive bridges and viaducts, although none of these are of exceptional individual size. Before reaching Jubbulpore, 615 miles from Bombay, and effecting a junction with the East Indian branch line from Allahabad, the railway throws off a short branch of 12 miles to the coal fields of Mohpani, and crosses the upper part of the Nerbudda river itself by a viaduct and bridge 1052 feet long, consisting of six arched

openings of 40 feet, and five girder spans of 137 feet, placed 81 feet above the lowest water. The foundations of this structure presented no difficulty, beds of solid rock being found almost on the surface. The piers and abutments of the Nerbudda bridge are built for a double line, the girder superstructure for a single line only. The total cost of the work is given approximately as £67,000.

Returning now to Callian, below the Western *ghâts*, the point from which the two main trunk lines of the Great Indian Peninsula Railway bifurcate—one going north-east to Jubbulpore, the other south-east to Poona and Raichore—the first section of the south-east extension passes by a fairly easy line of 30 miles to the foot of the Bhore *ghât* incline. This short length is, however, exposed to extraordinary floods from the rapid and violent torrents which descend from the line of *ghâts* and hills on either side, and is consequently provided with an unusual number of the smaller class of bridges and culverts. The works necessary for carrying the line of railway up the Bhore *ghât* are of extraordinary magnitude and difficulty. Before the route could be pronounced economically passable for a railway, many years had to be expended in preliminary studies and surveys, until at length a series of inclines was laid out, on one portion of which it would still be necessary for trains to be dragged up by means of a stationary engine; but as time went on, closer and more detailed examination gradually enabled the engineers to modify bit by bit, and improve little by little the possible alignment, until at last a route was planned out which, although involving a succession of stupendous and costly works, was nevertheless pronounced to be passable by locomotives along its whole extent, and the work of actual construction on this bold and difficult undertaking was commenced in January of the year 1856.

The Bhore *ghât*¹ incline commences near the village of Padushurree or Kurjut, about 30 miles from Callian, and

¹ The data for this description of the Bhore *ghât* incline, as well as that of the previous description of the incline on the Thul *ghât*, is principally derived from a paper read before the Institution of Civil Engineers, by J. J. Berkeley, Esq., M.I.C.E., on the line and works of the Great Indian Peninsula Railway, in the year 1859-60.

ascends from thence to the highest summit level of the *ghât*, situated at Lanowlee, 2027 feet above the sea. The total length of the incline is 15 miles 68 chains, and the total rise in this distance, from the level ground at the foot of the *ghât* to the summit level, is 1831 feet, the average rise over the whole distance being 1 in 46 feet of length. The actual gradients on the ascent, however, vary according to the necessities of the ground, and in consequence of the obligation on so great a length of rise of introducing short breathing places of level linc. The whole incline is, in fact, divided into four sections, separated from each other by short lengths of level and contrary rise, to enable the speed of the *descending* trains to be checked, and the trains themselves to be brought to a stand. The steepest gradients on the ascent are 1 in 37, extending in one length for 1 mile 38 chains, and 1 in 40 for 8 miles 4 chains, the remaining grades being 1 in 42 and 1 in 75, with a short length of 1 in 330 at Khandalla station. The total extent of level line amounts to 1 mile and 15 chains only.

Out of the whole 15 miles 68 chains of incline forming the total ascent of the Bhore *ghât*, no less than 10 miles 34 chains are curved. The sharpest curve is one of 15 chains, or 990 feet radius, on a gradient of 1 in 75, having a length of 1452 feet, Another, 660 feet long, has a radius of 20 chains, and the remaining curves, of various lengths, are from 30 to 80 chains radius; the total length of the straight portion being 5 miles 34 chains. A double line of rails of the 5 foot 6 inches gauge is carried throughout the entire ascent of the *ghât*, making one of the widest and most splendid mountain roads in the world. It is not easy by means of mere quantitative figures to convey an adequate idea of the magnitude of engineering achievements; so large a portion of the real difficulties encountered depending far more on the special features and conditions of the obstacles that have been overcome, than on the mere quantity of materials removed or built up. The double line of railway of broad gauge constructed up the Bhore *ghât* consists of a continuous series of heavy cuttings and embankments, reaching 76 feet in depth or height on the central line, broken up by a rapid succession of tunnels pierced through projecting head-

lands, and by bold lofty viaducts of masonry over the deep rocky ravines and gorges with which the face of the precipitous cliffs is constantly intersected. The cuttings and tunnels are, for the most part, blasted through basaltic rocks of the hardest description, and embankments are largely built up of rocky materials. The line is frequently carried clinging to the steep hill-sides, with the inner portion of its formation surface notched or benched into the rock, whilst the outer portion is carried on artificial bank, having an enormous outward slope, or the outer half may be supported by long lengths of masonry retaining-wall built up from great depths below, or be carried on a series of arch-vaulting planted against the slope. In many such situations, as well as elsewhere, the line is exposed to the frequent danger of landslips from the steep slopes situated above its course. The soil, filled with massive boulders of rock, becoming loosened by the heavy tropical rains, huge masses are liable to be dislodged and projected downwards with terrific violence, and, unless prevented, may dash into and create havoc on the surface of the railway. In some of these places the amount of labour and expense involved in reducing or protecting the upper slopes; in the construction of catch-water drains, and overhead passages for discharging the collected water over the course of the railway into the valley below, in order to obviate the risks of landslips, is enormous.

The total quantity, of mostly hard rock-cutting—reaching a maximum depth on the central line of 76 feet—on the Bhoré *ghât* formation of the railway is upwards of 54 millions of cubic feet, or 2 millions of cubic yards. The quantity of material in the embankments aggregates $67\frac{1}{2}$ millions of cubic feet, or $2\frac{1}{2}$ million cubic yards, and owing to the excessive steepness of the sidelong ground along which the banks are carried, whilst the height on the central line may be 50 to 75 feet, the toe of the outer slope is, in some cases, situated in the valley 150 to 300 feet below the formation level.

There are four stations on the incline, the first, named Thakurwada, is placed at a distance of 5 miles from the bottom, and is provided with catch, or safety sidings, into which any descending or runaway train, or detached vehicles,

can be turned and stopped when necessary; the second is a reversing station, situated at Battery Hill, in the 12th mile; the third is at Khandalla, in the 14th mile; and the fourth at Lanowlee, on the summit level of the *ghât*. At the reversing station—by means of a turntable and sidings—the engines are turned and brought round to the other extremity of the trains, which then proceed in a reverse direction to that from which they entered. The principal object of this arrangement was to prolong the length of base, and to reach the highest possible level before attacking the difficult features of the main *ghât* precipice lying between the reversing station and Lanowlee.

At the commencement of the ascent from near Padushurree the railway is carried, nearly in a semicircle, round the western and southern sides of a long irregular spur projecting from the *ghât* range. Continuing to cling to some portion of this spur, and gradually mounting by a stiff gradient of 1 in 40, the line at the 10th mile reaches a narrow neck of hill connecting it with the main *ghât* cliffs. At the end of this neck the reversing station is placed, 1349 feet of the total height being now surmounted, leaving 482 feet to be still climbed in the last $4\frac{1}{2}$ miles before reaching the crest of the *ghât* at Lanowlee. Returning to the bottom end of the incline, the railway, after passing some exceptionally heavy embankments in the 2d and 3d miles, traverses a group of six tunnels, the longest of which is 429 feet, and is then carried over the remaining distance to Thakurwada station in the 6th mile by a series of formidable works. Here, in a length of 2 miles, occur eight considerable tunnels and five lofty viaducts. The largest of these tunnels, through hard trap rock, is 1305 feet, the remainder being from 147 to 873 feet. The viaducts are of masonry, having four to eight arches of 50 feet span, the piers reaching 77, 98, 129, and 143 feet in height above ground. Beyond Thakurwada the railway, following a south-east line, is carried for some distance along a natural bench or step on the hill-side, without meeting any serious obstacle. Reaching the 8th mile, it is passed over two ravines by two viaducts of six 40-feet, and four 30-feet arches, having piers 48 and 88 feet high, and continuing along the same bench, in the succeeding

2 miles it traverses nine tunnels, the longest of which is 846 feet, situated in the 10th mile. The line, still on grades of 1 in 40 and 1 in 50, passes along the neck of hill joining the long spur up which it has hitherto climbed with the main *ghât*, and reaches—after passing over another viaduct of one 60-, and ten 40-foot arches—the reversing station of Battery Hill. Leaving the reversing station by the sharpest curve on the incline, viz., that of 15 chains radius, on a grade of 1 in 75, the line pierces the projecting bluff of a solid basalt hill by a tunnel 1023 feet long, and now enters the great gorge or ravine down which flows the main stream of the *ghât*. Winding up the side of this ravine, and clinging pertinaciously to its southern flank, the railway climbs by a stiff gradient of 1 in 37, the 1 mile 38 chains leading to the short comparative bit of level at Khandalla station, passing on its way through another rock tunnel 126 feet long, thence by lesser gradients of 1 in 40 and 1 in 50 it mounts the remaining 2 miles to the summit of the Bhore, at Lanowlee.

The works on the Bhore *ghât* incline comprise twenty-five tunnels of a total length of 3986 yards, or over $2\frac{1}{4}$ miles, the two longest being one of 435 yards—or 1305 feet—and one of 341 yards—or 1023 feet—in length, carried without a shaft through a mountain of basalt. Generally, from the rugged character of the cliffs, it was rarely possible to sink summit shafts, and the tunnels had to be driven from the two ends. Being always on steep gradients, and often on sharp curves, the most careful and accurate setting out was necessary in order to secure a true junction of the headings. There are altogether on the *ghât* eight lofty viaducts of arched masonry, having a total length of 2961 feet, or over half a mile. The two largest are 504 feet long, having a maximum height of no less than 160 and 163 feet above foundations. Of smaller bridges there are twenty-two of spans from 7 to 30 feet, and eighty-one culverts of various size. The construction of this barely 16 miles of mountain railroad occupied seven and a quarter years, and it cost £1,100,000. The average number of labourers and workmen of all kinds employed during two seasons was 25,000, and in the year 1861 upwards of 42,000 men are stated to have been engaged on the works.

Among the many peculiar difficulties encountered, both on the Bhore and on the Thul *ghât* inclines, were the unhealthy nature of the hot and rainy seasons (the latter with a rainfall of 200 inches), and the fatal epidemics which so often scattered and dispersed the armies of men engaged; the rugged and precipitous character of the ground, impeding the haulage and transport of material, and harassing all engaged on the operations; the sudden and dangerous landslips from the hill-sides, and the extreme hardness and solidity of the trap rocks so largely dealt with; the scarcity of water at certain periods of the year, and the difficulty at all times of providing the ordinary necessities and comforts of the workmen. There are probably but few travellers now daily passing up and down the magnificent Thul and Bhore *ghât* inclines, quietly seated in comfortable railway carriages, who can at all adequately realise the extraordinary nature of the obstacles which have been so successfully overcome, and the great skill and daring of all those engaged—especially during the first years—in shaping and carving out of the rocky mountain sides those wide luxurious roads on which they now so easily and securely travel. To form a true conception of their surprising magnitude, it is necessary to pass along them either on foot or by open trolley, closely observing all the numberless ingenious expedients resorted to for making the rough ways smooth, and converting the stupendous natural inequalities of the precipitous hills into a series of uniform inclined surfaces, as well as closely regarding from below and from above the details of the towering embankments and masonry viaducts by which the low parts have been filled up, and the constantly recurring wide and spacious tunnels, or deep rock-cuttings, by which the projecting mountainous ridges and bluffs have been brought low; until the whole rugged and inhospitable region has been smoothed down, and rendered easy and secure for the daily transit at all seasons of railway trains crowded with men and merchandise.

From Lanowlee—where the railway has at length gained the summit level of the Western *ghâts*—the course followed by the south-east extension of the Great Indian Peninsula line is *via* Poona and Sholapore to Raichore, where it joins the

Madras railway at 409 miles from Bombay. For the first portion of the distance it traverses a somewhat rough country, with a ruling gradient of 1 in 181, but for the most part the works are of an ordinary character. Crossing the rivers Bheema and Seena by two bridges—the first of twenty-eight masonry arches of 40-feet span, with piers 60 feet high, and the second of twelve similar arches, with piers 54 feet in height—the line, a short distance before reaching Raichore, crosses the Kistna, a stream of considerable magnitude, by a girder bridge 3855 feet long, consisting of thirty-six clear spans of 100 feet each, with piers formed of iron cylinders filled with concrete, 49 feet high above the lowest water. The piers and abutments of the Kistna bridge have been constructed for a double line; the superstructure carrying a single line only, and the completed cost of the structure is given as £127,300.

The total length of the Great Indian Peninsula system of main lines and branches is 1288½ miles. The north-east main line as far as Khandwa, 352 miles from Bombay, is laid double, as well as the 60 miles from Bhasavul to Sheogaum on the Nagpur branch. On the south-east trunk line the rails are double for a distance of 46 miles from Callian, making in all 459 miles of double track. On the rest of the railway the earthworks are for the most part made for a single, and the masonry of bridges and viaducts for a double, line of way. The rails originally laid were of iron, weighing 68 and 84 lbs. per yard, these are now being gradually replaced by steel rails of 69, 82, and 86 lbs. The sleepers, which were originally of wood, are also being largely replaced by iron bowls. As far as Sholapore the line was opened in sections at various times, being completed to that town in June 1860. The extension beyond Sholapore, to meet the Madras railway at Raichore, was delayed; not being commenced until the year 1865, and the permanent bridge over the Kistna river, near the end of the section, was opened for traffic in October 1873. The Great Indian Peninsula Railway Company, in addition to their own lines, work, under contract with the Government, the Dhond and Munmar State Railway, the Berar branches, and the Wardha Valley State Railway, which opens up a valuable coal field at Warora, in the Central Provinces.

**Madras
Railway.**

The original portion of the 'Madras Railway' system of lines was, as we have seen, that to the south-west, from the city of Madras, through Arconum and Menil, to the opposite sea-coast near Beypoor (now extended to Calicut). From this trunk line an important branch, $87\frac{1}{4}$ miles long, extends to Bangalore, and one of 26 miles to Ootacamund. The first sod of this railway was turned on the 9th June 1853, the intention being to construct an 'experimental' line from Madras to Menil, a distance of 50 miles, but before this length was completed it was decided to extend the railway to the western coast, and the final contract was accordingly signed in 1855. The distance from Madras to Beypoor is 406 miles. The line, leaving the terminal station at Madras situated almost on the sea-beach, passes Arconum, the junction station for the Bombay line, at 42 miles, and traverses the width of the peninsula without encountering any serious engineering obstacles. The range of Western *ghâts* on the opposite coast is passed by the gap at Palghat, at a point only 800 feet above the level of the sea, and affording a fairly easy descent to the sea-coast.

Following now the section of the Madras railway connecting with Bombay: Shortly after leaving Raichore, and the Great Indian Peninsula Railway terminating at that place, the line encounters the large Tungabudhra river, which it crosses by a girder bridge 4060 feet long, consisting of fifty-eight spans of 64 feet each. Running almost due south, it traverses a moderately easy country, and reaches the junction station of Guntakal—now an important centre and meeting-point of an extensive system of narrow-gauge lines in the Madras Presidency. Here the Madras railway trunk line bends to the south-east, and after passing over about 25 miles of rough and hilly country approaches two important rivers, viz., the Penner and the Chitravati, which it crosses by two fine bridges lately reconstructed, one 1830 feet long, opened in 1889, of thirteen girder spans of 131 feet each, with foundations 54 feet below the lowest water; the other, 2670 feet long—opened in 1890—of nineteen girder spans of the same size, with foundations 78 feet below low water. The respective cost of these bridges is approximately £112,000 and £136,000. Several other streams of some magnitude are also shortly after-

wards encountered, including the Papaghni river, over which a large girder bridge of fifteen spans of 131 feet is now in course of construction, in replacement of an earlier structure. A few miles beyond Cuddapah the railway reaches and crosses the river Cheyer by a long bridge of 3500 feet, costing £124,500, and consisting of fifty spans of 64 feet, with a maximum depth of foundations of 100 feet. From the Cheyer river to the junction with the Madras Beypoor (Calicut) railway at Arconum, 42 miles from Madras, the line traverses a hilly country, cut up with ravines, and necessitating much heavy embankment and rocky cutting, but containing no works of more than average importance. The total length of the Madras Railway system of lines as now open is $889\frac{1}{4}$ miles, of which the length from Raichore to Arconum is $307\frac{1}{2}$ miles, the remainder belonging to the south-west system.

The weight of the rails on the Madras Railway vary from 65 to 84 lbs., laid on iron bowl sleepers. Originally the south-western section was laid with wooden sleepers, and an experiment was made of using stone blocks $2' \times 2' \times 1'$ in their place; these were, however, soon discarded, and in 1861 the jungle-wood sleepers first used were replaced by cast-iron bowls, which are now almost entirely employed.

The early history, general alignment, and principal constructional features of the three parent lines of the Indian railway system, viz. the 'East Indian Railway,' the 'Great Indian Peninsula Railway,' and the 'Madras Railway'—aggregating 3653 miles—have now been succinctly traced. It would be neither agreeable to the reader, nor suitable to the limited compass of this volume, to attempt to follow in similar outline the development and course of the remaining 14,000 miles of the existing railways in India. It will, in the succeeding chapters, be sufficient for the main purpose in view to illustrate, with greater or less particularity—according to relative importance—only those great works of the first magnitude and interest which are to be met with scattered over the country on the various lines of railway, reserving for a concluding chapter a *résumé* of such of the general aspects and statistics of Indian railways, considered as a whole, as may be of general interest.

CHAPTER X

REMARKS, GORAI BRIDGE, DUFFERIN BRIDGE

Preliminary observations on some of the peculiarities and circumstances of Indian rivers—Position of bridges—Design affected by character of the river—Arched masonry bridges—Conditions rarely suitable—Iron structures—Bridge piers and abutments—Determination of minimum waterway—Security of bridge abutments—Training works—Selected examples of large or interesting railway bridges in India—The bridge over the Gorai river, Eastern Bengal Railway—Particulars and details of construction—Sinking the cylinders—Floating the girders into position—The Oude and Rohilkund Railway—Outline of system—Particulars of bridges over the Ganges—The Dufferin Bridge at Benares—Descriptive details of design—Erection of the bridge—Preliminary work—Sinking the main pier caissons—Great depth of foundations—Accident at No. 4 pier—Remedial measures—The minor piers—Erection of superstructure, and completion of the work.

THE selected examples of large railway structures in India, illustrated in this and the following chapters, are almost entirely confined to iron or steel bridges of some magnitude, carried over the great rivers of the country. It will serve, therefore, to the greater interest of the reader, as well as to his better appreciation of the more difficult problems occasionally to be solved in connection with large bridge construction in India, to preface this chapter with a few preliminary observations on some of the special peculiarities and circumstances of Indian rivers, as affecting the general features of the design and location of large railway bridges. In making these observations, however, no attempt is made to treat in a comprehensive manner so exceedingly important and difficult a subject; the observations are confined to the indication of a few broad general features of bridge location and design, suited to the general reader.

In selecting the exact spot for bridging a large river, the

engineer is usually restricted to very moderate limits of deviation from the direct route proposed to be taken by the railway. Within such limits he will seek for some portion of the valley where the main channel of the river is not only concentrated, but where, from all reliable indications, it appears to be fixed in a permanent manner. Failing the discovery of such a position, some more or less considerable outlay will be necessary for regulating the channel and preserving the permanency of the bed, by means of artificial training works. The whole design of the contemplated bridge will in great measure be governed by the character of the river bottom at the point selected for the erection of the structure. In ordinary cases where permanent rock, or other sufficiently hard strata, occurs on the surface, or is placed within easy reach below water, and where suitable building materials are obtainable at ordinary expense, a bridge with masonry piers connected by stone or brick archwork will probably be the most economical in first cost; and, if so, will certainly be the most convenient, the most pleasing, and altogether the most desirable construction. A well-designed and well-built arched masonry bridge, once made on a secure foundation, entails little or no subsequent expense, and the line of railway laid over it is free from the many inconveniences arising from the contraction and expansion of large iron or steel superstructures. The heavy expense of frequently painting the iron girder work to avoid corrosion; the liability to slow deterioration under the constant inherent motion of its parts, and the vibration of passing trains, together with the rattling noise experienced under the traffic, are great drawbacks in the case of all iron or steel structures. In the plains of India, however, the conditions necessary for security and economy in the erection of arched masonry bridges of large size are rarely met with, for in all cases where the expense of pier foundations reaches beyond a certain proportion, economy in first cost has to be sought by increasing the width of opening, so as to limit the number of the piers, and thus the size of span soon extends beyond the practical limits of arch-work. Bridge piers and abutments, in the great majority of cases, are constructed of stone or brick masonry, but the use of iron for piers, as well as for the

superstructure of bridges, is sometimes imposed by local conditions, amongst others, by any special liability of the district to earthquake.

The determination of the minimum waterway to be allowed in the case of bridges over the larger class of rivers, especially in the great alluvial plains of upper India, is attended with many peculiar difficulties. As a rule, little or no means exist of ascertaining the true area of the basin drained by these rivers, especially if liable to receive spill water from other river basins. Moreover, the areas are usually so enormous, and subject to so many fluctuating conditions of rainfall, and physical constitution, and the problem is complicated by so many highly variable conditions, each affecting in some degree, and some largely, the maximum flood discharge, as to place its theoretical calculation at the best on a very empirical and uncertain basis. In these circumstances the engineer, naturally solicitous above all for the permanent stability of his work, is apt to err on the safe side, and provide for a greater area of waterway than necessary, rather than incur the risk of unduly contracting the limits of the highest recorded flow in the river during high floods.

It is rare in the plains of India to find a river flowing within well-defined banks. A tolerably permanent high bank may often be found on one side, behind which one abutment of a bridge may be securely placed. The proper position for the further abutment then becomes the difficult problem. In such cases the main channel will invariably be found nearest the high and more or less permanent bank, and the main openings of the bridge will of course be there provided; a less expensive structure being designed as a continuation of the main openings for such distance over the opposite low ground as may be deemed necessary for security. In all cases where the piers and abutments of a bridge can be rendered perfectly secure against scour, and capable of withstanding the concentrated force of the severest floods, at a less cost than increasing the lineal waterway of the whole structure, the length of the bridge will be safely contracted, and the river will be largely permitted to adjust its own sectional area to the discharge, which it will do by scouring away its bed to the extent

necessary ; but in frequent practice the increased cost of protection and of training works thereby entailed, will exceed the saving due to shortening the bridge. Every bridge site in the great plains of India possesses, in fact, so many special and peculiar features of its own, that the determination of the water-way to be allowed is only very partially reducible to general principles, or to considerations applicable in all cases. The two important objects which the practical engineer will always have in view, and which will mainly govern his designs, will be the perfect security of the bridge abutments, and the establishment, by suitable training works where necessary, of a permanent and well-defined channel, for some distance above and well through the site of the bridge, evenly embracing its water-way, and constraining the passage of the water through the whole width of the work, with a fairly uniform velocity of current.

It is now necessary to select for the purpose of illustration a few additional examples of large, or otherwise interesting bridge constructions occurring on Indian railways, out of the very numerous sum-total of such works, the latter comprising very many of scarcely inferior proportions to those which the space at command permits detailed mention.

On the Goalunda extension of the Eastern Bengal Railway, between the years 1867 and 1870, a bridge was constructed over the Gorai River, which, although not a work of especially remarkable size, is an interesting example of construction carried out, under peculiar conditions, by the application and employment of special methods. The data for the following description of this bridge is collected from a very full paper on its construction, read before the Institution of Civil Engineers by its designer and builder, Sir Bradford Leslie, K.C.I.E., M.I.C.E.¹ The Gorai River is the largest and most important of the many arms or branches into which the Ganges is broken up on reaching its delta at the head of the Bay of Bengal. At the site chosen for the railway-crossing, the river in the dry season is about 1000 feet wide, with a depth of 40 feet of water, but during the rainy season the width reaches 1600

¹ *Vide* vol. xxxiv. *Min. Proc. Institute of Civil Engineers.*

feet, with a flood rise of 28 feet, and a velocity of current of nearly 5 miles an hour, at which time the bed is scoured out some 24 feet, so that the body of water then reaches over 90 feet in depth. The alluvial deposit forming the bed of the river consists of a light sandy clay and loam, followed by a stratum of stiffer clay overlying a coarse grey sand.

The railway bridge thrown across the Gorai consists of seven main girder-spans of 185 feet each. On the west side, beyond the seven main spans, a raised portion of the river bed—covered, however, by 30 feet of water in floods—is crossed by a cast-iron screw-pile viaduct, of nine spans of 46 feet 3 inches, so that the total length of bridge and viaduct construction is 1744 feet. Each pier of the main bridge is composed of two iron cylinders, placed 37 feet 6 inches apart from centre to centre; this width being sufficient to allow for a double line of rails if required. The cylinders are sunk to a maximum depth of 98 feet below low water (those forming the land extremities being sunk to the same depth as those in mid-stream), and the total depth to which the foundations were sunk was determined with reference to the amount of scour anticipated. The lower portion of each cylinder, for a height of 30 feet 6 inches, is built up of wrought-iron rings, each 4 feet 6 inches high, bolted together by internal flanges, and is 14 feet diameter at the bottom—where the lower edge is strengthened to form a strong cutting edge—and 13 feet 4 inches at the top. Above the wrought-iron portion, a cast-iron conical piece narrows the diameter to 10 feet, and the upper length of the cylinder is formed of cast-iron of this diameter; the cast-iron portion being put together in rings of four segments, each 9 feet high. The separate segments are bolted together by means of internal projecting flanges, leaving the piers smooth on the external face. When completed, the pier cylinders were filled in with concrete and brickwork, and were joined together at the top by two wrought-iron connecting girders, which serve to carry the main girders of the superstructure, at a height of 50 feet above low water. The superstructure girders are solid beams, 12 feet high, and 3 feet wide on the top and bottom members, placed 13 feet 6 inches apart in the clear, so as to carry a single line only. The interesting features of the Gorai

bridge are to be found in the methods employed in its erection, both in sinking the pier cylinders, and in the emplacement of the girder superstructure.

The treacherous nature of the river-bed, and the depth and strength of the current, made it undesirable to attempt the work of sinking the cylinders by the aid of temporary fixed stagings. A pair of floating pontoons, each 140 feet long by 80 feet wide, joined together by a platform 17 feet in width, containing the necessary openings for the two cylinders, were therefore provided. The pontoons were furnished with powerful overhead travelling cranes, engine power, and all the necessary gear for manipulating the heavy weights that would have to be dealt with, and were securely anchored into position at the site of each pier. Three lower rings of cylinder, in all 12 feet 6 inches in height, and weighing 30 tons, were erected on timbers placed across the opening in the pontoon platform, and a temporary water-tight bottom of pine staves was inserted at some distance above the lower edge. An inner lining of brickwork, supported on the projecting ring flanges was also commenced. The depth of water in the river was too great to allow a sufficient length of cylinder to be slung and lowered so as to reach the river-bed in one operation, hence the necessity of the temporary bottom to render the tube buoyant and self-supporting. Three lower rings were suspended and lowered into the water, and the tackle to be used for controlling and adjusting the position of the cylinder in going down, was fitted. Successive rings were then bolted on, and the internal lining of brickwork was continued, adding weight until the cylinder was sunk into, and was steadily buoyed up by the water, so that it could now be freed from the suspending chains. By adding fresh rings, and building additional brick lining, the process was continued until the bottom of the river was reached, when the interior of the cylinder was filled with water. The temporary water-tight bottom was now battered out, and the cylinder was allowed to sink into the soft soil of the river-bed until supported by it. The operations for pitching the pier cylinders were carried out with only one mishap, caused by a cyclone which occurred in 1869, and in consequence of which the lower portions of two cylinders were

overthrown and submerged; one of these was, however, recovered, but the other was permanently lost, and had to be replaced.

The sinking of the cylinders through the alluvial soil of the river-bed to the requisite depth, was effected by excavating the earth from the inside of the cylinder by a rotating boring tool 9 feet in diameter, consisting of a disc fitted with blades and cutters. The boring-tool was slowly revolved by a compressed-air engine placed above, through an intermediate vertical shaft, formed of a pipe 13 inches in diameter, placed inside another line of piping 26 inches outside diameter; the annular space between the two pipes being divided into a series of air-jackets, making a hollow working shaft of great strength, and practically self-supporting in water. The object of this ingenious hollow shaft was for the purpose of removing the earth by a strong current of water constantly flowing up the central pipe. To establish this current, a 12-inch syphon pipe was provided, the inner leg of which was immersed in the hollow boring shaft, and the outer leg into the water in the river. The air was exhausted from the syphon pipe, and being replaced by water, a blow from the bottom of the cylinder, up the shaft, and out by the syphon, was at once set in motion; in quantity proportionate to that discharged into the cylinder by a pair of 13-inch centrifugal pumps. The soil of the river bed, loosened and churned by the boring head, was discharged together with the water, and by this means the cylinder was gradually made to sink. The necessary additions to the length of the pipe-shaft and the readjustment of the syphon, were made from time to time, until the designed depth of sinking was reached. The land cylinders, which were pitched in the dry season, were sunk, by a modification of the same method, through about 120 feet of the alluvial soil of the river-bed, the necessary water being supplied by pumping.

The cylinders forming the piers being sunk, and finished off at the requisite height of 50 feet above low water, the first main girders of the superstructure were erected and riveted up complete, in two parallel rows on the embankment of the east approach to the bridge, and were rolled forward into position by means of two powerful overhead lorries, from

which, by the aid of overhead lifting gear, the girders could be suspended. The lorries were furnished with flanged wheels to run on rails, by means of which they could be moved to and fro, whilst the weight was off them, but when the weight was lifted and suspended, the two trollies carrying it were moved forward on series of $3\frac{1}{2}$ inch iron-bar rollers, each 10 feet long, placed between the iron-shod sills of the lorries and the rails. The first span of the bridge being dry, the girders were hauled into place over a temporary staging between the piers. This span was completed, and the railway was laid at its proper level on the flooring girders; the temporary line on the approach embankment being at the same time raised to the necessary height. The six remaining girder-spans were then erected, and had to be launched over the water; this was done by floating the forward end of the girders on a pontoon furnished with carrying shears of the necessary height, the after end being carried by the lorries.

The pontoon carrying the forward part of the load was warped across the stream by the aid of suitable tackle, devised for the purpose, and provision was also made for adjusting and maintaining it in proper alignment during the operation. In carrying out this system of launching, provision had to be made for a possible considerable variation in the water-level. To meet this contingency, the height of the supporting shears carried by the pontoon was made adjustable, and it was further arranged that when the forward end of the girders was floated over the pier on which it was to be landed, the amount of lowering required should not exceed 12 inches, and this degree of lowering was effected by admitting water into the pontoon and sinking it to the required extent. Numerous precautions were also necessary to secure a sufficient lateral strength and stability of the moving girders in case of high winds, which would act against an exposed surface of 2400 square feet, and to properly distribute the weight of about 65 tons borne by the pontoon. These various delicate operations connected with the launching and placing of the main girders were rapidly and successfully carried out without the smallest mishap.

The first pier cylinder was put into the water in November

1867; and the whole bridge was completed, at a cost, including protection works, of £148,375, by the end of the year 1870. The average time occupied in launching the girders across the water-spans was about one hour, and the whole superstructure of the seven main spans was erected and placed in position in seven weeks and three days.

The late Oude and Rohilkund Guaranteed Railway Company, whose various undertakings were taken over by the Government under the contract terms in 1889, constructed a system of broad-gauge lines situated almost entirely north of the Ganges river, and opened up the rich tracts of country in Oudh and Rohilkund, lying between Benares on the east, and Saharanpur on the north-west. The company, which commenced operations in a somewhat humble manner, as the 'Indian Branch Railway Company,' in the year 1864 entered upon the construction of a short branch line from the left bank of the Ganges opposite Cawnpore to Lucknow, a distance of 45 miles, and subsequently, under its old or new title, gradually extended lines of rail from Lucknow eastwards to Fyzabad and Benares, and north-westwards through Bareilly and Moradabad to Saharanpur, ultimately developing, with branches, a system 692½ miles long. From the isolated position of these lines, cut off entirely from the East Indian and other railways south of the Ganges, the company was soon constrained to connect itself with the general railway system of India, by throwing bridges over the sacred river of the Hindus, and this in no less than four places. No other railway company has as yet anywhere bridged this river, unless the East Indian Railway Bridge over the Hooghly channel, near Calcutta—already referred to—is considered to be a Ganges bridge.

The two earliest bridges carried over the Ganges by the Oudh and Rohilkund Railway Company, were those situated at Cawnpore and Rajghat, both on branches, the first connecting Lucknow with Cawnpore; and the second connecting the upper districts of Rohilkund with Aligarh on the East Indian Railway. The first of these bridges, viz., that at Cawnpore, is 2830 feet long, and consists of 25 deck girder-spans (with cart-road below) of 100 feet each, and 2 of 40 feet. The girders are carried at 32 feet above the lowest water; and the piers

are founded on single 18-foot wells, sunk to a maximum depth of 65 feet below the same point, into the sandy river-bed. The Rajghat Bridge, which is 3040 feet long, has 33 deck-spans of 80 feet, placed $24\frac{1}{2}$ feet above low-water, and single $12\frac{1}{2}$ feet foundation wells sunk 55 feet. These bridges cost £174,700 and £79,820 respectively—the latter being one of the cheapest structures of its size yet made. The third bridge over the Ganges is on the main-line extension of the railway from Moradabad to Saharanpur, at Balawali. This fine and relatively recent work—opened early in the year 1887—is 2904 feet long, and has 11 clear spans of iron girders, carrying the roadway between them, of 248 feet each, or 264 feet centre to centre of piers, placed 40 feet above the level of lowest water. The piers are carried on double circular wells 20 feet in diameter, sunk to a depth of 100 feet below low water in pure sand. The finished cost of this bridge was £277,271.¹

The latest, largest, and most important of the railway bridges erected by the Oudh and Rohilkund Railway Company over the sacred Ganges, is that situated immediately below the town of Benares, called the 'Dufferin' Bridge, in honour of the Earl of Dufferin, during whose Vice-Royalty it was constructed, and by whom it was officially opened in September of the year 1887. This splendid work is undoubtedly in some respects the most perfect specimen of railway bridge engineering in India, and a short description of it will be of more than ordinary interest. The following account of the Dufferin Bridge is chiefly drawn from official records, and from a very full descriptive paper on its construction read before the Institution of Civil Engineers on the 4th March 1890.²

For many years after the Oudh and Rohilkund Railway Company had completed its line north of the Ganges to Benares, and to a point on the left bank of the river, situated opposite the terminus of a short branch of the East Indian Railway, from their main line at Mogul Serai, a cart service was main-

¹ For true cost of these and other railway bridges stated in Indian rupees, see Appendix K.

² *Vide* vol. ci. *Min. Proc. Institute of Civil Engineers*.

tained across the intervening river by means of a temporary bridge of boats. In the year 1879 it was determined to connect the two systems of lines on either bank by a permanent bridge over the formidable channel of the Ganges lying between them. The construction of the bridge was approved by the Secretary of State for India in July of that year, and active steps were at once taken to prepare alternative plans and estimates for a combined railway and road bridge, on the site which had been already selected by the chief engineer of the company.

The engineers had to decide upon the most suitable and least expensive manner of throwing a railway bridge over a river with a bed consisting virtually of pure sand extending to an unknown depth, carrying a dry season body of water about 1800 feet wide and 37 feet in maximum depth, and liable to a rise of 50 feet during the highest floods, at which times the water, overtopping the low right bank of the river by some 7 or 8 feet, inundates the country for 5 or 6 miles inland. On the left-hand side the river-bank is high, and is not liable to be overtopped. During the greater part of the dry season the velocity of the current is moderate; but during high floods it reaches 15 miles an hour, and the sandy bed of the river is then sometimes scoured to a depth of over 30 feet, giving a possible depth of water in full flood of no less than 120 feet in all. In order to allow ample headway for the free passage of the river navigation, it was decided that the underside of any structure that might be designed should not be placed at a lower level than 75 feet above the lowest water in the river—or 25 feet above the top of the maximum floods. The principal points which the engineers had first to determine were: the total length of bridge waterway, and the size of the individual spans; the description of pier, the depth of foundations necessary—considered in reference to the extreme limits of scour—and the general design and character of the superstructure, so as conveniently to utilise the bridge both for the railway and for ordinary wheeled traffic, and further—the general data for the contemplated work being settled—it was necessary to decide upon the most practical, as well as the most economical and expeditious methods of construction,

whether as regards the sinking and founding of the piers, or for the erection of the superstructure.

These initial questions were, after full investigation and discussion of various alternative proposals, finally settled as follows:—The total open water-way of the bridge was fixed at 3507 feet, made up of seven large spans of 356 feet each, carried over the deep channel of the river, situated towards its left and permanent high bank, and nine extension spans of 114 feet each, to pass over the raised portion of the river-bed lying beyond the right dry-season bank. It was decided that the piers should be founded on single elliptical blocks of brick-work, pierced with three excavating chambers, and enclosed in an iron shell or caisson sunk into the river-bed. Moreover, in consideration of the limits of scour in high floods—so far as yet observed—it was deemed necessary that the foundation caissons and blocks should be sunk in the pure sand to a minimum depth of 120 feet below low-water level—that is to say, to 83 feet below the ordinary dry-season bed in its deepest part—but that this depth of foundation should be increased, if careful soundings taken during extreme floods, should indicate in the course of operations, that the bed was likely to scour to a greater depth than 33 feet below the deepest dry-season bed—or 70 feet below low-water-level.

With regard to the superstructure, it was determined to employ girders constructed entirely of steel, this being at the time the largest proposed application of steel for structural purposes. The larger girders were designed of the compound triangulated type, 355½ feet in length, and 35 feet 4½ inches in depth; the smaller girders 113 feet 8 inches in length, by 11 feet 5½ inches in depth, and it was agreed that the roadway both for rail and for cart traffic should be carried on the same level, between the large girders, and over the top of the smaller extension spans. The height of the bridge and the depth of the main girders being so great, and the right bank of the river being so low, it was not considered economically practicable to arrange a separate road for ordinary wheeled traffic, it became necessary, therefore, to provide a metalled road 22 feet in width—supported on strong buckled plates, on the same level as the rails, to be used for such traffic in the intervals

between the passage of trains, and to place footways for pedestrians 5 feet wide, carried on cantilevers outside the main girders.

Several schemes were proposed for getting the huge main spans of girderwork into position—such as floating them into place by the aid of pontoons, or raising them from near the water level by hydraulic lifts simultaneously with the building up of the piers themselves, and some others. All these plans were, however, discarded, as in one manner or another open to practical objection under the circumstances of the river, and the girders were ultimately built up in place—in spite of the deep water in the channel—on very cleverly arranged stagings of full height, erected on the river-bed between the piers.

Practical work on the construction of the bridge commenced on the 19th January 1881, being started simultaneously at the two abutments—placed 3507 feet 3 inches apart—and operations for the most part of each working season were subsequently carried on by night as well as by day, by the aid of powerful electric lights. As a preliminary, it was necessary that the distance between the two abutments of the bridge should be very exactly measured. This measurement was effected in the following manner: first, two lines parallel with the centre line of the work were ranged, each 85 feet on either side of it, so that these lines being always clear of obstruction during the progress of the work, the intermediate measurements could be made and transferred from them. To ascertain the exact total length, the portion on the dry bed was levelled, and the measurement was made by steel tapes: that across the deep water channel—a distance of about 1800 feet at low water—was first fixed by a trigonometrical triangulation, and then by a fine steel wire stretched across the channel, over pulleys exactly 20 feet high above water level. The wire was strained by weights until it exactly touched the water surface in the centre, and fixed points on either bank were then plumbed up to the wire and marked on it by solder marks. The wire was now carried on shore, and being fixed and strained in precisely the same manner over a truly levelled piece of ground, the exact distance could then be directly measured. This measurement was found to be within an inch of that trigonometrically deter-

mined. Subsequently, when the work carried on from either end of the bridge was joined near the middle of the river, an error of a little over $\frac{1}{2}$ an inch was detected.

On the Benares, or left-hand side of the river, the approach line of railway crosses the Rajghat plateau, where in former years there had been a strongly fortified post, to command the river, crossing from the Grand Trunk road. 'Tradition assigns to this naturally very strong position a great antiquity, and points to it as being the site of the stronghold of the ancient rulers of the once mighty kingdom of Benares, which is said to have extended from the borders of "Chin" (Thibet) to Malwa, and from the sea to within ten days' journey of Lahore.' The British fortified post on the plateau was abandoned in the year 1865.

The piers of the Dufferin Bridge, carrying the large 356 feet girder spans, were founded on single elliptical wells 65 feet long, and 28 feet wide. The iron foundation-caissons varied in height to suit the depth of water through which they had to be sunk, the largest was 50 feet high, others being 42 feet and 26 feet respectively; they were constructed of iron plates $\frac{1}{2}$ inch and $\frac{3}{8}$ inch thick, with inner and outer shells 5 feet apart, connected together by horizontal and cross bracings. From the base of the outer shell, the inner shell inclined at an angle of 45 degrees, up to a height of 6 feet, thus forming a strong cutting edge which was further strengthened by a cast-steel shoe. The interior wedge-shaped space thus formed at the bottom, between the two shells, was at first filled in with cement concrete, but it was afterwards found preferable to use pure sand only. The caissons were divided into three internal excavating chambers, by double cross walls also furnished with tapered cutting edges, situated about 6 feet above the base of the caisson. On the top of the caissons, midway between the inner and outer shells, an iron crating of angle bars, well tied together, was framed, which served to strongly bind together the brickwork of the foundation blocks and the upper brickwork of the pier. The system adopted in sinking through the water was briefly as follows. The first 10 feet of the caisson having been built on a temporary platform, between a pair of iron floating pontoons coupled together at a distance of 32 feet

apart, and strongly moored into position, were lowered by chain slings into the water by the aid of powerful tackle. Additional sections were added to the top of the caisson, and it was gradually lowered; the weight being augmented by the concrete and brick linings, until the lower cutting edge reached, and was adjusted in its true position on the river-bed. The suspending chains were then released, the interior brickwork was brought up to a height of about twelve feet above water-level, and the pier was now ready for sinking. The sinking through the river bed was effected by mechanical diggers 8 feet in diameter, working in the three excavating chambers. Each digger weighed $3\frac{1}{4}$ tons when empty, and contained 130 cubic feet of material when full, then weighing about 6 tons more. They were worked by steam travellers carried on an overhead staging 57 feet in height erected on the pontoons, each capable of lifting 20 tons. The material lifted by the diggers was deposited into shoots at the side of the pontoons, and discharged into the river. By this means rather under one foot, or at the rate of 1.43 feet per day whilst the diggers were in action, of sinking was effected; the elliptical pier blocks being sunk at that average rate per working day.

The foundations of the seven piers for the main spans were carried down to varying depths below the water-level. The first three on the left bank of the river were secured into a bed of firm yellow clay at a moderate depth, but piers Nos. 4 and 5—the first of which has the deepest foundation in the world—were forced down through sand to the great depth of 141 and 140 feet below low water, or about 104 feet below the deepest dry-season bed; these piers being thus no less than 215 feet in height from the bottom of their foundation to the underside of the girders. During the operation of sinking the piers, many interesting and curious objects: ancient relics, as well as animal remains, were met with, which were carefully collected and preserved, the position and actual depth at which each article was found having been precisely recorded.

The work at No. 4 pier was seriously hampered by an accident (the only serious one which occurred during the progress of the works) which might have entailed an enforced modification of the bridge superstructure. The lower cutting

edge of the iron caisson,—which in this case was 26 feet in height—had reached a thin bed of clay situated about 50 feet below the river-bed, or $70\frac{1}{2}$ feet below low water, and the masonry had been built up to a height of 91 feet, so as to add as much weight as possible. The diggers had excavated holes into the clay, about 9 feet below the lower edge of the caisson, when a considerable portion of the side of the hollow excavation suddenly fell in, displacing a large volume of water, which was consequently forced upwards through the excavating chambers, and overflowed the top of the brickwork. The sudden and violent pressure of the water burst the sides of the pier masonry, which, being new, and the mortar not having properly set, was fractured in two lines from the top down to within a few feet of the top of the caisson. As the rainy season was then close at hand, nothing could be immediately done, and it was at first feared that an almost irremediable disaster had occurred. As soon, however, as the floods had subsided, it was found that the fractured portion of the brickwork, 62 feet in height, 46 feet in width, and extending 21 feet below the river-bed, had fallen away, and thus the difficult operation of its removal by explosives or other means, was obviated. To remedy this serious injury to the pier, the engineer in charge of the work, with ready resource, devised a double wrought-iron shield of exact size and shape to enclose the gap. This shield was rapidly constructed at the site of the works, and was sunk through the bed of the river, down to the base of the fracture, by means of dredgers working within it; and when the broken surfaces of the brickwork had been trimmed and cleaned, and the shield was correctly fitted into place, the interior space was filled in with cement concrete, and the top of the patch was strongly bonded with iron rails into the old work. By this ingenious and thoroughly successful expedient the pier was rendered virtually as strong as ever, and the whole was afterwards sunk $70\frac{1}{2}$ feet deeper than it was at the time of the accident.

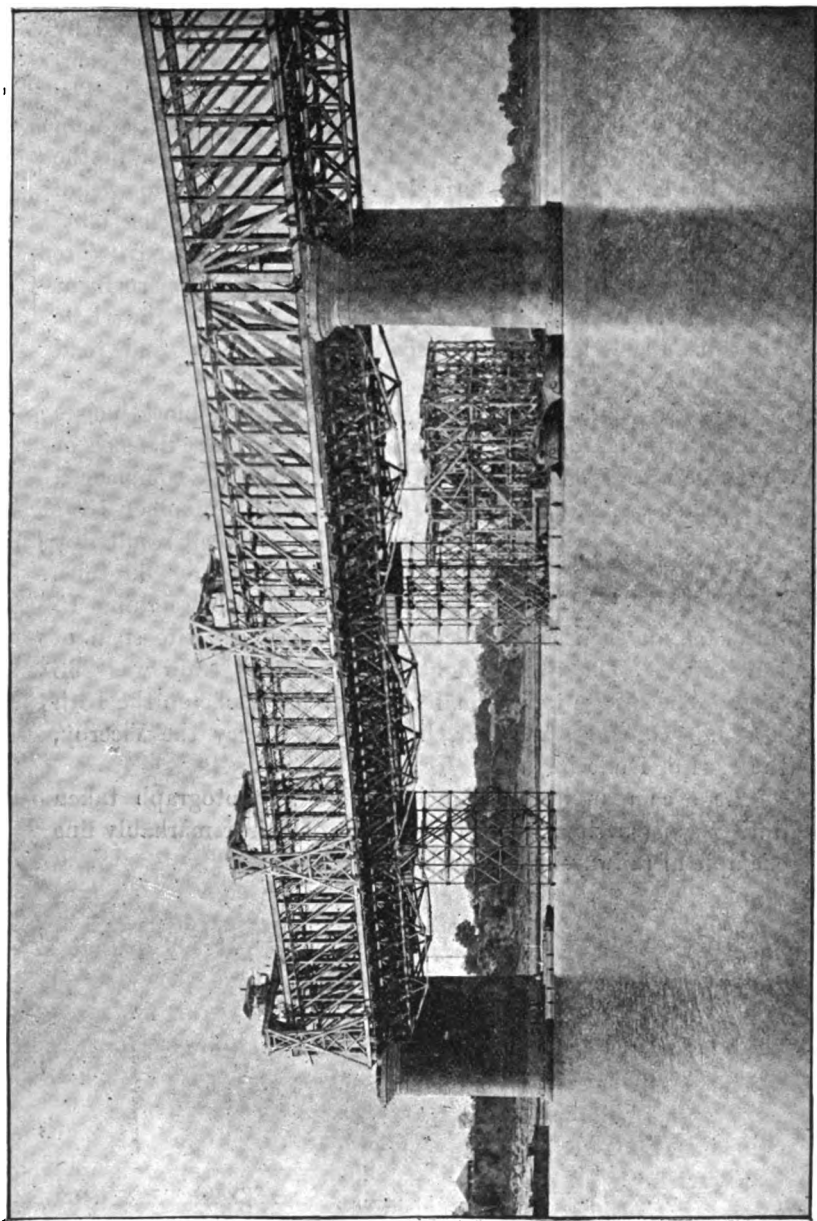
When each pier had been sunk to its proper depth, the three excavating chambers were filled in solid with concrete, and plugged at the top with brickwork. The foundation masonry was built up to a few feet above low water, and was

finished off with a rough stone plinth, on which, on a slightly smaller sectional plan, the upper pier work was built up in solid brickwork to the necessary height of $72\frac{1}{2}$ feet above low water level, each pier being finished off with a handsome terminal cornice.

The nine smaller piers for the extension spans were founded on two $12\frac{1}{2}$ -foot wells, with iron curbs, pitched 25 feet apart from centre to centre, sunk from 67 to 157 feet below ground-level by means of dredgers. At 5 feet above low-water level the two wells were connected by a corbelled arch, and the solid piers were then erected on the top. These piers are 35 feet long, and 10 feet wide, with parallel sides and semicircular ends. The total quantity of brickwork in the Dufferin Bridge is 1,876,289 cubic feet, or 69,492 cubic yards, and the cost of the main piers was Rs. 7,57,988, or an average of Rs. 1,08,284 per pier, sunk to an average depth of 102 feet below low water.

The main girders of the bridge were erected in place on a staging and platform formed by utilising the 114-foot-span girders afterwards used in the extension spans. Three pairs of these girders were supported in each larger span on two intermediate temporary piers, formed by clusters of twelve 6-inch solid iron screw piles, pitched 10 feet apart, well braced together, and connected at the top by steel-plate girders; the extension girders intended to carry the weight of the main spans in course of erection being temporarily struttled and strengthened to the necessary extent. Some difficulty occurred in erecting the temporary piers in the deep-water spans, where the screw piles had to be fixed in 65 feet of water. Artificial mounds or islands of sand, supported by walls of sand-bags, were here formed to give lateral support to the lower portion of the piling, and the temporary structures were stiffened by steel-wire guys or ropes, secured to anchors up and down stream. The main girders were erected, piece by piece, by the aid of travelling gantrys or overhead cranes, carried by the staging; they were set to a *camber*, or rise in the centre, of 9 inches, which was reduced to 6 inches on the supports being removed, and to $4\frac{1}{2}$ inches under the full load of the roadway.

The riveting together of the steel-work of the huge girders was almost entirely done by hydraulic riveters, and as the main



'DUFFERIN' BRIDGE OVER THE GANGES AT BENARES, IN COURSE OF CONSTRUCTION.

spans were successively completed and the temporary staging was no longer required, the 114-feet girders were removed by the pontoons, and carried to shore, where they were then completed, and lifted bodily into their final place by derricks. The weight of a pair of main girders is 491 tons, and that of a main span complete is 746 tons, or 5222 tons of steel-work in the seven larger spans of the bridge. The extension spans weigh 127 tons each, or 1143 tons in the nine spans, making 6365 tons in the whole bridge. The cost of the steel superstructure of the bridge complete, with road metalling and permanent way, is given as Rs. 25,18,695, and the total cost of the whole work as Rs. 48,91,151, exclusive of the railway and road approaches.

On both abutments of the Dufferin Bridge block-houses have been built, to contain troops for the military defence of the structure. Construction work on the bridge was commenced in January of the year 1881. On the 24th September 1887 the completed girder-work was tested with excellent results, by a train, consisting of two engines, each weighing 88 tons, placed in the centre, and loaded ballast wagons weighing 15 tons each, on each side, sufficient to cover one entire span of the bridge. The total weight of the testing train was 296 tons. The bridge was formally opened for traffic on the 16th December of the same year, by His Excellency the Viceroy, the Earl of Dufferin.

The accompanying illustration, from a photograph taken during construction, will give an idea of this remarkably fine example of railway-bridge engineering.

CHAPTER XI

NORTH-WESTERN SYSTEM, ATTOCK AND LANSDOWNE BRIDGES

The North-western Railway system—Outline of some of the important bridges—Detailed description of bridge over the Indus at Attock—Flood-rise of the river—Liability of the district to earthquakes—The bridge site—The design of the bridge—Getting in the foundations—Erection of the pier columns—The temporary stagings for girders—Erection of the main girders—Completion and testing of the bridge—The Lansdowne bridge over the Indus at Sukkur—Site and design of the bridge—The cantilevers—Foundation of abutments—The vertical pillars—The main inclined struts, and horizontal ties—First erection of the steel-work in England—Detailed description of the erection of the bridge at Sukkur—Temperature—Difficult setting out—Building the struts and horizontal ties—Completion of the cantilever framework—Bridging the central gap—Suspended staging employed—Completion of the work.

THE 'North-western Railway' of India is a magnificent system of 5 foot 6 inch gauge lines, situated for the most part in the Punjab, Scinde, and the frontier districts, aggregating, with numerous branches, a total length of nearly 2400 miles. The system stretches from Delhi to Lahore and Peshawur; from Lahore to Karachi, Quetta, and to the borders of Afghanistan. A considerable portion of the present North-western Railway was constructed and worked for many years by the late Scinde, Punjab, and Delhi Railway (Guaranteed) Company, which commenced operations as early as the year 1858, but the greater portion of the system has been constructed at various times by direct Government agency—in great measure as frontier military railways. In the course of their construction the railways have been carried over the whole of the great Punjab rivers—most of them, viz., the Indus, the Sutlej, the Chenab, and the Jhilum, having been bridged in two places. The size and main particulars of the chief of these structures will be found detailed in Appendix K.

Excluding the two bridges over the Indus, some of the more remarkable of these works are the 'Empress' bridge over the Sutlej at Adamwahan, consisting of sixteen spans of 250 feet each, 4210 feet in total length, with foundations carried 103 feet below low water, costing over 71 lakhs of rupees. The 'Sher Shah' bridge over the Chenab, consisting of 17 spans, of 200 feet each, 3650 feet in total length, with foundation-wells carried 75 feet below low water, costing over 28 lakhs. The 'Alexandra' bridge over the same river, consisting of 64 spans, of $133\frac{1}{2}$ feet each, 9088 feet, or over $1\frac{1}{4}$ miles long, with foundations 75 feet below low water, costing over 56 lakhs. The 'Victoria' bridge over the Jhilm at Chak Nizam—opened in 1887—consisting of 17 spans of steel girders, of 150 feet each, 2720 feet long, with foundations 82 feet below low water, costing nearly $19\frac{1}{2}$ lakhs. The 'Kaiser-i-Hind' bridge over the Sutlej, near Ferozepore—opened also in 1887—consisting of 27 spans, of $144\frac{1}{2}$ feet each, of new pattern steel girders, carried on brick piers $26\frac{1}{2}$ feet by $14\frac{1}{2}$ feet, built on wells 23 feet in diameter. The bridge is 4293 feet long, with foundations 78 feet below low water, and cost over 41 lakhs of rupees. Each of these works, from the various character of the great rivers crossed, presents features of the highest engineering and general interest, but the space at command will only permit the above cursory notice.

It is necessary, however, to furnish a more detailed sketch of two very remarkable structures, either of which—as indeed will many of those omitted—compares favourably with similar erections in any part of the world. The works to which we refer are, the railway bridges over the Indus at Attock, and over a lower reach of the same river at Sukkur, the last of these bridges, as regards magnitude of clear rigid span, was for some time the largest in the world, and has since only in one instance been surpassed. The railway bridge at Attock carries a section of the North-western Railway running from Lahore to Peshawur (near the north-west frontier), and also the Grand Trunk Road, over the Indus river. This section of line was originally constructed for purely military purposes; it was completed as far as the Indus at the end of the year 1880, and beyond that river to Peshawur early in 1882, but the magni-

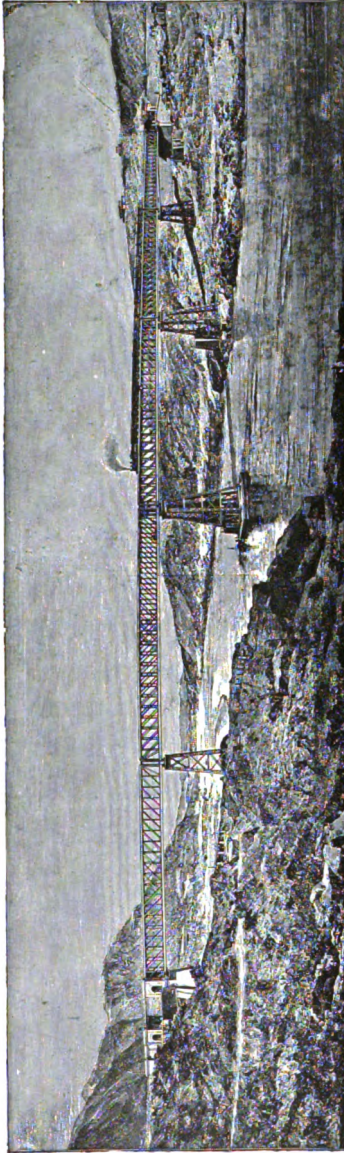
ficent bridge over the river, together with the heavy cuttings and tunnels on the approaches, were not opened until the 24th May 1883.

Above the site of the bridge at Attock the Indus drains an area estimated as equal to that of Great Britain and Ireland, viz., 120,000 square miles. Rising in the elevated regions of an unexplored portion of the Himalayan range of mountains, outside British territory, the exact length of the river is unknown, but is taken to be upwards of 900 miles. Leaving the mountain ranges about 30 miles above Attock, the river traverses a plain country in a broad shallow bed, reaching 2 miles in width; but before arriving at Attock, and for some distance south of that place, its channel is contracted by ranges of rocky hills, through which it winds in deep gorges for a distance of about 90 miles, with a cold-season water surface ranging from 300 to about 1200 feet wide. The volume of water is usually at its lowest during the winter months, from November to March, and at this time in its most contracted parts the river carries a maximum depth of water of about 30 feet. As the hot season advances, the melting of the Himalayan snows causes the water to rise an additional 20 feet or so by the end of May. The highest floods commonly occur during the monsoon months, when the rise of water at Attock reaches as much as 70-feet above low-water level. The river is also subject to exceptional floods of almost unlimited volume and rise, caused by landslips or heavy accumulations of ice, blocking the course of its mountain tributaries. Immense quantities of water impounded by the barriers thus formed are occasionally suddenly released, creating violent and unexpected floods in the main river. A flood known to have been due to temporary impounding of the water occurred in February 1858, when the water rose 70 feet at Attock, and it is probable that the great flood of 1841, said to have risen over 100 feet above low water at the same place, had a similar origin.

The Attock railway bridge presents an example of a design specially modified and adapted to meet peculiar and unusual local conditions. It was necessary to take into consideration the possible re-occurrence of abnormal floods, such as those noted above, and it was accordingly determined to place the

bottom of the girders well above the level of the great flood of 1841, or at a height of 111 feet above low water in the river at the point of crossing. The district of Attock is, moreover, liable to the contingency of earthquakes, slight shocks being of frequent occurrence, with a direction of seismic wave generally east and west. To meet this source of danger it was considered advisable to employ a more yielding and elastic material than stone or brick for the piers of the bridge, and to substitute an open wrought-iron frame-work. The wisdom of this decision was fully confirmed even during the construction of the work, for, on the 31st March 1883, a sharper earthquake shock than usual occurred, when it was found that the girders of the first span had moved forwards and backwards on the pier over one inch, and the movement was probably much greater on the higher piers in the centre of the river where it could not be measured. The expansion rollers placed under the ends of the girders permitted this degree of movement without causing any appreciable strain, but had not these been in perfect working order a considerable stress would have been thrown on the piers. In the design of the bridge, provision had also to be made for carrying the Grand Trunk Road as well as the railway. The two roads are carried at different levels, the rails above, and the cart, or military road below, between the main girders.

The site selected for the Attock bridge was at a point in the narrow gorge situated about two miles below the old Sikh Fort, which for many centuries guarded the crossing on this part of the Indus. At the bridge crossing the width of the cold-weather water surface is barely 600 feet, and the river is divided into two nearly equal channels by a central rocky shoal. Owing to the contracted section of the passage, and the consequent great velocity of the current, as well as from the prevalence of high winds which sweep through the gorge, the rocky surface of the valley within the limits of the highest floods is everywhere swept perfectly clean and bare. The channel on the east or left bank of the river carries the deepest and swiftest stream, and here the surface of the rock below water is also clean, but the right channel, having a more moderate current, has a sandy bed overlying the rock.



THE ATTOCK BRIDGE.

TO THE
ALABAMA

The design finally adopted for the bridge was as follows :— The openings are five in number, the first two spans are 257 feet each in the clear, the third and fourth spans, which cross the permanent water channel of the river, are each 308 feet in clear width, and the fifth or last span, on the west side, is similar to the first and second. There are thus three spans of 257 feet and two of 308 feet, and the total length of the bridge is 1655 feet over all. The girders are carried at a height of 111 feet above the lowest water, the rails being placed at nearly 141 feet above the same level. The four piers are each formed of 8 wrought-iron columns or standards connected by horizontal and diagonal cross-bracings at intervals of 23 feet of vertical height. The four central columns form a rectangle, 19 feet by 14 feet at the top, and are only slightly inclined downwards, whilst the two up and two down stream columns, joining the main standards in the upper tier, are widely spread out so as to act as struts to prevent overturning, bearing, however, their due proportion of the load. Each column or standard is $2\frac{1}{2}$ feet square in section, and is built up of wide angle bars at the corners, joined together by $\frac{1}{2}$ -inch iron plates. On two sides the plates are not continuous, but spaces are left at regular intervals, the object being to admit entrance into the interior of the columns for the purpose of riveting, and for subsequent repainting of the iron-work. On the summit level the four main columns are secured together by a cross framing of girders forming a platform on which the main girders of the bridge are carried.

The main girders, which are $26\frac{1}{2}$ feet deep, 3 feet 3 inches wide on the booms, and are spaced 18 feet apart from centre to centre, are constructed of steel, being calculated to bear a working strain of $6\frac{1}{2}$ tons on the square inch. The general aspect of the completed bridge, with surroundings, is picturesquely conveyed by the accompanying engraving, reproduced by permission from *Engineering* of November 14th, 1884. The following outline account of the methods of construction employed in the erection of the Attock Bridge is abbreviated from a descriptive article on that work, published in vol. xxxviii. of *Engineering*, Numbers dated November 28th, and December 12th and 26th, 1884.

By the adoption of 308-feet spans for the two main openings of the bridge over the permanent water-channel all difficulty with regard to the foundations of the iron piers, except in the case of one, viz. No. 3, situated on the rocky shoal in the centre of the cold-weather stream, was avoided. The surface of the rock below water at the site of the central pier, exposed to the full force of a strong current, was bare, except as regards the fine micaceous sand lodged in the crevasses or hollows. It was not practicable, therefore, to enclose the area of the foundation by means of a timber cofferdam. The foundation was consequently secured in a different manner. The outline of the space to be enclosed was irregular in plan, being determined by the form of the rocky shoal, and extended up stream considerably beyond the actual requirements of the pier. It was determined to enclose this space by sinking, and building up to water level an enclosing dam or wall, formed of bags of Portland cement concrete. To effect this in the deep water and strong current, and in the temporary absence of proper diving apparatus, barges were moored just outside the line of the proposed wall, and as much as possible of the fine sand, which in places filled the crevasses of the rock, was removed by a spoon dredge, the remainder being cleared by hand by native divers, who, however, could only work imperfectly, and for short intervals at a time, owing to the intense cold of the water in the snow-fed river. When the rock was thus cleared, small bags loosely filled with Portland cement concrete were lowered on to the rock, and rammed into the cavities, until gradually a thick enclosing wall of bags was built up to water level. Above this level a wall of rubble stone, set in hydraulic mortar, was built up to a further height of 5 feet.

The enclosed area was also divided into ten rectangular compartments by cross walls built up in the same manner, and in November 1881 pumping plant was got to work, and some of the compartments were pumped out. It was then found that the surface of the rock was not so sound as had been supposed, and that, owing to numerous fissures, the influx of water would be too great to allow of the cells, or chambers, for the shoes of the pier columns being sunk into it to the necessary depth. Proper diving apparatus having now been

obtained, it was determined to discontinue the pumping, and the compartments into which the dam had been divided were soon cleared of all sand and loose matter by the divers. The compartments were then filled in solid with cement concrete, which was left for the time necessary to harden.

Square cells were then cut down through the concrete to the surface of the rock, and were continued into the latter until perfectly sound and solid rock was met with. In cases where passages communicating with the outside river were cut into, the process had to be repeated; cement concrete being filled in, allowed to harden, and then cut through. The cells were 7 feet square, or just a little larger than the shoes of the columns. When all the 8 cells had been carried into the rock to the required depth, which in the case of the central pier was about 21 feet, the pier columns were cut to the necessary length, and the massive iron shoes were riveted on. Each bottom length was then lowered into its proper cell, and temporarily adjusted in place. The next length of the columns were fastened on, and the shoes were now brought into exact horizontal and vertical position. Fine Portland cement concrete was carefully rammed under the shoes, as well as inside and around them, and the cells were completely filled up with the same material up to the level of the top of the dam. In order to protect the standards of the central pier from the shocks of floating rafts, or other objects carried down the river, a concrete fender or cutwater, was subsequently constructed on the rock, on the up-stream side of them.

The method adopted in building up the pier columns was as follows:—A 50-foot derrick or jib was placed near the centre of the pier, capable of being inclined towards any particular column to be operated on. The 23-feet lengths of column between the horizontal and cross bracings having been previously riveted up, were hoisted into place, and the section was braced together and completely riveted. The derrick was now raised on a platform supported on the uppermost tier of bracing, and the next length was hoisted and completed, and so on, until the pier was finished to the full height. The first column shoe was set on the 6th February 1882, and the four piers were all erected and complete by the end of May of the same year.

The main girders of the bridge were built in place on platforms supported by staging erected between the piers. In the case of the three smaller spans of 237 feet, no difficulty was experienced, as the bed of the river in those spans was dry for the greater part of the year. The platforms were here carried on temporary piers spaced about 42 feet apart, formed of double columns built up of wrought-iron cylinders 3 feet in diameter, and in 9-foot lengths, with angle iron flanges; this material having been collected in considerable quantity for the purpose of constructing temporary bridges during the Afghan campaign, and in part by the use of angle iron standards, with cross struts and bracing, which happened to be available. For the two main spans of 308 feet, across the water channel of the river, a different system had to be adopted. In these spans, viz. Nos. 3 and 4, no intermediate supports were admissible, principally owing to the depth and strength of the current, and to the necessity for keeping open a clear wide channel for the heavy timber rafts and large boats laden with produce from the upper reaches of the river. The staging, therefore, in the main spans consisted of a series of long struts springing from a point near the base of each pier, and spreading out like a fan to support a horizontal beam of double whole timbers, on which the girder-erecting platform was laid. The pair of main long struts or booms on either side were spaced 19 feet apart, centre to centre, so as to come under the girders, and were braced together. All the intermediate struts forming the fan were similarly braced, and rigidly connected with each other by horizontal half-timbers, or 'ledgers,' at equal vertical distances of 12 feet; the ledgers were also secured to the main columns of the piers by heavy wrought-iron straps. The two outermost struts from opposite sides were connected above by a whole beam, 63 feet long, of sal wood, trussed with three vertical struts 10 feet deep, and by rods of 2-inch round iron, the whole forming when complete a gigantic strut and strain-beam truss, 300 feet long, and over 100 feet high.

These massive stagings proved exceedingly satisfactory, the maximum deflection or sinking under the enormous load of over 600 tons imposed upon them—in addition to their own weight—being only $1\frac{1}{8}$ inch. They proved, however, to be by

far the most difficult, as well as the most tedious, part of the whole bridge operations. The stagings were commenced in October 1882, and the second one was not completed until the beginning of February 1883; the work of erection having been much delayed by storms and high winds, which are very prevalent at Attock, during which it was unsafe to allow men to work in such a high and exposed situation, and where their limbs would quickly become numbed by the cold.

The erection of the girder work was effected by the use of gantry cranes moving on rails laid on beams outside the girders. In the case of the first of the 308-foot spans, from the laying in place of the bearings, until the top booms were closed in, eleven days were occupied, and in the case of the second span ten days sufficed for the same work. The complete riveting took about a week longer in each case, and on the 5th May 1883 the first locomotive passed over the bridge.

The structure a few days afterwards was officially tested with a test train, consisting of three locomotives weighing 64 tons each, and eight loaded wagons of a gross weight of 18 tons each, the engines being placed in the centre of the train. The Government of India rules for testing railway bridges are, that the load shall be allowed to stand on each span from ten to fifteen minutes; the testing train is then moved first slowly across the span, and lastly the train is driven across at the highest speed. In each case the deflections are carefully observed, as well as the lateral oscillation under the high-speed test. The result of the trials in each case at the Attock Bridge was very satisfactory, and the bridge was at once opened for public traffic. The total cost of the Attock Bridge is officially given as Rs. 32,20,516, but it is not stated whether this excludes the block-house defences which have been constructed for the military fortification and protection of the bridge.

The section of the North-Western Railway, extending from Lahore, *viâ* Mooltan to Karachi, crosses the Indus at a point close to the town of Sukkur. For many years a break here occurred on the railway, and the passage was effected by a ferry. Subsequently landing-stages, with steamers and flats, were provided, by means of which the railway vehicles were transported across the river; but soon after the year 1880 active

steps were taken for the elaboration and provision of a permanent high-level bridge, to render secure this important link in the chain of communication between upper India and the coast. At Sukkur the Indus passes through an isolated ridge of nummulitic limestone of small elevation, and the river is unequally divided into two channels by the island of Bukkur. The left or Rohri channel carries the main body of water, which is here 70 feet deep at low water. The rise of the river in times of highest floods is 17 feet, and the velocity of the current is about nine miles an hour.

It was found practicable to bridge the right or Sukkur channel by three girder spans of 278, 238, and 94½ feet respectively, the erection of which presented no difficulty, but the main or Rohri channel—owing to the great cost, and undesirableness on many grounds of employing a central pier—could only be crossed by a single span of exceptionally large dimensions. Hard limestone rock, sloping steeply down to the water, is found on the left bank and on Bukkur island. At the upper part of the island the channel could have been crossed by a single span of 650 feet, but the approach embankment would have cut through the middle of the town of Rohri, and its increased cost, together with the heavy compensation that would have to be paid for land and property, annulled the advantage of this alignment. It was therefore determined to cross the channel somewhat lower down, at a site where the width of the single span could not be reduced below 820 feet, or 790 feet in clear width from face to face of the masonry abutments on either side. The structural features of the design adopted for spanning this exceptionally large opening have been much criticised, chiefly on account of the special difficulties of erection of the ironwork which were entailed.

The 'Lansdowne Bridge'—so named after the then Viceroy and Governor-General of India—consists of single cantilevers, one on each side of the channel, each having a projection or overhang of 310 feet. The central gap, 200 feet long, between the projecting ends of these cantilevers, is spanned by independent girders. The general features of the design and aspect of the huge main opening of the bridge—the superstructure of which is throughout constructed of steel

—will be best understood from the illustration (*vide* Frontispiece). Each cantilever virtually consists of a gigantic shear legs, or guyed crane, used to support the bridge platform at a height of 52 feet above low water, or 35 feet above maximum floods. The foundation-work consisted only in clearing away the material down to the rock on either bank, which was benched to receive the abutment masonry. In the absence of suitable stone this was constructed of Portland cement concrete. The anchorings for the back stays or guys, which are cellular structures 32 feet by 12 feet by 6 feet—weighing 35 tons—are situated about 250 feet to the rear of the abutments, and about 50 feet below rail level, and they are bedded firmly into or behind the solid rock in cement concrete. On the abutments the main bed-plates for the support of the cantilevers are also cellular, 20 feet long by 10 feet by 8 feet—weighing 55 tons. They are secured to the abutments by fourteen holding-down bolts, 9 feet long and 3 inches in diameter, and further, to provide against any backward thrust, they are connected with the solid rock behind them by a filling of Portland cement concrete. The pillars and struts of the main framework of the cantilevers are longitudinally spindle-shaped, square in section, and are built up of curved corner-plates stiffened by angle bars at the edges, and tied together by horizontal and diagonal braces forming an open framework. The first vertical pillars, carried on the abutments somewhat in the form of the letter A, are placed with feet 100 feet apart, the legs are 170 feet high, and weigh 183 tons. The main inclined struts similarly disposed, forming the ‘jib’ of the crane, are 230 feet long, and weigh no less than 240 tons. These members are joined together at the top by a horizontal tie-girder 123 feet long, and weighing 86 tons; the three members constituting the enormous primary triangle of the cantilever framing. The entire steel work of each cantilever was made in England, and was first put together in the maker’s yard, with the aid of a timber scaffold (such as could not, however, be used at the site of the bridge), before shipment, and the huge erection for a long time formed a most conspicuous object on the banks of the lower Thames. Apart from its great size, the chief interest of the Lansdowne Bridge over the Indus lies in the difficulties encountered in its erection,

difficulties which were successfully overcome by many ingenious expedients. It would not be possible, without the aid of numerous diagrams, and the introduction of too many technicalities to be readily understood by the unprofessional reader, to enter into any full and detailed explanation of the erection of this remarkable work. The following brief account—the data for which has been principally derived from a paper descriptive of its erection read before the Institution of Civil Engineers on the 2d January 1890—will convey a general idea of the methods employed.

The first members to be erected were the large vertical pillars on the abutments. These in actual construction were built up with a slight backward rake—or inclination of 6 inches to allow for the requisite elevation—or ‘camber’ at the end or nose of the cantilever, and it was, therefore, necessary first to erect a timber scaffold to support them during construction. The scaffold was built to the profile of the holding-back guys, and served also to erect them. The pillars were built up from the bed-plates, and the guys from the anchorings, until they met at the top, and the junction had to be made so as to give the backward rake of 6 inches to the pillars at a temperature of 100°, which was fixed upon as the normal temperature, for at Sukkur the temperature in the sun runs up to 180°, and often exceeds 90° during the night. The next member of the cantilever framework to be erected was the huge primary strut. These immense booms, 230 feet long, and weighing together 240 tons, supported on a small base and riveted to the bed-plate, had to be built out with a rake or inclination in two directions, and their construction consequently involved a very difficult piece of setting out to preserve them in proper alignment and direction. A temporary staging was erected on the first lengths of the roadway girders, which it had been possible to place in position by supporting their outward ends on a temporary pier built in the river just outside the abutment. On this staging was placed a double derrick crane, with a sufficient sweep to command a considerable section of the length of the main strut. A piece of the strut—generally about 30 feet long and weighing 5 tons—was lifted out into its place, and held by 1½ inch wire rope; its proper position

was adjusted with great and careful accuracy, the various connections were made, and the work was then riveted up. After the strut had been thus built out beyond the reach of the derrick, another one, 75 feet long, was erected at a higher level, on one of the cross or 'distance' girders, and the building out continued; the work being held back by strong back ties secured to the vertical pillars, and by a special main tie from the summit of the latter.

On the completion of the enormous struts to full length and height, it was found that the exact span for the upper horizontal tie was in error to the extent of only $\frac{1}{8}$ inch on one side of the river, and $1\frac{1}{2}$ inch on the other. The next operation was the erection of the permanent horizontal tie itself, connecting the head of the vertical pillars with that of the struts. The weight and length of the horizontal tie was too great to admit of its being lifted in one piece; it was, therefore, decided to erect it on a temporary suspension bridge, or suspended staging, carried between the heads of the two main members. The suspension cables, however, being attached to the strut at the outer end, the operation presented this difficulty—that the horizontal pull of the ropes when loaded was more than sufficient to counterbalance the weight of the strut by about 20 tons. This difficulty was met by loading the nose of the strut to the requisite extent to counterbalance the increasing horizontal pull of the temporary bridge as the load came on it, the main tie being first slackened. On the suspension cables, braced trestles were arranged, so as to support the steel work of the horizontal tie during its construction, and until the head of the main verticals and the huge inclined struts were permanently joined together, thus completing the first triangle of the cantilever framework.

As soon as this triangle was successfully framed on each side of the channel, two firm permanent points of support were available from which to hang a system of overhead suspenders, or carrying cables, from one to the other, extending for a distance of 547 feet across the channel, and by the aid of these suspender cables, and an ingenious arrangement of tackle and gear, worked from the horizontal ties by portable engines placed below, the remaining less heavy portion of the canti-

lever steel work was built out over the river, the work being assisted by two barges of 400 tons burden (provided with suitable carrying trestles), whenever the current permitted them to work.

On the completion of the two cantilevers projected from either abutment, it was found that their ends or noses were exactly level, and in correct line—or rather in the middle position of the diurnal variation caused by the alternations of temperature, for, as the bridge lies north and south, the effect of the sun acting on alternate sides of the steel work caused the nose to oscillate nearly an inch either way. The width of the central gap was also correct at mean temperature. The only work now remaining was the erection of the central and independent girder span, 200 feet in length, joining the noses of the cantilevers, and completing the connection across the river. The gap is spanned by a pair of ordinary girders resting on rollers placed at the ends of the cantilevers. In designing the structure it was supposed that these girders could be floated into position, but this was not, for various reasons, found practicable. It was then proposed that they should be built on the cantilevers and launched across the opening, but it was finally decided to use a staging built out from the cantilever noses, so as to enable the girders to be erected in place. The temporary stage employed—as it was not possible to provide any central support from the river-bed—was a deck bow-string bridge 196 feet 8 inches in clear span, and weighing 56 tons complete without the floor-planking. The line of links forming the bottom chord was drawn across the gap by the overhead tackle, and on the link pins the stumps of the verticals and diagonals were strung. Next a length of the top chord, with the verticals and diagonals hanging loose, was sent out by the overhead tackle and placed in position, each vertical being dropped over the stump belonging to it, the joints being made by the use of cottered or slotted pins with keys. This operation was repeated until the temporary bow girder was completed, each bay being successively secured by the cross-bracing. On the completion of the top chord the holding-back chains were slackened off, and the previously suspended structure became a stiff girder; the pair of girders were then

horizontally braced to each other. This temporary work was completed, with some difficulty, in seven days. The permanent girders were erected on sand boxes, sufficient camber, or rise in the centre, being given in setting the lower booms, to allow for the deflection of the bowstring staging girders. The pieces were all run out by the useful overhead gear, and the work of erection was practically completed in four and a half days.

The floor of the Lansdowne Bridge is formed of corrugated deck plating filled with wood, so as to give a cartway on the same level as the railway, which passes over the bridge by a single line. A footway for men and beasts of burden is also corbelled out on both sides. Work on this truly noble bridge was begun on the anchors of the Bukkur cantilever in April 1887, but at first progressed slowly for want of the steel work. From November 1887 the work of erection was rapidly pushed forward until its completion and testing in March 1889. The total weight of steelwork in the huge main span is 3316 tons. The total cost of the Lansdowne Bridge, including the three minor spans over the Sukkur channel, is given as Rs.33,46,720, of which Rs.27,89,340 is the cost of the great cantilever span over the Rohri channel.

CHAPTER XII

NORTH-WESTERN SYSTEM—KHOJAK TUNNEL—OTHER RAILWAYS

The Sind-Pishin section of the 'North-Western Railway'—Outline of system—The new Quetta loop by the Mushkaf and Bolan valleys—Rapid construction of the line from Ruk to Sibi—Hurnai Valley line—Extension of the railway from Bostan to Chaman—The Khojak Tunnel—Largest railway tunnel in India—Descriptive details of construction—Progress of the shafts and headings—The rope inclines—Completion of the tunnel—Extraordinary effects of an Earthquake—General particulars of the North-Western system of railways—Outline of other railways—The Bombay Baroda and Central India—The Tapti and Nerbudda Viaducts—The Rajputana-Malwa State Railway of metre gauge—Principal structures and works—The Bengal, Nagpur, and Indian Midland Railways—Principal works—The Railway water-supply at Jhansi—East Coast Railway—The Bezvada bridge—Railways in Burma.

At Ruk Junction, situated only a few miles beyond the point where the Lahore and Karachi trunk section of the North-Western Railway crosses the Indus by the Lansdowne Bridge, the Sind-Pishin section of the same railway commences. The main line of the latter, 335½ miles long, has been constructed as a frontier military line, and may be divided into two portions. The first or level desert length of 133½ miles, runs from Ruk Junction to Sibi, situated near the foot of the Beluchistan Mountains, and the mouth of the Bolan and Hurnai valleys. The second or mountain railway length extends from near Sibi, *viâ* the Hurnai valley, to Bostan (situated a few miles north of the frontier military station of Quetta) and thence proceeds *viâ* Kila Abdulla and the Khojak Pass and tunnel to New Chaman, on the northern or Afghanistan side of the dividing Amran range of mountains, within a distance of 70 miles of Kandahar.

A loop line extending from Sibi, *via* the Bolan Pass to Quetta and on to Bostan, was originally constructed, but the portion of this loop, 98½ miles long, passing through a very difficult line of country from Sibi to Quetta, was made under great stress as a temporary military line, and after having been maintained in the face of great difficulties for some years was in November 1891 made over for reconstruction on a new alignment. The new Quetta loop by the Mushkaf and Bolan valleys is not yet open, but work on it is being rapidly pushed forward, as it is of the highest importance that a second alternative line of railway should be permanently maintained between Sibi Quetta and Bostan, in case the main line by the Hurnai valley should at any time be blocked by landslips or other accidents; always liable to occur on a severe mountain railway. On the Mushkaf alignment of the Quetta loop, the works are generally of a very heavy character. There is one tunnel of more than usual importance, viz., that being driven through the line of hill forming the watershed between the Mushkaf and Bolan valleys known as the 'Panir.' This tunnel will be about 3000 feet in length. The line—which will be about 86 miles long—runs along portions of the old Quetta loop from Bolan Junction to Nari Bank—4 miles, and from Kolpur to Quetta—25 miles. The new portion from Nari Bank to Kolpur is, therefore, about 57 miles in length. The total rise from Sibi to Kolpur is 5463 feet, and the railway gradients over intermediate lengths are, 1 in 55, 1 in 35, 1 in 33, and 1 in 25. From the mouth of the Mushkaf valley the country is very difficult, involving eight tunnels and four crossings of the Mushkaf river. In the Bolan valley there will be three tunnels, and some exceptionally high embankments and deep cuttings. On approaching Kolpur the works are again exceedingly heavy, including numerous rock-cuttings, three tunnels and large bridges for nine crossings of the Bolan river at high levels above its bed. Information as to the details of these works is at present very scanty.

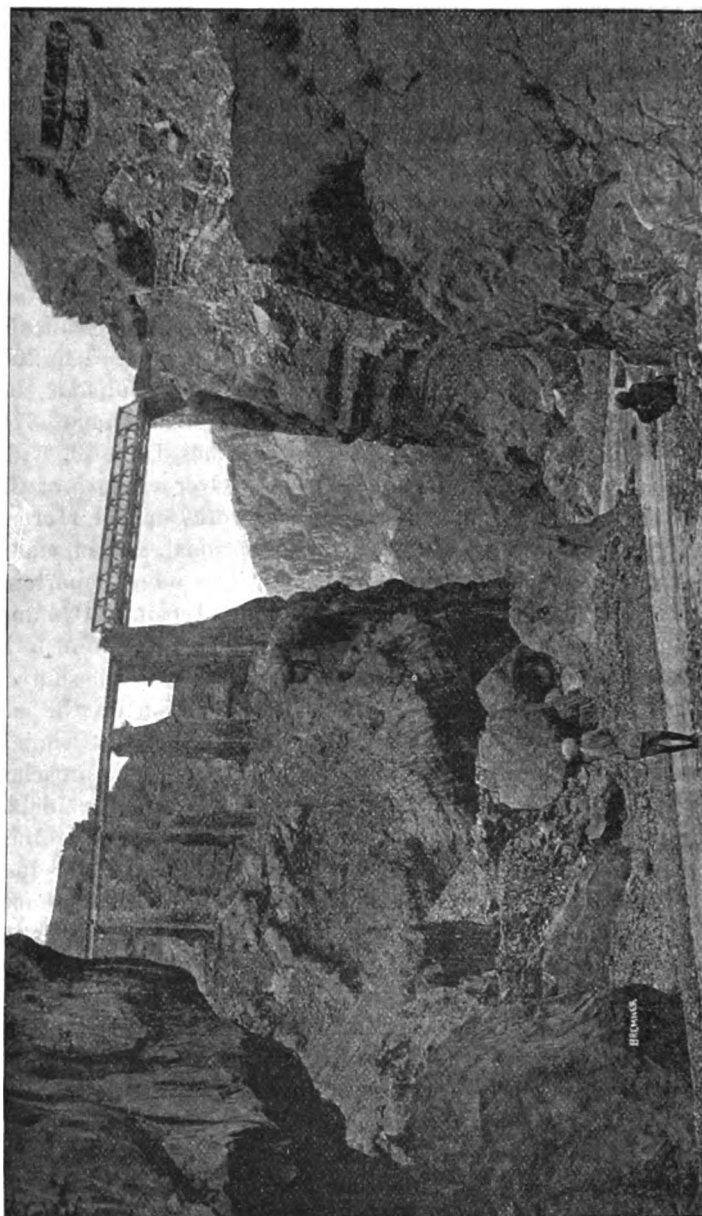
Turning now to the main line, and to the first portion of the Sind-Pishin section from Ruk Junction to Sibi. At the end of the year 1879 it was determined to push forward—for emergent military purposes—and with the greatest possible

rapidity, a line of railway communication from the Indus valley to the Bolan Pass, this being the best available route leading from British India into Afghanistan. Only four months from the date of receiving the first order, a broad-gauge railway, 133½ miles long, was opened for military traffic from Ruk to Sibi. The greater portion of this length of line traverses a triangular-shaped waterless plain, dry, barren and treeless, locally named the 'Put' or desert. This sandy plain slopes at an average gradient of 1 in 2000 from the foot of the Beluchistan Mountains towards the Indus valley. For the first forty miles, however, from Ruk, the ground slightly falls away from the elevated channel of the Indus, and the railway over this length is carried through thick jungle, except near the towns of Shikarpur and Jacobabad, crossing in its course several large inundation canals and water-distributing channels.

The rapidity with which the materials for the Ruk Sibi section of the Sind-Pishin Railway were collected, and the line laid and made serviceable for locomotive traffic, has hardly ever been surpassed. Although the work in itself was of the simplest character, its prosecution was attended with exceptional difficulties in connection with the housing, feeding, and watering the large working parties of men and animals whilst crossing the terrible desert portion of 93 miles, as well as from the character of the climate during the winter months, which is hot by day and intensely cold by night. The supply of water was based on the estimated requirement of 5000 men at two gallons per day, and 2000 beasts at five gallons, equal to a daily supply of 20,000 gallons, and the supply was furnished by training out water tanks by the material trains running to the 'tip,' or advanced head of the works. The execution of 133½ miles of railway in 101 days, or at an average progress of 1½ miles per day is a feat worthy of mention, and was only possible under the most perfect system of organisation in every detail of the operations. Yet so ably conceived were all the arrangements for the regular and orderly supply, whether of railway material, or of food, water, fuel and shelter for the labourers and staff, during the fifty working days occupied in carrying the railway over the ninety-three miles of inhospitable desert, that practically no special inconvenience

was experienced, and from first to last the work progressed with the utmost regularity and mechanical precision.

From near Sibi—the end of the desert section—the main line traverses, *viâ* the Hurnai valley, a very difficult mountainous country, involving works of exceptionally heavy character. The line throughout has been constructed for a single line as far as Gulistan (situated a short distance beyond Bostan), beyond which it is double. The length of the line from Sibi, *viâ* Hurnai and Bostan, to New Chaman, the present terminus of the railway, is $202\frac{1}{4}$ miles: of this length the Sibi-Bostan portion was opened in the year 1887. The ruling gradients on this portion vary between 1 in 45 and 1 in 76, with 1 in 200 between Sibi and Nari. Between Bostan and Gulistan the ruling gradient is 1 in 100, and from Gulistan to Chaman, $37\frac{1}{2}$ miles in length, the ruling gradient reaches 1 in 40, with curves of a minimum radius of 819 feet. Over a length of 67 miles the bridging, tunnelling and earthworks on the Hurnai valley section of the railway are of exceptional, and in many cases of an extraordinary description. The more important tunnels are nine in number, the two longest being 2024 and 1233 feet respectively. The total length of these tunnels is 8402 feet or 1·6 miles, and their construction cost the sum of Rs.2,36,231. At 316 miles from Ruk Junction on the extension of the railway from Bostan to Chaman, the great Khojak tunnel pierces the Khwaja Amran range of hills, the approaches to which on either side involve earthworks of a most formidable character. The Khojak tunnel—the largest railway or other tunnel in India, has a total length of 12,870 feet, or just under $2\frac{1}{2}$ miles. Of this, 7870 feet are $\frac{3}{4}$ lined with masonry, and the remaining 5000 feet is $\frac{1}{4}$ lined. It has been completed with a section wide enough to carry through the hill a double line of the standard or 5 foot 6 inches gauge, at a total cost of Rs. 65,24,372. Very little information is available as to the methods and details of construction of this recent and interesting work, which was commenced in April of the year 1888: was practically completed in September 1891, and was formally opened for traffic on the 1st January 1892. The work on the tunnel was aided throughout by a special staff of European miners, tunnellers, and electricians.



CHUPAR RIFT, HURNAI VALLEY RAILWAY.

The orders of Government for the extension of the Sind-Pishin Railway from Kila Abdulla (10 miles beyond Gulistan) through the Khwaja Amran range, were issued at the end of 1887, but owing to the severity of the winter in these high regions nothing could be immediately effected at the main tunnel, or for the rope inclines over the summit of the pass, which it was decided to construct for temporary purposes, and for use during the construction of the main work. Staff quarters and workmen's shelters were, however, got ready; the excavation of the deep cutting at the eastern approach to the tunnel was commenced, as well as the east and west lined shafts. Small shafts were also sunk at each main entrance down to the tunnel level. In the course of the following year, viz. 1888-89, the heading from the east portal of the tunnel was run out to meet the east cutting, and towards the west was carried 2296 feet into the hill. The second lined shaft was pushed down to the full depth of 318 feet, and the headings were carried 932 feet eastwards towards No. 1 shaft, and 1249 feet westwards towards No. 3 shaft. During the summer months the springs failed, and water for all the working parties on the east side of the hill had to be brought up in tanks from Kila Abdulla, a distance of ten miles. The work at No. 3 lined shaft was sunk to the full depth of 281 feet, and the east heading from it was carried 2740 feet towards No. 2. In this shaft, on the 2d March 1889, a large spring was tapped. Before any steps could be taken the pumps were 8 feet under water, and by the 13th the water had risen 156 feet in the shaft, necessitating vigorous measures to keep down the influx.

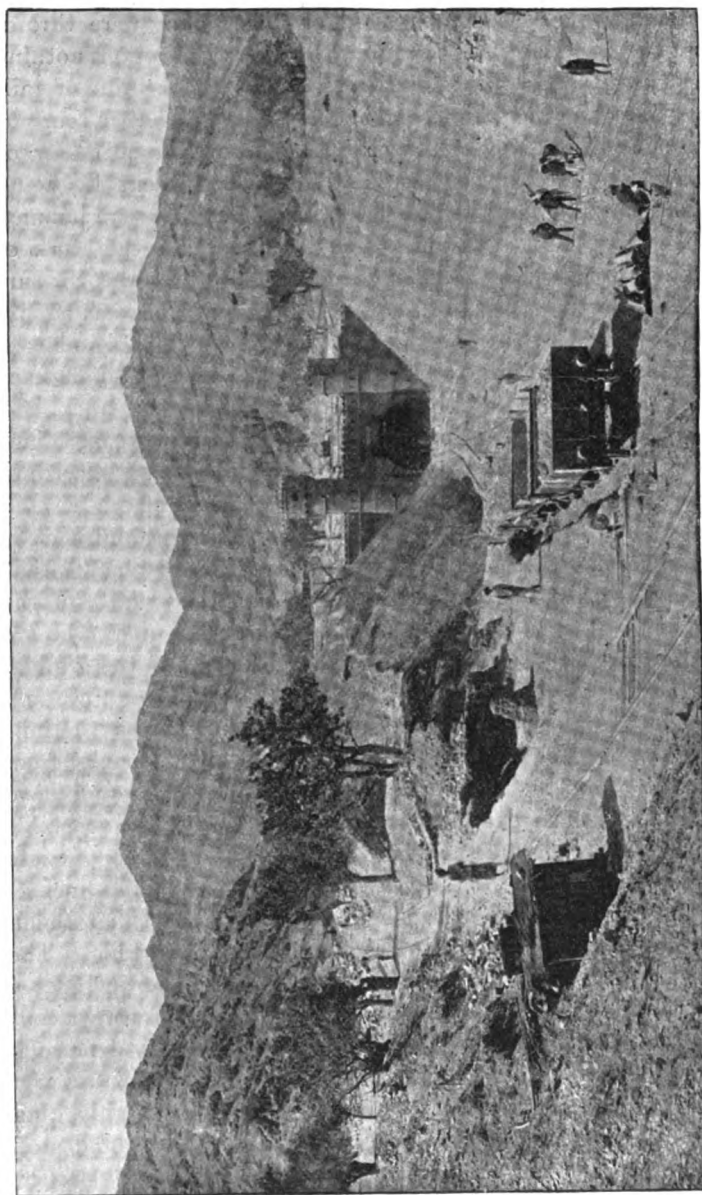
The gallery from the west portal was driven for a distance of 2000 feet eastwards; here also the heading was exceedingly wet, but being on an ascending grade the backward drainage was easy. This length of tunnel was joined to the heading from No. 3 shaft on the 28th April 1889. At the end of the official year, 1888-89, the length of headings driven was 7373 feet, out of the total length of 12,870 feet, 607 feet of the masonry lining for double line was also executed, and the rails (also for double line) were completed from Kila Abdulla on the permanent formation. A temporary railway about seven miles long was laid up to the foot of the rope inclines, Nos. 1

and 2 of which were got to work over the Khojak summit in October 1888, and No. 3 in February 1889. These inclines served the purpose of conveying over the ridge, fuel and all materials required for the west tunnel works and for the railway beyond. Sixteen miles of permanent way material was thus conveyed over the hill. The site for the New Chaman Station or terminus of the line, was also selected at a spot about six miles below Chaman Fort, at the foot of the western slope of the Khwaja Amran range.

During the year 1889-90 the headings from the shafts, which throughout were driven in water-bearing shales or shingle with layers of soft mud, requiring heavy timbering, were pierced so as to practically complete this operation, the progress during the year being 5070 feet. The masonry arching was also completed for a length of 5997 feet. The headings of the tunnel were joined towards the end of April 1890. Owing to the large quantity of water met with, and also to the extremely treacherous nature of the ground in the final 300 feet of the workings, which caused frequent slips and entailed the most careful timbering, the progress of the headings was very seriously delayed during the last few months. The progress of the arching was also very greatly affected by the same cause.

By September of the year 1891 the masonry lining was virtually completed, and the first construction train passed through the tunnel from end to end on the 5th of that month. On the 1st January 1892 the section of line from Kila Abdulla to New Chaman station, 29.35 miles in length, laid with a double track, and passing through the Khojak tunnel, was formally opened for traffic; the works throughout this difficult section of line having occupied nearly four years in all.

To convey an idea of the vicissitudes and dangers to which some Indian railways are exposed, the following press notice of the extraordinary effects of an earthquake, which occurred on December 20th, 1892, in the Quetta district and southern parts of Afghanistan, will be of interest:—‘In the neighbourhood of the Khwaja Amran range the shock was very severe: a tower in one of the blockhouses was cracked, some walls were shattered, chimneys were shaken down, and several old houses



MOUTH OF KHOJAK TUNNEL

tumbled into ruins. In the Khojak tunnel the noise was deafening, and workmen engaged on the roofing were thrown from their perches to the ground. There was, however, nothing very extraordinary in these effects; it was on the line of railway between the tunnel and Old Chaman that a curious phenomenon occurred. At mile 643 (from Karachi) four or five lengths of rail were found to have been bent by being opened out sideways, while all the joints near by were jammed up tightly. The bent rails were removed, and the work of putting in new ones was proceeded with. What was the surprise of the engineers to discover that the measure was less by 2 feet 6 inches than the original length. This was due to a crack or 'sheer' which crossed the railway bank at an angle of about 18 degrees, exactly at the place where the track had been contracted. This crack bears a little east of the meridian, passes through the old bazaar near Chaman Fort, and according to native reports, extends across the main range of the Khwaja Amran eighteen miles away. The fact clearly established by the shortening of the railway track (says the *Pioneer*) is that the earth's crust has contracted $2\frac{1}{2}$ feet in the vicinity of the Khojak. This will be good news for those scientists who are on the watch for facts to support the theory of the gradual contraction of the earth. The evidence is indisputable, and the photographs taken on the spot show exactly how the rails were twisted out of the straight. One rather shrinks from thinking what the effect on the Khojak tunnel would have been had it come within the destructive action of the shock.'

The total length of the whole North-western system of State railways at the end of the year 1891 was 2399 $\frac{1}{2}$ miles, including 98 $\frac{1}{2}$ miles temporarily made over to the Mushkaf Bolan Railway, and 11 miles constructed, but not working. The system is administered entirely by the State, and includes a considerable mileage of non-commercial frontier railways constructed and maintained as a portion of the military defence of the empire. The kind and weight of the permanent way over such an extensive system of lines varies considerably, but 68 lbs. double-headed steel rails, and 75 lbs. flat-footed steel rails are the most commonly used for renewals, laid on sleepers of cast-iron, wrought iron, or wood in different situations.

The total capital outlay on the whole North-western system of railways, exclusive of steam ferries and suspense items, is given as Rs. 3333,46,055, or 38½ millions sterling at par of exchange, or an average rate of Rs. 1,59,757 per mile of road.

An early and important trunk line of railway on the standard gauge is that belonging to the 'Bombay Baroda, and Central India Railway Company.' This railway, 460½ miles long including branches, with 60 miles of double track, extends from the Bombay terminus at Colaba to Ahmedabad, and effects a junction with the Rajputana-Malwa State Railway of metre gauge, extending thence to Agra and Delhi. The latter railway has been leased to the Company from the 1st January 1885 to the 30th June 1900. Some portions of the Bombay Baroda, and Central India Railway were opened as early as the year 1860, and the system has since gradually expanded to its present dimensions. The line runs northwards from Bombay *via* Surat in close vicinity to the coast, in accordance with the system of coast lines originally advocated by Colonel Kennedy, to which reference has been made in a previous chapter. The principal engineering works on the railway, which, however, contains many of considerable secondary importance, are the viaducts over the Nerbudda and Tapti rivers.

The bridge originally constructed over the Nerbudda was seriously injured by a flood in the year 1876. The structure was repaired and maintained for some little time, but was eventually replaced by an entirely new viaduct, which was opened in 1881. The new viaduct is constructed with piers for a double road, and consists of twenty-five spans of 183½ feet, each carried at a height of 48½ feet above low water, and with foundations 76 feet below the same point. The total length of the work is 4687½ feet, and it was completed at a cost of Rs. 37,75,759. The Tapti viaduct is a smaller structure, having thirty spans of 60 feet each, carried at 50½ feet above low water. The greater portion of the permanent way on the Bombay Baroda, and Central India Railway system is laid with double-headed rails weighing 68 and 69 lbs. per yard, on timber sleepers, iron sleepers being, however, used for renewals. The earthworks are generally for a single line, but the piers and abutments of bridges are made to carry a double track.

The Rajputana-Malwa State Railway—which is a metre gauge system of lines, aggregating, with branches, 1674 miles in length—represents the first and only important trunk system constructed on that gauge in India. The main line extends from Ahmedabad, *viâ* Ajmere and Jeypore, to Delhi and Agra, and has numerous important branches, or connected narrow-gauge lines. The first section opened for traffic was from the Delhi end in the year 1873. The line is constructed for a single track. Sufficient land, however, is occupied to admit of another line of rails being laid. The rails originally used were 36 lbs. and 40 lbs. weight per yard, laid on wooden cross sleepers. The 36 lb. iron rails have nearly all been replaced by steel rails, weighing $41\frac{1}{4}$ lbs., and steel rails of 50 lbs. section are now used for renewals on certain lengths.

The principal structures on the Rajputana-Malwa State railway are the bridges over the Nerbudda, and over the Jumna at Agra and Muttra. Important bridges also occur over the Bangunga, Shallas, Dhund, Amanishah and Sipra rivers—the latter consisting of six spans of 150-foot girders, on masonry piers, and there are heavy works on the ascent of the Vindhya range of hills, and on that of the Aravalli range west of Ajmere. The viaduct over the Nerbudda is a fine structure, consisting of fourteen spans of 183 feet, carried at a height of 80 feet above low water, costing Rs. 18,73,925. The bridge over the Jumna at Agra has sixteen spans of 133 feet each, with foundation of piers 70 feet deep, and that over the same river at Muttra has seven spans of 150 feet, with pier foundations sunk 71 feet below low water. The cost of these Jumna bridges was Rs. 18,33,877 and Rs. 8,49,000 respectively.

The two most recently finished standard-gauge trunk-lines now open for traffic in India are the Bengal-Nagpur, and the Indian Midland railways, both constructed by companies. The Bengal-Nagpur main line extends from Asanol (132 miles west of Calcutta on the East Indian Chord line) to Nagpur, the chief city of the Central Provinces, where it connects with the Great Indian Peninsula Railway from Bombay. It consequently completes an important direct communication, 1278½ miles in total length, between the two capital cities of India, viz. Bombay and Calcutta. The main line of the Bengal-Nagpur

railway is 627 miles long, and including the Umaria-Katni State line, taken over by the company in 1888, the system has a total mileage of 860½ miles. From the Nagpur end the first 145½ miles of the line was originally constructed as a provincial State railway on the metre gauge. This length was, however, converted to the standard gauge, when the extension of the line to join the East Indian railway near Calcutta was undertaken by a company. The converted length from Nagpur to Raj Nandgaon was opened in November 1888, and the new trunk system, which was opened in sections, was completed, including nearly all its branches, early in 1891.

On the main line the permanent way consists of 75 lbs. flat-footed steel rails laid on transverse steel sleepers. There is a good deal of heavy bridge-work on the railway, the two largest structures being that over the Sheonath, consisting of fourteen girders spans of 150 feet each, and over the Damuda, of two spans of 100 feet, and ten of 200 feet each. Two important tunnels also occur on the system, viz. the Saranda tunnel, 1641 feet long, through rock and rocky shale, costing over 7½ lakhs of rupees,¹ and the Bhortonck tunnel, 1000 feet long, through hard rock interspersed with veins of quartz, costing over 2 lakhs of rupees.

The Indian Midland Railway is an important system, comprising 677½ miles of standard-gauge lines, the main trunk of which, 315½ miles in length, extends from Bhopal (where it is in communication with Bombay by the Bhopal-Itarsi, and Great Indian Peninsula railways), *via* Jhansi, to Agra. A branch, 180½ miles in length, extends eastwards from Jhansi to Manikpur, on the Jubbulpore branch of the East Indian Railway. From Jhansi also another branch, 135½ miles long, extends northwards to Cawnpore, and a short branch of 46½ miles runs from Bina to Saugor. The Bhopal-Itarsi State line, of 57 miles, is worked by the company, and the system—which was virtually completed by the end of the year 1889—embraces several projects, initiated and partly or entirely constructed, by the State, the whole being taken over and worked under contract by the Indian Midland Railway Company.

¹ The work is not quite finished (1893).

The main line and branches of this railway are constructed for a single line, with flat-footed steel rails weighing 80 lbs. to the yard, laid on oval pot sleepers weighing 80 lbs. each (except on the length from Cawnpore to the Jumna near Kalpi—where the rails are of 75 lbs. section). There is a large amount of bridge-work of an important and costly character. The bridge over the Chambul river (opened only in May 1891) consists of twelve spans of 186, and two of 136 feet, carried at the great height of $112\frac{1}{2}$ feet above low water, with pier foundations 75 feet below the same point. The cost of this work was 32,71,035 Rs. The bridge over the Jumna at Kalpi (constructed by the State) consists of ten spans of 250 feet each, placed $76\frac{1}{2}$ feet above low water, with pier foundations sunk 90 feet, and cost Rs. 25,27,545. There are two bridges across the Betwa river : one (Manikpur) opened in 1889, has thirteen spans of 150 feet, with one of 60 feet, carried at $77\frac{1}{4}$ feet over the lowest water—the other (Laltipur) has nine spans of 150 feet. These bridges cost Rs. 13,95,181 and Rs. 7,64,672 respectively. The bridge over the Ken (Banda) has twelve spans of 100 feet each, and one of 250 feet, carried at 66 feet above low water, and cost Rs. 7,36,008. Besides these bridges there are numerous others of considerable size. Between Jhansi and Gwalior some heavy rock-cuttings over the Antri pass, with a bridge of nine spans of 100 feet, and one of 60 feet, over the Sindh river. On the Bina-Saugor branch the ruling gradient is 1 in 100. On the main line the ruling gradients are 1 in 200, and 1 in 150, and from Jhansi to Manikpur 1 in 125.

The principal centre of the Indian Midland Railway is situated at Jhansi, from which place four separate lines of rail radiate in different directions. The large railway staff of all departments here collected forms a very considerable civil population, and in order to provide water, both for the railway locomotives and works, and for the staff of employés, some extensive water-supply arrangements became necessary. The yearly rainfall in the Jhansi district is comparatively low and fluctuating, and it was considered advisable to provide a sufficient storage of water to meet all the demands of the railway during several years of deficient rainfall. For this purpose a storage reservoir, covering 150 acres of ground, and containing

400 million gallons of water, has been constructed near the village of Guddia, situated about 4 miles west of Jhansi station, by throwing a weir across the Pahooj river, where it passes through a gap in the granite hills, and it is calculated that this reservoir will be sufficient to meet all the demands of the railway during a period of three successive years of minimum rainfall. The reservoir depends for its supply on a catchment basin of 84 square miles; and 4 inches of rainfall on this,—allowing for absorption, etc.—is estimated to be sufficient to fill the reservoir.

The main weir, which is 620 feet long, and 34 feet high, above the bed of the river, is founded on solid rock, and is built of masonry throughout. It has been made of sufficient section to allow for its future raising if necessary. At the north end the weir abuts on the rocky base of the hill. At the south end it terminates in a substantial abutment, raised well above the highest water-level, on which the boilers and pumping machinery are placed. In continuation of the main weir, behind the abutment, and connecting it with the face of the hill which bounds the reservoir on the south, is a massive bund or embankment, 750 feet long, on which the delivery main is carried. This bund is constructed of earthwork. Three hundred feet down stream is a secondary dam, designed to head up the water and form a cushion for the overflow of water from the main weir. The pumping machinery is calculated to deliver 24,000 gallons of water per hour, direct through 4 miles of 9-inch main, to a height of 87 feet, into a high service reservoir constructed at Jhansi, from which the distribution takes place by gravitation. This system of railway water supply has been constructed at a cost of 2,92,000 Rs.—or £29,200 at par of exchange.

On the 17th March of the current year (1893) a large railway bridge on the new 'East Coast Railway,' now in course of construction, was opened for traffic. This important bridge—which crosses the river Kistna at Bezvada, and is the largest in Madras, has occupied three years in construction. It consists of twelve girder spans of 300 feet each, carried on piers of stone masonry. The East Coast Railway of standard gauge, will, when entirely completed, connect Madras with Calcutta,

and will considerably shorten the journey between the two cities. The portion of it at present under construction has a length, with branches, of 516 miles.

No allusion has been made in this volume to the lines of railway constructed in Burma; these being outside the limits of India. In concluding the present chapter, however, it may be of interest to give a few particulars regarding the railways in that province. The Burma railways are all of the metre gauge, and emanate from the port of Rangoon. The 'Irrawadi Line,' 161 miles long, extends from Rangoon to Prome, and is laid with steel rails of 50 lbs. section for a distance of $29\frac{1}{2}$ (9 miles of which are double), and beyond with rails of 40 lbs. to the yard. The bridging is heavy, owing to severe floods from the Irrawadi river. The 'Sittang Line' runs 166 miles from Rangoon to Toungoo, and is laid for a single track, with steel rails of $41\frac{1}{4}$ lbs. section on wooden sleepers. The bridging is especially heavy, there being 15,790 lineal feet of waterway, or an average of over 94 feet per mile of line. From Toungoo the 'Mandalay Line' extends 220 miles to the latter city, and is laid with steel flat-footed rails of 50 lbs. to the yard. There are seven important bridges on this length, each with three or four spans of 100 to 150 feet. The 'Mu Valley Railway' has been carried for 53 miles north of Mandalay, and is in course of construction for a further $261\frac{1}{2}$ miles to Mogaung.

The total mileage of railways open for traffic in Burma, including branches, at the end of March 1892, amounted to 630 miles. The Irrawadi line to Prome was opened in the year 1877. The Sittang line to Toungoo in 1884-85; and the extension to Mandalay was completed in the year 1889.

CHAPTER XIII

GENERAL WORKING RESULTS AND STATISTICS—CONCLUSION

Mileage—Capital cost, and working results of Indian railways—Value and exactitude of Indian railway statistical returns—Growth of the Indian railway system—The standard gauge—First departure from it—Introduction of the metre gauge—Principally confined to feeders—Special gauges—Change of policy—Assisted companies—Mileage and respective gauges of Indian railways by quinquennial periods—Classification and mileage—Capital outlay and cost per mile—Reasons of difference in mileage cost of standard and metre gauge lines—Working results—Gross earnings—Working expenses—Percentage of working expenses to gross earnings—Net earnings—Return on the whole capital expenditure—Passengers and goods traffic—Main results—Classes of vehicles—Rates and fares—Early introduction of two classes only—Passenger and goods rolling-stock—Distribution of persons employed—Native engine-drivers and shunters—Accident returns—Fuel supply—Consumption of fuel—Indian coal—Centralised administration and control of Indian railways—Advantage to India—Imperfect powers of the Board of Trade in England—Concluding remarks.

It is now time to convey as briefly as possible to the reader, a general idea of the whole extent of the Indian railway system, and by the assistance of such statistical details as may be of general interest, to indicate some of the principal data respecting the mileage, capital cost, and working results of Indian railways, considered as a whole, and to note their exceeding value and importance to the Government and peoples of India. In doing this, it will be unavoidably necessary to make use, to a certain extent, of figures, and tabular statements, expressive of quantities and values, for which the indulgence of the reader is craved.

It would, as a preliminary, be a matter of very considerable interest to illustrate in some detail, the very admirable and uniform manner in which Indian railway accounts and statistics of all kinds are placed before the public, as well as the very perfect and minute system of external financial con-

trol exercised. In these respects, Indian Railway administration has perhaps from the very beginning been well in advance of that in any other country of the world, and notwithstanding the unfortunate circumstance that statistical details of expenditure are somewhat complicated by the unavoidable intermixture of two standards of value, and that some apparent confusion is occasionally created by the non-coincidence of the financial and calendar years, it would not be too much to say that the railway statistical returns of all kinds, published and exhibited yearly under the system enforced by the Indian Government are, on the whole, more perfectly clear, exact, and valuable for every purpose of record and comparison, than any similar returns that have yet been elaborated by any railway or Government authority in existence. It would, however, be impossible to indicate—even in outline—within the very limited compass of such a volume as the present, dealing as it does not only with railways but with every variety of public works—the system and principles on which the elaborate accounts and comparative statistics of Indian railways are compiled; the attempt, moreover, would be a trespass on ground of too special and technical a character.

Initiated on the 18th April 1853, with the opening of the first section of the Great Indian Peninsula Railway, between Bombay and Tannah, a distance of $20\frac{1}{4}$ miles, the Indian railway system has steadily, and with a judicious rate of progression, expanded, until its total mileage open for public traffic, is now practically equal in extent to that of the United Kingdom. Including all classified denominations, and gauges of line, the mileage of Indian railways, on the 31st March 1892, reached 17,564 miles, of which 1116 $\frac{1}{4}$ miles only were laid with a double track, and extensions equal to nearly 1700 miles were in course of construction.

The gauge of all the earlier lines—which, as we have seen, were constructed by companies working under a fixed Government guarantee, was originally established at 5 feet 6 inches, and this still remains the 'standard' railway gauge of India. The first departure from it was in the year 1863, on the opening of $27\frac{1}{4}$ miles of a railway on a special gauge of 4 feet, built by the 'Indian Branch Railway Company;' afterwards the Oudh and

Rohilkund Railway Company, between Nalhathi and Azimgurh, in the North-west Provinces. This line remains a solitary instance in India of a railway constructed on that gauge. In the year 1864, a line from Arkonum to Little Conjevaram, in Madras, was built by the 'Indian Tramway Company,' under a subsidy system, on the 3 feet 6 inches gauge, but was afterwards, in 1878, converted to a width of one metre, or 3 feet 3 $\frac{3}{8}$ inches.

The idea of superseding the 5 feet 6 inches gauge originally adopted for Indian railways, by the construction of lines of a narrower and lighter description, which could be opened with greater rapidity, and at a less initial cost, had been frequently mooted, but in the year 1870, at a time when about 4600 miles of main trunk lines on the standard gauge had been constructed, the recommendation that a narrower width should be employed in the case of all future lines of railway was made by the Viceroy and Governor-General of India, and supported on the ground of economy. The Indian Government authorities came to the conclusion that a gauge of 3 feet 6 inches was the maximum that should be used in the future, but the precise dimension was left for determination in England, and a committee was appointed to consider the subject, with the result that a gauge of 3 feet 3 $\frac{3}{8}$ inches, or one metre in width, was accepted as the gauge for future railways. This decision led to a memorable controversy between the advocates for adherence to the original broader gauge, and for strict uniformity in this particular, and those who contended that the evils of a break of gauge had been greatly exaggerated, and that the circumstances of India were such, that the country was practically constrained for the future to be content—either with a narrower and much cheaper kind of railway than heretofore, or submit to a disastrous diminution in the rate of development and progress towards a complete railway system.

This heated and lengthened discussion—which emulated the celebrated 'battle of the gauges,' fought out in the early days of English railways, when Brunel introduced an altered gauge on the Great Western, was attended, however, with little immediate advantage beyond placing on record the views of the contending parties. The Government of India had, in

fact, come to a decision on the subject; the metre gauge was introduced into the country, and in the year 1873, 91½ miles of a trunk line (eventually extended to 1261 miles), viz. the Rajputana-Malwa State Railway, was opened for traffic. From this date the construction of metre gauge lines in India has steadily progressed. They were introduced, on the score of an urgent economy, as the future type for all Indian railways; but notwithstanding the supposed inability, in 1873, of the country to continue the construction of the more perfect, and, in consequence, more costly standard gauge lines, the relative length of railways on the two gauges, built from the year 1873 to 1892, inclusive, have in round figures been as follows—broad gauge lines 5000 miles, metre gauge lines 7000 miles. The main trunk routes having been originally made on the broader gauge, its continued use in a large number of cases became a practical necessity, and India, although it has reaped some possible advantages in the possession of a greater total mileage of railways than it might otherwise so early have enjoyed, has had to submit to whatever evils may have resulted from a break in uniformity.

With the exception of the Rajputana-Malwa State Railway, the metre gauge has been practically confined to feeders of the larger lines, or to more or less isolated systems, and it is probable that the evils of want of uniformity of gauge will be very greatly mitigated or removed, when the aggregate of these lines or systems throughout India are connected together in such a manner as to form a complete internal network of narrow-gauge railways, subsidiary to, and working within, a main framework of trunk lines of the heavier description. There is, in fact, room in India for both kinds of railways. In more than one case, however, injudiciously located metre gauge railways have been converted, almost on the eve of completion to the standard gauge, and the conversion of the Rajputana-Malwa trunk line itself has been powerfully urged. Moreover, the economy and advantage of the continued employment of the metre gauge, even for feeder lines, is still seriously called in question by many persons. In addition to the metre gauge, a small mileage of lines of special abnormal gauges have been constructed in various parts of India, under

peculiar or local conditions, but these lines in no way affect the general railway system of the country.

With regard to the construction of railways generally, in the year 1869 a new policy was inaugurated by the Indian Government. The earlier system of guarantee was abrogated on economical grounds, and it was determined thenceforward to largely or entirely construct Indian railways by direct Government agency. Subsequently, however, the policy of constructing new lines by the aid of assisted companies—working under modified terms more favourable to the State has been resorted to, and in one case, viz. that of the Bengal and North-western Metre Gauge Railway, a line has been constructed by a limited liability company, with a free gift of land, but no guarantee.

The mileage and respective gauges of Indian railways, together with the rates of construction, from the commencement down to the 31st March 1892—a period of practically thirty-nine years, can be best exhibited in the form of the following table, showing the length of lines opened in the several quinquennial periods from 1853 to 1892 inclusive—the last period being short of nine months.

LENGTH OF LINES OPEN DURING QUINQUENNIAL PERIODS—
1853 to 1892.

Quinquennial Periods.	Standard Gauge.	Metre Gauge.	Special Gauge.	Total Mileage opened.
	Miles.	Miles.	Miles.	Miles.
1853 to 1857 inclusive, . . .	288½	*	*	288½
1858 to 1862 „ . . .	1965½	82*	*	2047½
1863 to 1867 „ . . .	1493½	80½*	27½	1600½
1868 to 1872 „ . . .	1410½	23½*	*	1433½
1873 to 1877 „ . . .	607½	1324½	20	1952
1878 to 1882 „ . . .	1336½	1396½	90½	2823½
1883 to 1887 „ . . .	1917	2200½	113½	4231½
1888 to 1892 (31st March), . .	1085½	2064½	37½	3187
Total Miles actually open, . .	10,103½	7171½	288½	17,564
Lines under construction or sanctioned on 31st March 1892,				2694½
Total Mileage open, under construction, or sanctioned on 31st March 1892,				20,258½

* Originally 'Special Gauge,' afterwards converted to Metre Gauge.

It will be seen from this table that 17,564 miles of railway of all classes have been opened for traffic in the thirty-nine years previous to 1892, or an average throughout that period of $450\frac{1}{2}$ miles per year, equal to an average rate of 1.44 miles of railway per working day. Excluding the first quinquennial period, the maximum mileage was opened in the years 1883 to 1887, and the minimum in the years 1868 to 1872. In addition to the above it may be mentioned that there were in existence at the end of 1891-92, $37\frac{1}{2}$ miles of steam tramways outside municipal limits. The classification of Indian railways, and the mileage worked under each class, on the 31st March 1892, are exhibited in the following table:—

CLASSIFICATION AND MILEAGE OF INDIAN RAILWAYS.

Classification of Indian Railways.	Standard Gauge.	Metre Gauge.	Special Gauge.	Total.
	Miles.	Miles.	Miles.	Miles.
State Lines worked by Companies, .	3316 $\frac{1}{2}$	5088 $\frac{1}{2}$	*	8404 $\frac{1}{2}$
State Lines worked by the State, .	3491	1146 $\frac{1}{2}$	63 $\frac{1}{2}$	4701
Total State Lines, .	6807 $\frac{1}{2}$	6234 $\frac{1}{2}$	63 $\frac{1}{2}$	13,105 $\frac{1}{2}$
Lines worked by Guaranteed Companies,	2588 $\frac{1}{2}$	*	*	2588 $\frac{1}{2}$
Assisted Companies,	184 $\frac{1}{2}$	136 $\frac{1}{2}$	59	379 $\frac{1}{2}$
Lines owned by Native States and worked by Companies,	399 $\frac{1}{2}$	122	71 $\frac{1}{2}$	593 $\frac{1}{2}$
Lines owned by Native States and worked by State Railway Agency, .	124	*	*	124
Lines owned and worked by Native States,	*	620 $\frac{1}{2}$	94	714 $\frac{1}{2}$
Foreign Lines,	*	58 $\frac{1}{2}$	*	58 $\frac{1}{2}$
Total Miles,	10,103 $\frac{3}{4}$	7171 $\frac{1}{4}$	288 $\frac{1}{2}$	17,564

It will be learned from the above table that the State owns 13,105 $\frac{1}{2}$ miles out of the total mileage of 17,564, of Indian

railways. This length includes several important lines such as the East Indian, the Scinde, Punjab and Delhi, and the Oudh and Rohilkund Railways, originally constructed by guaranteed companies, but since acquired by the Government under the contract terms. The comparatively small mileage as yet owned by native States will also be remarked.

The total capital outlay against all Indian railways, including that incurred on collieries, surveys of lines abandoned, or not yet begun, on unfinished lines, steamboat services, suspense accounts, and, in fact, on all heads—up to the end of the calendar year 1891, amounted to 22,767 lakhs of rupees, or over 227½ millions sterling at par of exchange.

Excluding the expenditure on collieries and surveys of lines abandoned or not yet begun, but including unfinished lines, steamboat services and suspense accounts, the total capital outlay amounted to 22,676 lakhs of rupees, or over 226½ millions sterling at par. Deducting, however, for purposes of comparison, the cost of unfinished lines, steamboat services and suspense accounts, the capital outlay on *open* lines of railway—the mileage of the several classes opened and working at the end of 1891, and their average cost per mile were as follows:—

CAPITAL OUTLAY AND COST PER MILE.

Gauges.	Miles open on 31st Decr. 1891.	Capital Outlay.	Average Cost per Mile.
	Miles,	Rs.	Rs.
Standard Gauge, . . .	10,047·73	16,347,27,103	1,62,696
Metre Gauge, . . .	6,946·68	4,961,69,625	71,425
Special Gauges, . . .	288·31	86,13,182	29,875
Total of all Railways, . .	17,282·72	21,395,09,910	1,23,795

The very great difference, as exhibited by the above table, between the cost per mile of the standard gauge lines and that of the metre and special gauges requires some comment. It must not be overlooked that the difference is very largely due to the inferior weight, as well as to the finish and equipment

generally, of the smaller classes of railways, and to the comparative absence on these lines of engineering works of the first order of magnitude. The 5 feet 6 inches—or standard gauge—railways form the main trunk lines of communication throughout India; the metre-gauge lines, with the principal exception of the Rajputana Malwa State Railway, are for the most part subsidiary or feeder lines. On the broad-gauge railways from 11 to 12 per cent. of their total length is laid double, and on all the older lines, forming a large proportion of the whole, the earthwork formation has been made for a double track, as well as the bridge and culvert masonry in many instances. On the metre-gauge, however, there is practically no double line, and little or no provision for doubling the rails has been made. The broad-gauge railways of India are, in point of weight and quality of permanent way, ballasting and fencing, and in great respect also as regards station accommodation, fully equal to the best European lines, whilst the majority of those of the narrower gauge are constructed with light rails of $41\frac{1}{4}$ lbs. per yard, have as a rule a minimum of station accommodation, and in many cases are unprovided—at least for many years after opening—with full ballast, and are also commonly unfenced. Many of the lines of special gauge are still lighter and less finished in these particulars—especially in station accommodation—and have, moreover, in many instances been laid on ordinary cart roads, with works of a very limited kind.

On the standard-gauge railways, nearly all the heaviest engineering constructions and works of special magnitude are to be met with, whether as regards the enormous bridges over the principal rivers of the country—some of which we have illustrated in previous chapters—or the splendid and costly mountain roads for surmounting the Thul and Bhore *ghāts*, on the Great Indian Peninsula Railway, and the difficult passages through the mountains of Beluchistan on the extension of the Sind-Pishin Railway to Quetta and the Afghan frontier. On the main trunk routes these difficult and costly undertakings had of necessity to be encountered, whilst in the case of the majority of the metre-gauge lines—constructed for the most part as subsidiary and feeder railways—the occurrence of

any specially difficult and expensive works would at once have been an effectual bar to their original construction.¹ To exemplify this, it is only necessary to turn to the tables of large bridges and tunnels, given in Appendices K and L, from which it will be seen in the case of important bridges that for the standard-gauge lines 127,911 lineal feet, or $24\frac{1}{4}$ miles in length, of large bridge-work, costing 925,25,694 rupees, have been provided, against 21,014 $\frac{1}{2}$ lineal feet or less than 4 miles, costing 116,42,982 rupees, on the metre-gauge lines, whilst on the latter railways no tunnels of important size will be found, against 45,431 lineal feet or $8\frac{3}{8}$ miles of tunnelling, costing 150,45,991 rupees, which have been necessitated on lines of the standard gauge. Again, the average age of the standard-gauge railways is greater than the average age of the metre-gauge lines, and the former have developed and carry a far heavier traffic. Their capital cost, therefore, includes a much larger proportion of expenditure, due to additions and improvements—subsequent to the initial outlay—to meet continually augmenting requirements. It will thus be seen that the actual capital cost per mile, as exhibited in the table, of the broad and metre gauge railways of India, does not fairly represent a true comparison under similar conditions of the relative mileage-cost of the two descriptions of railway.

Turning now to 'working results': the gross earnings on all Indian railways for the calendar year 1891 (the last year for which the information is available) were 2404,02,790 rupees. Of this amount 76·56 per cent. was earned by the standard-gauge lines, 22·88 per cent. by the metre-gauge, and the balance of 0·56 per cent. by the special-gauge lines. The following table shows the distribution of the gross earnings under the main heads of account:—

¹ Vide 'Indian Railways,' by F. J. Waring, M.I.C.E., vol. xcvi. *Min. Proc. Institution of Civil Engineers.*

GROSS EARNINGS.

Gauges.	Coaching.	Goods.	Miscellaneous and Steamboat.	Total.	Miles Open.	Gross Earnings per Mile of railway open.
	Rs.	Rs.	Rs.	Rs.		Rs.
Standard Gauge,	552,25,243	1240,28,024	48,08,415	1840,61,732	10,047'73	18,318'73
Metre Gauge, .	216,93,010	313,59,838	19,58,026	550,10,874	6,946'68	7,919'01
Special Gauges, .	6,19,367	6,93,304	17,513	13,30,184	288'31	4,613'72
TOTALS—Rs.	735,37,620	1560,81,166	67,84,004	2404,02,790	17,282'72	13,910

The total 'working expenses' on all railways during the year 1891 were 1180,38,471 rupees, distributed as follows:—

WORKING EXPENSES.

Gauges.	Working Expenses,	Miles open.	Working Expenses per mile of railways open.
	Rs.		Rs.
Standard Gauge, . . .	831,03,801	10,047'73	8270'90
Metre Gauge, . . .	290,82,250	6,946'68	4186'50
Special Gauges, . . .	8,52,420	288'31	2956'60
TOTALS—RS.	1130,38,471	17,282'72	6540'60

The percentage of working expenses on gross earnings on all railways taken together was 47·02 per cent., distributed throughout the various heads of service as follows:—

PERCENTAGE OF WORKING EXPENSES ON GROSS EARNINGS.

Gauges.	Maintenance, per cent.	Locomotive, per cent.	Carriage and wagon, per cent.	Traffic, per cent.	General per cent.	Steam-boat and Miscellaneous, per cent.	Total per centage.
Standard Gauge,	12'64	15'09	4'36	6'87	4'05	2'14	45'15
Metre Gauge, .	13'69	17'79	4'21	8'06	6'93	2'19	52'87
Special Gauges,	14'94	20'40	6'08	11'08	9'73	1'81	64'08
TOTALS,	12'89	15'74	4'33	7'17	4'74	2'15	47'02

The 'net earnings' realised were 1273,64,319 rupees, distributed over the three classes of railways as below :—

NET EARNINGS.

Gauges.	Net Earnings, Rs.	Miles open.	Net Earnings per mile of railway open.
Standard Gauge, . . .	1009,57,931	10,047·73	Rs. 10,047·83
Metre Gauge, . . .	259,28,624	6,946·68	3,732·50
Special Gauges, . . .	4,77,764	288·31	1,657·10
TOTALS, . . .	1273,64,319	17,282·72	7,369·40

It will, from the above table, be deduced that in the year 1891, on every mile of open railway the net earnings of the standard-gauge lines were as one rupee against slightly less than 6 annas in the case of the metre gauge, or as £1 against 7s. 6d.

The return on the whole capital expenditure on open lines, including steamboat services, etc. during the year 1891, was 5·76 per cent. distributed as follows :—Standard-gauge lines 5·98 per cent.; metre-gauge lines 5·04 per cent.; special gauges 5·42 per cent. The mean mileage worked during the year was 17,037·63 miles, and the total results may be summarised as follows :—

GENERAL RESULTS, INCLUDING STEAMBOAT SERVICES AND SUSPENSE ACCOUNTS.

Gauges.	Mean Miles worked.	Capital outlay, Rs.	Average cost per mile. Rs.	Gross Earnings, Rs.	Working Expenses, Rs.	Per cent.	Net Earnings, Rs.	Per cent on Cap.
Standard Gauge,	10,055·82	16,869,18,826	162,696*	1840,61,732	831,03,801	45·15	1009,57,931	5·98
Metre Gauge, .	6,695·22	5,149,13,408	71,425	550,10,874	290,82,250	52·87	259,28,624	5·04
Special Gauges,	286·59	88,09,682	29,875	13,30,184	8,52,420	64·08	4,77,764	5·42
TOTALS,	17,037·63	22,106,41,916	123,795*	2404,02,790	1130,38,471	47·02	1273,64,319	5·76

* Excluding Steamboat and Suspense.

The total number of passengers carried by all the railways in India, during the year 1891, was 122,855,377, and the gross earnings amounted to Rs. 775,37,620, or Rs. 14,110 per mean mile worked. The number of passengers booked per mean mile worked was 7211. The average distance travelled per passenger was 45·98 miles on the standard-gauge lines, and 38·17 on the metre-gauge railways. Of the total number of passengers carried the two lowest classes constituted 97·34 per cent., the second class 2·26 per cent., and the first class 0·40 per cent. of the whole.

The total tonnage of goods carried was 26,158,953 tons, or 1535 tons per mean mile worked, and the gross earnings were 1560,81,166 rupees. The passenger mileage reached 5,226,107, 973 miles, and the goods ton mileage 4,438,992,431 ; the total number of train miles being 60,800,165.

The main results of working all the Indian railways during the year 1891, divided over the three heads of gauge, will be found detailed in Appendix M.

There are, as a rule, four classes of vehicles for passenger traffic on Indian railways, viz. 1st, 2nd, 3rd, or intermediate, and the 4th, or lowest class. The fares charged vary considerably in working, but the schedule of maximum and minimum fares for coaching traffic are as follows :—

	Maximum pies per mile.	Minimum pies per mile.
First class,	18	12 equals 2½d. to 1½d. at par.
Second class,	9	6 „ 1½d. to ¾d. „
Intermediate,	4½	3 „ ¾d. to ½d. „
4th or lowest class,	3	1½ „ ¾d. to ½d. „

The ordinary fares for the lowest class are from 2 to 3 pies per mile, or from one, to one and a half farthings. A man can, therefore, generally travel by railway a distance of 400 miles within the 24 hours, for the small sum of Rs. 4.2.8, or say, 8s. 4d. at par of exchange. To get over this ground by ordinary road journeys would take him from thirty to forty days, and the humblest traveller would of necessity expend a greater sum for his daily food during this interval ; the generality, even of the poorer class, would probably expend double this amount.

Although the railway passenger classes are so numerous on Indian railways, it was in India that probably the earliest experiment was made of employing only two classes for passengers, such as adopted now for many years on the Midland Railway in England. The Indian Branch Railway Company, afterwards the Oudh and Rohilkund Railway, originally introduced two descriptions of vehicles for passenger traffic, respectively called the 'Upper' and 'Lower' classes, corresponding with the 1st and 3rd classes on English lines. Subsequently, however, an intermediate fare, and a somewhat superior carriage was interpolated into the lower class.

At the end of the year 1891, the number of locomotive engines employed on the main railway system of India (*i.e.* excluding the special gauges) was 3763 in all, or 2535 of standard, and 1228 of metre gauge, and the quantity of passenger and goods rolling-stock, at the same time was as follows :—

**PASSENGER AND GOODS ROLLING-STOCK AT END OF
YEAR 1891.**

Classification.	Standard Gauge.	Metre Gauge.	Total.
First-class carriages, . . .	463	345	808
Second-class carriages, . . .	522	270	792
Third or intermediate carriages, .	233	90	323
Lowest or fourth-class carriages, .	3,565	2,666	6,231
Composite carriages, . . .	644	417	1,061
Miscellaneous carriages, . . .	930	456	1,386
Totals, Passenger rolling-stock, .	6,357	4,244	10,601
Goods vehicles of all kinds, . .	44,370	24,252	68,622
Brake vans,	2,067	926	2,993
TOTAL, Goods rolling-stock, . .	46,437	25,178	71,615

It will be of interest also to point out the number of persons of all races engaged on the service of Indian open lines of railway, as they are distributed throughout the various railway departments. At the end of the year 1891 the total number of persons so employed was 260,598, of whom 250,036 were natives of the country, 5936 were Eurasians, and 4626—or 17·75 per cent. only of the whole—were Europeans. The distribution of the above number of persons was as follows :—

DISTRIBUTION OF PERSONS EMPLOYED ON INDIAN RAILWAYS.

Departments.	Europeans.	Eurasians.	Natives.	Total.
General administration, including agency, audit, accounts, stores, medical, printing, police, etc., .	353	451	13,771	14,575
Traffic and telegraph departments,	1567	2197	54,625	58,389
Engineers' department, . . .	486	491	112,001	112,978
Locomotive and carriage and wagon, inclusive of steamboat establishments,	2220	2797	69,639	74,653
TOTALS, . . .	4626	5936	260,056	260,595

Of the 260,595 persons employed, 198,225 were engaged on the standard-gauge railways, and 62,373 on the metre-gauge. The total number of railway stations throughout India was 2427, or 1489 on the standard, and 938 on the narrow-gauge lines. The mileage open (of these two gauges) was 10,048 and 6947 miles respectively, so that the average distance apart of the stations is 6·75 and 7·40 miles.

The efficient training and employment of natives of the country in the responsible positions of drivers or shunters of locomotives, has for many years occupied the careful attention of railway authorities in India; and it will be of interest to the reader to note the gradual but steady increase in this important class of railway servants during the ten years,

1881 to 1890 inclusive, as exhibited by the following table :—

NUMBERS OF NATIVE DRIVERS AND SHUNTERS, 1881 TO 1890,
INCLUSIVE.

Class.	1881.	1882.	1883.	1884.	1885.	1885.	1887.	1888.	1889.	1890.
Drivers, .	278	335	391	456	519	580	650	724	808	826
Shunters, .	269	295	325	382	386	414	433	444	458	472
TOTALS,	547	630	716	778	905	994	1083	1168	1261	1298

Although, for persons who take ordinary care, there is certainly no safer mode of travelling than that by railway, nevertheless, in spite of the most stringent precautions, a certain yearly number of accidents to trains will inevitably occur on every railway, or railway system in the world. The accident returns on Indian railways for the year 1891 may be thus briefly summarised. The number of train accidents per 1000 train-miles was 0·07. Out of the 122½ millions of passengers travelling 56 were killed, or 1 in 2,190,000, and 135 persons were injured. The total number of passengers killed or injured, viz. 191, gives an average of 27 millions of miles travelled for each casualty. Few persons thoroughly realise the extraordinary security of railway travelling. Taking the last Board of Trade returns of railway accidents in the United Kingdom, and deducting the casualties for which the passengers themselves were clearly responsible, it appears that a traveller might expect to make 966,244 railway journeys without mishap, and 169 million journeys without being killed. A reasonably cautious person, therefore, making two journeys per day on every day of the week might hope to escape fatal accident for at least 270,000 years.

One of the most important questions connected with the economical working of Indian railways is that of fuel supply. The three or four thousand powerful iron horses that daily and hourly are traversing some portion of the length and

breadth of the country with so great a rapidity, drawing behind them such immense loads of vehicles, passengers, and merchandise, can only maintain their vigorous life and energy by a prodigious consumption of mineral or vegetable food, in the shape of coal, coke, or wood. In the year 1891, the locomotive engines on Indian railways consumed no less than 1,036,498 tons of coal, and 363,171 tons of wood, coke, or patent fuel. Of the coal consumed 216,822 tons were English, and 782,664 tons were of Indian production.

Although coal was known to exist in India so long ago as the year 1774, and was actually worked in 1775, it is only during the last twenty years—under the stimulus of railway requirements—that any notable development in the exploration and opening up of the chief coal-fields of the country has taken place, and it has been ascertained that the area in India over which the coal formation may be presumed to extend, is not far short of 40,000 square miles. Most of the more important collieries are worked in connection with the railways, and by direct or indirect Government agency. The yearly output of this important mineral, from collieries chiefly situated in Bengal, Assam, the Central Provinces, and the Nizam's territory, reached in the year 1891 a total quantity of 2,118,680 tons, as compared with 997,730 tons in 1881, of which—as we have seen—782,664 tons were burned on the railways, the balance going either to maintain the stocks in hand, or to industrial manufactures. A statement showing the quantity in tons of coal produced in India during the last twelve years, and the distribution of the output over the several provinces of the country is subjoined in Appendix N.

In the year 1857 the Indian Government had opened 288½ miles of railway, which carried during the year two millions of passengers and 253,000 tons of goods. By the end of 1891, 17,283 miles of railway were in operation, which carried during the year nearly 123 millions of passengers, and over 26 million tons of goods. As we have seen, the rates charged for passengers on these railways are as low as one farthing per mile, whilst the goods rates range as low as one halfpenny per ton per mile.

The centralised administration or control of Indian railways, constructed also under a rigidly enforced system of standard

dimensions both for works and rolling-stock, and under a thoroughly efficient and minute supervision exercised by the Government inspecting officers, acting with the widest powers, has been of incalculable benefit to the public, and has freed India from many of those evils which have grown up, and proved well-nigh insuperable, under the exercise of the largely irresponsible powers which in England and America has fallen into the hands of the great railway monopolists. In England, the officers of the Board of Trade, exercising their functions under a very strictly limited legislative authority, have little or no power to *order*; they are for the most part restricted to recommendations, that in many instances are quite insufficient to cope with the vast weight of private and monetary interests to which the recommendations are opposed.

The following extract from a memorandum issued by the India House in 1889, on some of the results of Indian administration during the previous thirty years of British rule in India, will fitly conclude the subject of railways:—

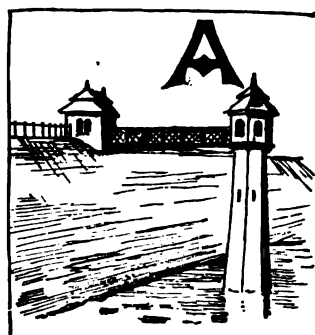
‘It is hardly necessary to refer here to the incalculable benefits done by railways, which in time of need carry food from prosperous districts to famine-stricken provinces; or to the impulse given to production and trade when railways carry to the seaports surplus products that would otherwise have found no market, and might have rotted in granaries; or to the enormous addition to the military strength of the country, when troops and material can be moved to the frontier, or to any scene of disturbance, at the rate of 400 miles, instead of 10 miles a day, and at one-sixth of the old cost. Railways have now been made, or are being made, on all the main routes in British or Native territory. The system of military railways on the North-west frontier is nearly completed, and several lines which do not pay commercially have been constructed for the protection of tracts specially liable to visitation by famine. Cross lines and branch lines have still to be made, and during the two years 1886 and 1887, new lines or extensions, aggregating 2228 miles, were opened. In the North-west Provinces and Oudh, the richest and most densely peopled tract in India except lower Bengal, railway extension has progressed so far that it has been stated that no village, except in the Himalayas and hill tracts south of Mirzapore, will be more than 40 miles from a railway station by June 1889, when the Indian Midland Railway, now under construction (1887-88) will be completed.’

WATER-SUPPLY OF TOWNS IN INDIA

CHAPTER I

INTRODUCTORY

Introductory remarks—Early adoption of well-sinking and impounding water in tanks—Method by which the modern water-supply of towns is effected—Ancient water-supply schemes all gravitation works—Absence of pipes, and means of pumping—Sub-soil wells—Roman aqueducts—The 'Pont du Gard'—Advance in modern water-supply arrangements—Increased purity and pressure of the water—Leading principles of modern water-works—Source of water—Rainfall—Consumption of water—Intermittent and constant service systems—Design of water-works—The reservoir—The embankment or dam—Foundation trenches—Puddle and other details—Waste-weirs and arrangements for drawing off water—Straining and screening—Pumping schemes—Conveyance of water—Conduits and pipes—Inverted syphon in lieu of aqueducts—Service reservoir—Settling tanks and distribution.



ALL sections of mankind, raised in the least degree above the lowest level of barbarism, have in every age recognised the supreme importance of a plentiful supply of pure water for the use of the inhabitants of those often densely-populated centres to which we give the name of cities or towns. In modern days, when the nature and causes of most of the diseases which afflict humanity are to some extent known and understood, a pure and ample water-supply is, on rational and scientific grounds, seen to be the *sine qua non* of all sanitary conditions, for it is to a scanty or impure supply of this great necessary of life that the bulk of the epidemic diseases, especially those connected with fevers or cholera, may be traced. All the known civilised communities of ancient Europe or America have left us certain evidence that the provision of water for the

wants of their great centres of population largely occupied their attention. This evidence is given us in the numerous and often vast ruins of aqueducts or other costly works constructed by them for this purpose.

In the East, whether in Palestine, Egypt, Arabia, Persia, India, or China, the artificial water-supply of towns was undoubtedly studied and practised before the dawn of European civilisation.

In India the art and practice of impounding the rainfall in tanks, or reservoirs, is probably contemporaneous with the first introduction of Aryan speech into that country. Owing to the extreme dryness of the climate of India, this was the most readily available method of securing and storing supplies of water in large quantity, especially in those parts of the country where, during the seasons of drought, the natural water-courses are either dry, or exceedingly scanty in volume. In Hindustan, all the larger cities naturally grew up along the banks of the great perennial rivers, where water for the use of the inhabitants was available in abundance. In the case of important towns or villages at a distance from the streams, a supply of water for drinking and domestic purposes would be largely derived from the subsoil by means of well-sinking, an art developed and skilfully practised at a very early stage by all the Eastern races ; but in order to obtain those larger volumes of water necessary for the frequent personal ablutions, washing of garments, and other purposes imposed by the religious customs of the country, the construction of artificial tanks for the impounding and storing of water in large masses, would soon be resorted to, wherever the opportunity of so doing presented itself. These tanks, so numerous in India, are generally supplied directly by the rainfall on their own catchment basins, but in some cases they doubtless were fed, either partially or entirely—in early times as at present—by ducts or channels led from the nearest, or most convenient permanent watercourse. In most cases the tanks are found at or close to the villages or towns ; these, in fact, having in some measure grown up around them ; but in many parts of the country instances are met with of storage reservoirs, constructed at suitable places situated at a distance from the towns supplied from them. In these cases

water from the main reservoir (a greater or less proportion of which may be utilised for the irrigation of the intermediate fields) is led by means of channels, or by enclosed masonry ducts, into one, or into many smaller tanks, or cisterns, situated either in the town itself, or in the neighbouring surrounding gardens, and from these tanks the water is distributed for the domestic service of the population, either by the portorage of a special caste of water-bearers or by the lower-class female population. One of the most familiar sights in India, as indeed generally in the East, is the crowd of female water-carriers, passing and repassing with their earthenware or metal vessels of water gracefully poised on their heads, or collected together in feminine gossip at the margin of well or tank.

The water-supply of towns in modern times is effected by one of two methods, viz. either by natural gravitation or by pumping. In the first method the water is collected from springs, or by impounding flood-waters in reservoirs, at an elevation sufficiently above the level of the town to command the whole or greater part of it, the water being delivered by the natural force of gravity. In the second method the necessary elevation is given to the water by the mechanical aid of steam, or other source of power, applied to the purpose of pumping it, either from rivers, reservoirs, or deep wells. The two methods may also be combined, a portion of the town being supplied by natural gravitation, and the remaining or more elevated portion being supplied by the intermediate agency of mechanical power, to raise or force the water to the required height.

With the exception, perhaps, of some cases where water may have been forcibly raised in buckets or other receptacles from moderately deep wells or other sources, by means of manual or animal power (or even by the aid of wind or water power), all the larger water-supply schemes of ancient times were gravitation works, working at a low pressure. No evidence exists until comparatively recent times of the employment of *pipes* for the conveyance of water under high pressures. Pipes of earthenware or of lead were frequently used in Roman times, but it is evident that neither of these materials could have been subjected to more than a very moderate degree of

pressure. Moreover, until the invention of the steam-engine, there was no means of artificially raising large quantities of water from a low to a high level. Ancient waterworks are, therefore, all of the low-pressure gravitation type of construction.

Subsoil wells were probably the earliest artificial source of water-supply, and allusions to them are to be found in all the most ancient human records. In China there exist numerous ancient 'Artesian' wells of great depth. An 'Artesian' well consists of a bore-hole carried down through some impermeable upper strata, into a lower water-bearing bed, the water in which, being subject to natural hydraulic pressure, at once rises, often to the surface, through the bore-hole. In many parts of Europe, but especially in Southern Italy, ordinary wells of depths often considerably over 100 feet were constructed by the early Romans. For a long time the city of Rome itself was largely dependent on this source of supply, but as the population of the city increased, and the Tiber became contaminated, the conveyance of pure water from great distances was undertaken, as testified by the ruins of many noble aqueducts constructed under the Cæsars, which still remain to fill the mind of modern travellers with wonder and surprise. In almost every country—for any length of time under the dominion of the Roman Empire—the remains of often gigantic water-conduits exist, some of which are even at the present day partially utilised for their original purpose. The Roman aqueducts were, as a rule, boldly constructed works, carrying the water collected from distant springs or lakes, in very direct lines, through tunnels in the hills, and passing over intermediate valleys in masonry channels carried on archwork, often in several tiers one above the other, reaching very considerable altitudes. The aqueducts had a regular gradient, or fall from end to end, usually from 2 to $2\frac{1}{2}$ feet per mile. They contained in some instances enormous quantities of masonry construction, everywhere lined with an excellent quality of cement.

One of the largest Roman aqueducts in Europe is the 'Pont du Gard,' which forms a portion of the conduit for the supply of the town of Nîmes in France. This aqueduct has been thus described: 'It consists of three tiers of arches, the lowest

of six arches supporting eleven of equal span in the centre tier, surmounted by thirty-five of smaller size; the whole is in a simple style of architecture, destitute of ornament. It is by its magnitude, and skilful fittings of its enormous blocks, that it makes an impression on the mind. It is the more striking from the utter solitude in which it stands—a rocky valley partly covered with brushwood and greensward, with scarcely a human habitation in sight. This colossal monument still spans the valley, joining hill to hill, in a nearly perfect state of preservation, only the upper part at the north extremity being broken away. The highest range of arches carries a covered canal about 5 feet high and 2 feet wide, shaped in section like the letter U. It is covered with stone slabs, along which it is possible to walk from end to end, and to overlook the valley of the Gardon. The arches of the middle tier are formed of three distinct ribs or bands apparently unconnected. The height of the Pont du Gard is 180 feet, and the length of the highest arcade 873 feet. Its date and builder are alike lost in oblivion, but it is attributed to Agrippa, son-in-law of Augustus, B.C. 19. M. Genieys, formerly engineer-in-chief to the municipality of Paris, estimated that the quantity of water conveyed by this conduit amounted to 14 million gallons per day.¹

The most important advances in the modern water-supply of towns as compared with ancient works, are the increased attention given to securing a supply of pure and wholesome water, free from every kind of contamination, and its more systematic and general distribution under high pressures by means of pipes. Increased purity is obtained by a more careful selection of the immediate source of supply, both as regards locality and quality of water, as well as by precautions taken to prevent defilement of the gathering-ground, and by resort to filtration wherever necessary. Many water-supply schemes of considerable magnitude and interest have been carried out during recent years by the municipalities of the larger cities of India, but before proceeding to give the reader an outline sketch of some of the more important of these works, it will be necessary to summarise, as briefly and clearly as possible, the leading principles of modern water-works.

¹ Humber, *On Water Supply of Cities and Towns*.

The Sun is the original dispenser, and the ocean—which occupies more than two-thirds of the surface of the globe—is the ultimate source of all water-supply. Under the influence of the sun's heat, chiefly within the tropics, where the heat rays, being more vertical, are more intense, the surface-water of the ocean undergoes continual evaporation. The aqueous vapour ascending to the upper and cooler regions of the atmosphere, forms those clouds which, driven by established aerial currents over the land, are there under various conditions of temperature and altitude condensed, and fall to the earth in the form of rain, hail, snow, or dew. The great volume of water thus derived—whether absorbed temporarily into the soil, partially retained in lakes, or hastening again to its distant birthplace in the sea, through those surface channels which it has worn for itself, named rivers—becomes in one manner or another available for the service of man, and for the refreshment of all animal and vegetable life. The supply of water, therefore, available for human needs is immediately dependent on the rainfall.

To all ordinary observers nothing appears more variable, uncertain, and inconstant than the fall of rain, even in those countries where, like India, it is plainly seen to be subject to a general seasonable periodicity. Close investigation, however, has clearly established that wherever accurate records, extending over long periods of time, have been kept, it will be found that the rainfall of any particular locality has a mean annual average quantity, due to that locality, during such periods, which will not greatly vary (local conditions remaining the same) during similar periods in the future. It has also been ascertained that if a reasonably correct estimate of this mean annual average for any given place is required, it can only be obtained on condition that accurate records of the actual rainfall have been recorded for a period extending over at least twenty years, and that records for periods of forty to fifty years will furnish a basis for a very close estimation of the real mean annual average. Hence in places where no record of the rainfall has been kept for the necessary length of time, a knowledge of the mean annual fall, with the amount and duration of the principal fluctuations above and below the mean—information

which is necessary to the engineer for water-works purposes—can only be approximately ascertained by comparison with, and deduction from, the records of the most suitably situated neighbouring places, where the rainfall *has* been recorded for the necessary time. It will thus be seen how important a thing it is that a regular and systematic measurement of all rainfall should be carried out in as many selected places as possible in every country. The study of rainfall, its distribution, and the various phenomena connected with its periodical fluctuations in long intervals of time, has occupied the time and attention of many scientific men during recent years, with the object of bringing to light the natural laws by which these fluctuations are governed; and the extreme importance of long series of rainfall observations is now universally recognised by all civilised nations in every part of the world.

The engineer intrusted with the design and construction of waterworks for the supply of a town has first to consider and determine what quantity of water will be required, and has also to take into account the natural growth of the population, so that the works as constructed may be able to meet an increased consumption at least for some years. He will also, wherever possible, design the works with a special view to their future enlargement or extension, at the least subsequent expense. The quantity of water is usually expressed by the average number of gallons consumed every day of twenty-four hours by each unit of the population, or as generally shortly stated, the 'number of gallons per head per day.' This quantity varies considerably, according to the habits and customs of the people supplied, and is dependent upon so many different circumstances that no very certain rule exists by which consumption, where not directly known, can be estimated. In England, owing to improved sanitary appliances, and the large amount of water sometimes used for trade purposes, the consumption, including wastage, varies from 20 to 50 gallons per head per day, but in India from 10 to 20 gallons are more common rates. Water is distributed to towns in one of two ways, viz. under a 'constant,' or under an 'intermittent' service—each of which may be at high or low pressure. In the 'constant' service system the water, in prac-

tically unlimited quantity, is placed at the disposal of the people; the pipes are always maintained full of water under pressure, and can be drawn from them at any time through the taps or valves provided. In the 'intermittent' system cisterns of a certain capacity are provided in numbers as may be necessary, into which the water is turned on during certain fixed hours; the cisterns being provided with self-closing taps which shut off the inflow of the water when they are full. In England, whichever system is employed, the water is invariably delivered into the houses. In India, however, it is more usual, in accordance with the habits and customs of the people, to employ a constant service, either at high or low pressure, delivering the water free of charge from standards erected at convenient places in the public streets and open spaces, but it is delivered also into the houses at special rates whenever demanded.

In Europe, contrary to what might be supposed, it has been found that the average consumption of water, including wastage, is less under the constant than under the intermittent system. As there can be no question as to the greater public convenience, and greater cleanliness of the former, it is probable that in all new works the employment of the intermittent system will be almost everywhere abandoned.

The engineer having estimated the proportion of the annual rainfall that he can reckon upon for his purposes—which will not be more than from 4 to 6 tenths of it, owing to absorption into the soil and evaporation, and having liberally determined the number of gallons of water per head of population that he proposes to provide, can now proceed to the general design of the contemplated works. If a main storage reservoir is contemplated, he can estimate its minimum capacity, so that it may be capable of supplying the requisite quantity of water, not for one year only, but for such number of years as the rainfall data with regard to the consecutive number of driest years may appear to indicate, so that at no time there may be serious risk of the supply running short. He can also determine the exact dimensions of the main pipes or conduits that are necessary. If the water is to be obtained from wells, or from a river by pumping, he can calculate the engine power

and size of pumps required, and fix, according to the special circumstances of each case, all the principal dimensions and details of the project.

He will at a very early stage have turned his attention to the selection of the best position for the reservoir, or for the pumping station, as the case may be, and to the quality of the water available, so as to decide upon the necessity or otherwise, or upon the best and most convenient means, of filtration or purification of the water. The engineer has also numerous other points to consider. In the case of a reservoir its elevation must be such as to command the whole area to be supplied, or if this is not possible, he may have to arrange for the supply of a certain portion of the area by means of pumping. He will have to consider the geological formation of the drainage basin off which the water entering the reservoir will flow, both as regards the material of which the soil is composed, the slopes, and generally all matters which affect the rate of flow or the contamination of the water. He will have to make quite sure that after he has made the reservoir, the water will really flow into and remain in it, and will not escape by underground fissures or by the too porous nature of the subsoil. In most cases, especially in thickly populated districts, he will have to carefully ascertain the extent to which the proposed works will affect the interest of individuals or of communities, by withdrawing from them water or conveniences to which they have established right, and to decide upon the most equitable means of compensation where such rights are interfered with. It will thus be seen that the actual construction of a water-supply project is often the least part of the labours of the engineer responsible for it.

We will suppose, however, that all the laborious initial work has been satisfactorily accomplished, that the exact spot for the storage reservoir embankment has been chosen, and that the nature of the ground on which it has to be reared has been carefully explored by means of trial excavations and bore-holes. It is evident—no matter what may be the material of which the embankment or ‘dam’ is to be formed—it cannot be merely erected on the surface soil, but some portion at least of its width must be firmly rooted in the ground in such a manner that no water can escape under it, and this can only be ensured

by carrying a certain part of the work down to some natural watertight stratum.

The foundation trench—of whatever width that may be decided, a width that will principally vary in proportion to the height of the embankment—will thus be cut from one side of the valley to the other, until it everywhere reaches a suitable retentive material, and this may in some instances occur only at very considerable depths. Generally, also, it will be necessary to remove from the whole seat of the embankment or dam all surface material likely to be injuriously affected by the action of the water. If the dam is to be a solid one of masonry or concrete, the construction will now be brought up to a more or less general level with these materials, or if an earthen embankment is intended, and the depth is not too great (in which case some intermediate cement concrete might be used) the trench will be filled in with an impermeable material called ‘puddle,’ formed of a certain quality of clay well worked with water into a homogeneous and retentive mass. This puddle will be carried up like a wall or core, through the heart of the embankment, and will only terminate at a height somewhat above the contemplated water-level in the finished reservoir; its purpose being to stop the passage of any water through the embankment. The earth forming the main body of the embankment—a large portion of which on either side of the puddle-wall will be of a carefully selected character—is at the same time built up systematically in thin layers, and with long slopes on the outer and inner sides of the puddle-wall. On the water-side the face of the earthen slope will be protected from injury by a stone pitching or by other suitable means. Tank or reservoir embankments have for centuries been constructed by the natives of India without any central puddle-wall, but that this omission has not proved hurtful to the stability of many of the works constructed by them, is due to the circumstance that the average height of their embankments is considerably lower, and their general thickness much greater, than in most modern examples constructed by English engineers; whilst the numerous ruins of native tanks which exist give evidence of a frequent absence of the necessary stability in their constructions.

Before commencing the embankment, the engineer will have made due provision for disposing of all water that might collect on the site of the reservoir that would injure or interfere with the progress of the works. This is sometimes done by cutting a 'catch-water' or flood-water channel round the site of the reservoir at a level a little above the margin of the full water-surface, to intercept all the water running off the catchment basin. The channel is constructed with a slight fall, and is dropped into the valley below the embankment. The small quantity of water that may collect from the rainfall on the actual site of the reservoir can then either be allowed to remain, or if in the way can be disposed of by pumping; or the permanent passage to be hereafter used for the discharge of water from the reservoir may be constructed before the embankment is brought up, and utilised.

The particular manner in which it is proposed to draw off the water from the completed reservoir will have been early decided upon, and the engineer will also have fixed upon the most convenient and most economical alignment of the aqueduct by means of which the water is to be conveyed to the town. In almost every case the influx of water into the reservoir, in relation to its consumption, will be such that (unless provided against) it will rise during floods to a height sufficient to overtop the embankment, and as the latter would in such a case be inevitably destroyed, as well as probably much life and property below, it is necessary to render such a contingency impossible. This is done by the provision of a waste or overflow weir, in some part of the embankment—or of several such weirs—made of a total length, and finished off at such an elevation as to carry off all surplus water tending to collect above a certain fixed level, which is usually placed at 6 or 8 feet below the top of the embankment. The water flowing over the waste weir or weirs, is discharged by means of a special channel led into the valley to a point at some distance below the foot of the embankment or dam.

Perhaps the most important matter connected with reservoir construction, especially where the water impounded is very deep, is the manner in which provision is made for drawing off the water. Formerly it was the almost universal practice to

take the discharge-pipes, in one manner or another, through the embankment; generally in its deepest part. They were often carried in a culvert similarly placed. However well and carefully constructed, experience has shown that such expedients are most dangerous to the stability of an earthen embankment. There is nothing more penetrating than water under pressure, and it will inevitably find out every weak spot that may exist. No form of stopping has been found which can in all cases be depended upon to prevent the water under such circumstances, from finding its way along the outside of culvert or other outlets constructed through the heart of an earthen embankment and its puddle wall. The unequal pressure of the embankment is also frequently the cause of irregular settlements, tending to break or dislocate the culvert masonry. In all properly executed works it is now usual to leave the embankment—the stability of which is of the first importance—perfectly intact, and to lay the discharge-pipes of the reservoir in a detached tunnel excavation made in the solid ground, passing them through one or more watertight bulkheads or stops in the tunnel. Careful provision is also made to prevent the water in the reservoir—which may stand at a great height above the tunnel passage—from passing along the outside of its lining, which latter may be either of masonry or of iron. The passage of water through the pipes carried in the tunnel, is controlled by suitable valves and gearing conveniently placed near the bottom of a water-tower built up from a good foundation in the bed of the reservoir; this tower being connected with the shore by means of a service foot-bridge.

There will be but few, if any, cases of water-supply where some method of straining or screening the water before its admission into the pipes or conduits will not be necessary, in order to get rid of the grosser solid matter held in suspension in the water and prevent its choking them. It is usual to pass the water through fine wire-gauze strainers, generally fitted in the water-tower; but these, even if very fine, are often insufficient to exclude fish-spawn. In Bombay, fishes which had no doubt passed through the strainers in the shape of spawn were formerly found in the water-supply pipes, grown to a length of over 4 feet, together with eels of even greater length, and

12 inches in girth. These, and other forms of animal life, dying in the pipes necessarily foul the water, and render it injurious for drinking purposes. Hence the necessity of very great care in efficiently screening the water before its entry into any system of piping.

If the circumstances of the case are such that no suitable site exists for the construction of a storage reservoir at a sufficient elevation to command the town, or if for other reasons it is considered preferable to obtain the required supply of water by pumping, the engineer will resort either to the stores of water contained in the subsoil, and will collect it into wells, sunk to a sufficient depth, from which it can be pumped, or he will draw the water from some permanent river. In either case he will have to provide sufficient engine power to overcome the friction of the water in the pipes, and to raise its whole weight to an elevation sufficient for his purpose. If the subsoil water is to be utilised, he will have to take great care that the wells are so located that the water collecting in them is not liable to contamination from organically impure surface drainage, and in case of river supplies there will be few cases where it will not be necessary to clear the water from sediment and other impurities, by means of settling tanks and filtration previous to its distribution.

Water drawn from river or even well sources can sometimes be supplied by gravitation if the water is tapped at a sufficiently high level to command the town, in which case a weir across the river, and probably a very long delivery aqueduct may be required. Or the water may be delivered by gravitation to the neighbourhood of the town, and then pumped into high service reservoirs, from which, after passing through settling and filtering tanks, it can be distributed by gravitation.

From the source of supply to the town, the water in all cases is conveyed either in cast-iron pipes, or in canals or conduits, open or covered over, or partly in the one manner and partly in the other. The selection of the particular method of conveying the water will be governed by various considerations, among the principal of which will be the greater head required to overcome friction in pipes as compared with canals or conduits. In cases where the source of supply is

situated at a great distance from the town to be served, conduits or open channels will be economical, but the great expense of constructing masonry or other aqueducts across wide and deep valleys will certainly, or probably, necessitate the cheaper expedient of cast-iron piping in the form of an inverted syphon in such situations. Whatever may be the means employed of conveying the water, the pipes or aqueducts will usually terminate in a 'service' reservoir near the town, constructed in such a situation as to command the whole area to be supplied by gravitation. The capacity of this reservoir will be sufficient to contain at least several days' supply of water in order that the aqueduct may be occasionally laid dry for necessary repairs. At the outlet of the service reservoir, meters or appliances for exactly measuring the quantity of water issuing from it will be generally provided, so that any unusual consumption may be at once detected. From this point, the distribution of water over the district to be supplied will be effected by means of main and service pipes, provided at various points with the necessary valves and fittings to control and regulate the flow of water, and with standards or cisterns to deliver it wherever required.

If the water should require cleansing and filtration before distribution, this operation can be carried out at any point between the source of supply and the service reservoir. In order to get rid of the main mass of the sediment that may be contained in the water, it is usually led or pumped in the first instance into a settling tank, or tanks, where an interval is allowed for the sediment to sink, and be deposited on the bottom. The cleared water is then passed into a filtering chamber, and is made to pass through beds of various filtering materials, such as clean pebbles, coarse and fine sand, charcoal, etc., after which it will be ready for distribution.

The reader will now probably have gained a general idea of the more ordinary arrangements made for the water-supply of towns, sufficient at least to enable him to follow the outline descriptions of some of the chief works of this kind executed from time to time in India, to which we will now proceed.

CHAPTER II

BOMBAY AND SHOLAPUR

Examples of Indian waterworks—Bombay water-supply—Rapid development of Bombay—Early studies for improving the water-supply—Rainfall at Bombay—Salsette, and surveys of the course of the Goper—The Vehar basin—The Vehar reservoir—Principal details—Further surveys—The Tulsi scheme—The Tansa reservoir project—Principal details of construction—Cost of works—Opening ceremonial in March 1892—Extract from speech by Viceroy—The Sholapur Waterworks—Ekruk Tank—Low-level canal—Sanitary commissioners' report—Proposals for permanent water-supply—Description of waterworks scheme as carried out—Low rate of consumption—Pumping power—Settling tanks—High service reservoir—Low service—Supply pipe and distribution—Opening of works.

Bombay Waterworks 1856 to 1892

THE examples of modern waterworks given in the following pages are arranged chiefly, although not entirely, in the order of their date of construction. In the important capital city of Bombay are to be found the earliest in point of date, as well as the latest, and most considerable of the examples selected for illustration. It will be convenient, therefore, to commence with the water-supply arrangements of that city.

The extraordinarily rapid development in modern times of the population and importance of the city of Bombay, due, not only to the exceptional advantages conferred by geographical position, and the possession of a magnificent natural harbour, but to the energy and commercial activity of its inhabitants, has been accompanied with a more than equally rapid development of its water-supply, so that at the present time there is probably no city of the old world that can compete with it in the abundance and excellence of its water.

Sixty years ago the population of Bombay was only about

250,000 persons. In the year 1850 it had grown to 556,000. In 1857 it was estimated at 700,000, and by the last census of 1891 it had reached a total, including the city, island, and cantonments, of 821,764. Before the construction of the first water-supply reservoir, viz. that designated the 'Vehar Lake' in 1857-58, the population of the city was mainly dependent for nine months of the year on the rainfall caught during the monsoon in old quarry and other shallow excavations which, being situated in the midst of a peculiarly dense and dirty population, became so thoroughly contaminated, especially during the hot season, that a charge 'for clearing dead fish from the tanks' was an item of annual recurrence in the accounts of the town authorities. An almost constant prevalence of malignant fevers and cholera epidemics, and an abnormal death-rate, checking the natural growth of the population, was the inevitable consequence of the extreme pollution of the only drinking-water the lower classes could then obtain.

The deficiency and impurity of the available water became so great as to occasion serious alarm, both to the Government and to the public, and the possible consequences of even a partial failure of the local monsoon rainfall became so appalling, that the most strenuous endeavours were made to search out and discover, within a reasonable distance of the city, some source of water-supply capable of meeting the growing demands of the population. The Island of Bombay, from seven to nine miles long and three broad, is composed of a low tract of clayey land, situated for the most part below the level of the highest tides; lying in a hollow between two low ranges of basalt hills which run nearly parallel with each other at a distance of about two miles apart. At the upper and lower extremities of the island these parallel ranges of hills are united by raised sandy beaches, elevated but a few feet above the level of the sea, and formerly liable to be breached by the waves; a large portion of the present area of the island was consequently at one time a salt-water lagoon, or marsh, until the water was shut out by artificial means, and it was gradually drained. On the north and north-eastern sides, the Island of Bombay is now connected with the adjacent islands of Salsette and Trombay, from which it is only separated by a low mangrove marsh, by several road

causeways, and the railway embankments and bridges, which unite both it and the intervening island of Salsette with the main continent of India. The annual rainfall of Bombay—precipitated entirely during the monsoon season, from early in June to late in September—varies from 80 to over 100 inches. Under such hydrographical and geological conditions a supply of water from the subsoil was obviously out of the question; the only possible source of supply being the collection and storage of the rainfall somewhere within a reasonable distance of the city. So long ago as the year 1828, a proposal was made by Colonel Sykes, chairman of the late Honourable East India Company, for collecting and impounding the surface drainage of the low ranges of hills immediately adjacent to Bombay. It was also proposed to bring into the town water collected and stored on the high land of the neighbouring island of Trombay. Nothing was, however, done, either at that time or subsequently, when under severe pressure of water famine Colonel Sykes's project was revived in the year 1845. In 1846 Captain Crawford, of the Bombay Engineers, pointed out the capabilities of the Goper valley, in the northern island of Salsette, 'The central plateau of which is drained by the Goper and its affluents, and is bounded and intersected by ranges of hills amongst which the occurrence of favourable sites for the storage of water might be certainly predicted.' The distance of this source of supply, and the inevitable costliness of the works involved were serious considerations, so that it was not until the year 1851, when the population of Bombay had reached nearly 600,000 persons and in the following years, that preliminary and detailed surveys of the course of the Goper, and of other neighbouring sources, firmly established the conclusion that the former valley was not only the nearest, but the then *only* practically possible locality from whence an adequate supply of water could be obtained.

It was found that the high ground on which the river Goper takes its rise afforded several excellent sites for storage reservoirs. On more detailed investigation, the basin of Vehar was shown to be sufficiently capacious for the collection and storage of a supply of water judged to be amply sufficient for some years to come. The quantity then considered necessary for the

wants of Bombay was estimated at a daily consumption of nearly eleven million gallons, or 4000 millions annually. At the rate of twenty gallons per head per day this would suffice for a population of 500,000 persons, whereas the population of Bombay was already estimated at nearly 700,000 (1856). It was urged, however, that the proposed supply would be in addition to that derived from existing sources, and that financial considerations were of paramount importance. On the other hand, it was admitted that the extremely rapid rate at which the population was increasing rendered it imperative that the works should be designed with a special view to capabilities of future extension, and that it was most desirable that the reservoir should be made as capacious as possible, in order to contain a reserve sufficient to meet the contingency of a deficient monsoon.

The area draining into the Vehar basin, above the sites proposed for the impounding reservoir embankments, is a little over 6 square miles, capable, however, of being enlarged to over $8\frac{1}{2}$ square miles by the extension of catch-water drains along the western slopes of the boundary hills. It was considered that the mean annual rainfall over the Vehar basin might be safely assumed at 124 inches—or that registered at the sea-level near Tanna—and that deducting $\frac{4}{10}$ of this fall, the remainder, or 74.4 inches, would yield an available annual supply of 6600 millions of gallons from the smaller, and about 9000 millions of gallons from the larger area. The actual storage capacity assigned to the Vehar reservoir was 10,800 million gallons, which, after deduction for evaporation and absorption, would leave an available supply of about 9800 million gallons. As the annual rainfall available for storage on the smaller catchment greatly exceeded the consumption of Bombay, it was calculated that the reservoir would retain a volume of water, as a reserve, nearly equivalent to a two years' supply.

The detailed plans and estimates for the construction of the Vehar reservoir were elaborated between the years 1852-56, and the work of construction was commenced at the end of the latter year. This large artificial lake, when filled to the level of the waste-weir, has a maximum depth of 84 feet. It covers

an area of 1394 acres, or 2.17 square miles, and it stands at 180 feet above the general level of Bombay. The water is impounded by three stone-protected earthen embankments, 42 feet, 49 feet, and 84 feet high respectively. The top width of the highest of these is 24 feet and of the two others 20 feet, the inner slopes in every case being 3 to 1, and the outer $2\frac{1}{2}$ to 1. Each embankment contains in its centre a puddle-wall 10 feet thick at the top, with a batter on each side of 1 in 8. The puddle-wall trenches were excavated from 15 to 25 feet deep, through the surface rock, below all surface springs, and well into the impervious solid basalt below.

The whole of the embankment slopes and top surfaces are covered with a pitching of squared basalt stone twelve inches in thickness, laid on a similar thickness of broken stone. It was considered necessary to cover the top and external slopes in order to protect them from injury by the exceedingly heavy monsoon rainfall of the locality. A waste-weir 358 feet long, having a cross width of 20 feet, and faced with chisel-dressed stone set in cement, was provided for the escape of surplus water. The water is withdrawn from the reservoir through a tower erected near the foot of the inner slope, the upper floor of which is connected with the top of the embankment by a girder foot-bridge in two spans of 85 feet 6 inches. The tower is provided with four inlets, each 41 inches in diameter, placed at vertical intervals of 16 feet. The three inlets not in use are closed by conical plugs, faced with gun-metal, and the fourth or open inlet is surmounted by a wrought-iron straining cage, covered with copper-wire gauze of 30 meshes to the inch, and having a surface area of 54 square feet. The conical plugs and straining cage are each capable of being raised or lowered by a gearing fixed on the top floor of the tower. At the bottom of the tower, or inlet well, and exactly over the orifice of the supply main, a conical seat carries a similar straining cage of copper-wire gauze, having forty meshes to the inch. The water thus passes through two strainers before starting for Bombay.

The supply main, 41 inches in diameter, and $1\frac{1}{4}$ inches thick is passed below the principal embankment, being laid in a level trench excavated in the rock, and filled with concrete, and is,

therefore, unfortunately inaccessible. That portion of the pipe line passing through the puddle trench, is supported on cut stone masonry set in cement. It is coated with 6 inches of puddle, and is then arched over with 4 rings of brickwork; two teak-wood washers being fixed transversely on the pipes to prevent water from creeping between the latter and the puddle.

The sluice-house is situated at the outside foot of the embankment. Here the large 41-inch main bifurcates into two mains, each 32 inches in diameter. One of these branches only was, in the first instance, continued into Bombay; the quantity of water delivered by it being considered sufficient for the requirements of the population at that time. The length of the 32-inch main from the Vehar reservoir to Bombay is nearly 14 miles, and its water was distributed throughout the town by means of sub-mains and service pipes in the usual manner; delivering water under a head of pressure varying from 165 to 180 feet, into the houses, as well as gratuitously to a large proportion of the inhabitants by means of self-closing conduits.¹

The supply from the Vehar reservoir was first delivered into the city of Bombay through the 32-inch main in March 1860. The works had been originally estimated to cost £250,000, but the final capital outlay on the project, including subsequent developments, reached a total sum of £650,000, the ultimate draw-off from the reservoir reaching a maximum of about 12 million gallons per day. No very long time elapsed, however, after the completion of the Vehar scheme, before it became evident that further steps would very shortly be imperative to augment the water-supply, owing to the rapidly increasing trade and population of the city, due in great measure to the opening up of the railways connecting Bombay with the interior of the country.

In the year 1868, survey parties were sent out into the island of Salsette, and into the mainland beyond it, to study and report upon the most favourable sites for reservoirs, as well as the most economical means of collecting, storing, and conveying into the town, an adequate supply of water to meet the well-

¹ Abridged from a descriptive paper on the Vehar Water-supply, contained in vol. xvii. (1857-58) of the *Min. of Proc. of the Institute of Civil Engineers*.

foreseen requirements of the near future. In the following year a special commission appointed by Government, considered, but rejected as too ambitious, a proposal for a huge artificial lake at Shivla, with an earthen dam 96 feet high, and a steel main 56 miles long. The commission, however, recommended the construction of a smaller reservoir at Tulsi, situated near the celebrated cave temples of Kennery in the northern part of the island of Salsette. Nothing was, however, definitely decided upon by the town authorities at this time, the Tulsi scheme being considered inadequate; but between the years 1870 and 1872 detailed and more exhaustive studies and surveys were carried out, both on the island of Salsette, and on the neighbouring mainland of the Concan, with a view to ascertain the full extent of the resources practically available for an extension of the water-supply adequate for the growing demands of Bombay. These surveys resulted in the first discovery and recommendation of a site for a reservoir of enormous proportions, situated below the spurs of the Western *ghâts*, on the Tansa river; a gigantic work eventually carried out, and only very recently brought to completion.

In the meantime the proposals for the construction of the smaller water-supply reservoir at Tulsi were again considered, and the execution of this work being determined upon, it was put in hand, and was completed in the year 1879. The Tulsi reservoir provided the town with an additional $4\frac{1}{2}$ millions of gallons per day, raising the total daily consumption of water to $16\frac{1}{2}$ million gallons. This was, however, but a mere temporary slaking of the ever-growing thirst of the city. Within $4\frac{1}{2}$ years—that is to say, as early as the 10th August 1883, a motion was proposed and carried at a meeting of the Municipal Corporation to the effect, that the water-supply available from the Vehar and Tulsi reservoirs being only sufficient for the ordinary domestic wants of the town, apart from its trades, industries, and sewerage system, it was absolutely necessary to provide an additional and permanent supply from a high-level source, which would give the city a continuous supply at full pressure. Whereupon the Municipal Commissioner was called upon to furnish the Corporation with a new scheme for such increased supply.

The exhaustive surveys and studies made in 1870-72, had demonstrated that the construction of the Tansa reservoir scheme would be in the nature of a final settlement of the question of water-supply for Bombay, and this scheme had now come within the range of practical municipal politics. The Municipal Commissioner accordingly recommended its adoption, and that a working survey and detailed estimates should be undertaken. This recommendation was accepted; a sum of £10,000 was voted for preliminary expenses, and on the 19th November 1885, the Corporation passed a resolution according sanction to the construction of the Tansa waterworks, estimated to supply the town with a daily supply of 17 million gallons, at a cost of £1,230,000. The execution of this magnificent project, which ranks amongst the foremost examples of modern engineering undertakings, was commenced in January 1886, and was opened with great ceremony by the Viceroy and Governor-General of India, on the 31st March 1892.

The Tansa reservoir is situated at a distance of about 55 miles from Bombay in a north-westerly direction. It lies on the mainland of the Concan, below the spurs of the Western *ghâts*, in a considerable valley bounded by low hills, distant about 7 miles from the Atgaum station of the Great Indian Peninsula Railway. Here a mighty masonry dam, or solid wall of artificial rock, stretching for nearly 2 miles across the Tansa country, and intercepting two considerable rivers, has been reared, forming behind it an immense deep artificial lake, having a waterspread covering from 6 to 7 square miles, formerly a dense jungle. The catchment area draining into this lake is 52 square miles of hilly country.

The dam, which is built of rubble masonry, is one of the largest in existence, being surpassed only in point of height by two or three large masonry dams in France. It contains no less than 11 millions of cubic feet, or 407,408 cubic yards, of masonry, a quantity sufficient to build a wall 104 miles long 10 feet high and 2 feet thick, or to construct a fortification round the whole island of Bombay, 10 feet high and 6 feet thick. The duct leading the water from the reservoir is 55 miles long, consisting of about 23 miles of masonry conduit, carried at numerous

points on massive aqueducts, 27 miles of iron main 4 feet in internal diameter, about 4 miles of tunnel, and nearly a mile of girder bridges. This gigantic work, which may be regarded as the finest town water-supply scheme in the world, has been made capable of providing a generous supply of pure water to a larger population than Bombay is likely to possess for twenty years to come. It was estimated to supply 17 million gallons of water per day, but, as a matter of fact, can easily deliver from 20 to 21 millions. It is calculated that during the hot season of 1892, and subsequent years, the water-supply of Bombay from the Tansa, Vehar, and Tulsi reservoirs (allowing for a reduced draw-off of 9 instead of 12 million gallons from Vehar, which had hitherto been overtaxed) will reach from 30 to 32 million gallons per day, as against 16 millions available in the previous year—or at the rate of, at least, 40 gallons per head of population per day. By laying an additional main from the reservoir, the water-supply from the Tansa lake as constructed, can at any time be increased to 26 million gallons per day. Nor does this exhaust the special provision made for the future. By raising the height of the dam, to an extent duly provided for, the available storage capacity of the reservoir can be increased so as to supply no less than 68 millions of gallons per day.

The estimated cost of the Tansa water-supply project was £1,230,000. It has actually cost £1,500,000, or a crore and a half of rupees, and takes rank as the most costly municipal work carried out in India up to the present time. On the occasion of the formal opening of the water-works, in the presence of an immense concourse of people on the 31st March 1892, the Viceroy and Governor-General of India is reported to have remarked as follows: 'The benefits of such a supply of water to your great and growing population cannot be overrated. It is on record that, 200 years ago, a traveller who visited the island of Bombay declared not only that provisions were scarce and bad, but that the unhealthiness of the water bore a just proportion to the scarcity and meanness of the diet. It is a pity that we cannot recall that traveller to life, and show him your splendid markets, which a predecessor of mine has declared to be finer than those of any great city of Europe,

and the works which we are to open this evening. There will not be a resident in the city, from His Excellency at Malabar Point, to the dweller in the humblest native bazaar—who will not be a gainer by what you have done. There is no result of European civilisation in India, which I look upon with more unmixed satisfaction than I do upon the great water-works, which so many of our principal cities have lately called into existence. I never look at a stand pipe in a dusty street without feeling that here at least is something which our civilisation has done for the country, and which has conferred upon it an absolutely unmixed advantage. . . . I am glad to congratulate your municipality on the readiness with which, as the representatives of the ratepayers of Bombay, they have faced the responsibilities of this great enterprise. There is, however, a special reason for which it is satisfactory to be able to dwell on the success which has attended municipal self-government here. Bombay may claim for itself the credit of having been the city which was the first to introduce into India a true measure of municipal self-government, and when the history of municipal institutions in this country comes to be written, the Bombay Council Act of 1872, which for the first time gave to your citizens a corporation, elected in great measure by the ratepayers of the city, will certainly be regarded as the most important departure of this kind which has yet taken place in India. The completion of these works proves that the municipal resolution of 1872 gave to your city something more than an ingenious paper constitution. It gave to it a civic body capable of seeing the necessity of such a project as this, capable of undertaking it, capable of carrying it through under the supervision of its own officers.'

As an evidence of the firmness and stability of the financial credit of the corporation and city of Bombay, it may be stated that in the year 1885, when the Tansa water-works scheme was determined on, the municipality was in debt to the extent of £1,335,515, and its paper stood at 100½. In 1892 the debt, after the completion and payment for the works, stood at £3,565,255, and its paper at nearly 114.

Sholapur Waterworks, 1879 to 1881.

The water-works carried out for the supply of Sholapur, the chief town of the Sholapur district of the Bombay Presidency, is an example of a small but very valuable and effective scheme. These water-works were commenced in the year 1879, and were practically completed early in 1881. The population of the town, as given by the census of the latter year, consisted of 59,437 inhabitants, of which 57,000 were reckoned as permanent residents within the area commanded by the water-supply.

At a distance of about 4 miles north of Sholapur is situated the 'Ekruk' tank, one of the largest of the reservoirs undertaken by the Government for irrigation purposes. This reservoir—the details of which are given under head Irrigation works in the Bombay Presidency,¹ was commenced in the year 1866, and in the year 1871 the low-level canal—one of the principal irrigation canals fed by it—was brought into operation. This low-level canal passes round the town of Sholapur at a distance varying from a $\frac{1}{2}$ to 1 mile from the outskirts, or from $1\frac{1}{2}$ to 2 miles from its centre. Before the date of the opening of the Ekruk low-level canal, the town population suffered greatly from the insufficiency and impurity of the water-supply, then derived solely from local wells and surface tanks, supplied by a very precarious and uncertain rainfall; but the opening of the canal greatly improved this state of matters, notwithstanding its inconvenient distance from the larger portion of the town. The beneficial effects were especially marked in the year 1876, when the total rainfall fell as low as $10\frac{1}{2}$ inches. The Sanitary Commissioner to the Government of Bombay, in his report for that year, remarked as follows:—'I may incidentally mention that had the Ekruk tank and canal not been in existence, the town of Sholapur must during this year perforce have been deserted, as all the ordinary supply of water had dried up, and the people were entirely dependent on the canal.'

From so far back as the year 1868, several proposals for a permanent water-supply for the town had been made; the

¹ *Vide* p. 208.

water to be taken either direct from the Ekruk reservoir, or from the canals derived from it, but beyond studies and estimates nothing was practically done until the year 1878, when the municipality decided to adopt the scheme since carried out and when the necessary funds were easily raised in the open market by a loan duly authorised by Government.

The existing water-supply scheme at Sholapur is essentially as follows:—The water is drawn from the Ekruk low-level canal, at a site situated in the fifth mile of its course, about a mile and a half from the centre of the town, and is passed at once into a settling tank, from which it is pumped direct through a rising main into two service reservoirs placed at different levels within the town, from which, under a constant service, the distribution is effected by gravitation. The population estimate, according to a return corrected up to 1872, was taken at 50,666 persons, and a daily allowance of 5 gallons per head was assumed—or a minimum daily demand of 253,330 gallons. This low rate of consumption was estimated under the consideration that the numerous wells and small tanks in and about the town would be still available for washing purposes. In the year 1881 the actual quantity of water consumed, which admitted of simple and accurate measurement, was recorded, and it was found that the actual average daily consumption per head, for the eight months May to December, was 4.52 gallons only, and the average daily consumption in each month was 257,005 gallons; the largest daily consumption being 5.14 gallons per head during the month of May.

It is certain, however, that during the first year, the population would draw more largely from the older sources of supply than they would do later, when the convenience and greater purity of the new water was more fully appreciated, and it would not in India, in ordinary cases, be sufficient to estimate the average consumption, even of a small uncommercial town, at so low a rate, without special provision being made for its augmentation during the hot months, or in times of drought and emergency. This, however, was done in the case of Sholapur. The water is taken from a permanent canal, derived from a large reservoir, in which the supply—so far as that town is concerned—is practically unlimited, and the pumping power—to provide

primarily against breakdown—was furnished in duplicate, so that a doubly increased consumption of water could on necessity be provided for.

Close to the Ekruk low-level canal, from which the water is drawn through a 9-inch pipe, fitted with a sluice-valve for regulating the supply, and a meter for measuring the flow—a settling tank is constructed. This tank is square in plan, measuring 146 feet on each side at the bottom level, and 148 feet on the top. The available depth of water, after allowing a space of $9\frac{1}{2}$ inches deep for deposit, is 9.60 feet. The tank holds 1,292,705 gallons, or rather over five days' estimated consumption. It is constructed entirely in excavation, carried through gravels and soft rock; the sides of the excavation being protected by retaining-walls of rubble masonry, carrying a parapet. The floor is formed of concrete, guttered to facilitate the cleaning and scouring out of the deposit, which is effected through a scouring-pipe fitted with a sluice-valve. From this settling tank the water is pumped by two direct-acting 'special' steam pumps, capable of being worked singly or in combination. Each pump is capable of raising 200,000 gallons in ten hours, and delivering the same to a height of 160 feet (including head due to friction in pipes), through a rising main, 10 inches in diameter, and 8500 feet long, when working at thirty-three strokes a minute. The water is pumped into a high service-reservoir situated on the highest ground in Sholapur, distant 8125 feet from the pumping station. This reservoir is circular, having a floor diameter of 95 feet, and a total capacity of 96,399 cubic feet; the available capacity being 88,193 cubic feet, or 549,442 gallons, which is equivalent to rather over two days of the estimated daily demand.

Close to the Bijapur, or northern gate of the town, a branch from the 10-inch rising main is taken off to a low-service reservoir, which is situated at a distant of 5800 feet from the engine and pump-house. This reservoir, which supplies the town, with the exception of the higher portions and suburbs, commanded by the high service, is similar in details of construction to the high-service reservoir. It is circular in plan, having a central pillar 10 feet in diameter at base, and eight arched radial walls, which support a roof of T irons and corrugated iron sheets. The thrust of the arches in the radial walls are

taken by buttresses projecting from the external wall, which also serve to strengthen the latter.

The diameter of the low-service reservoir is 82 feet on the floor, and $85\frac{1}{2}$ feet at full supply-level, which is 12 feet above the lowest bottom. The external wall is 10 feet high; is constructed of uncoursed rubble masonry, faced with coursed work on the outside face; it is 6 feet thick at the bottom, and 2 feet 6 inches at the top, the interior face having a batter or slope of 1 in 12, and the external face a curve of 17 feet radius. The floor of the reservoir is situated at a height of $58\frac{1}{2}$ feet above the floor of the settling tank, and its total capacity is 71,224 cubic feet, of which 68,711 cubic feet, or 1.69 days of the estimated daily demand is available.

The supply pipe, 10 inches in diameter, discharges over the reservoir wall into a small chamber, from which the water passes over a ledge or weir into a second chamber, and thence escapes through an opening into the main reservoir. The main 10-inch distribution pipe, and a cleaning or scouring pipe—the latter carrying a vertical overflow—are each provided with sluice-valves situated inside the reservoir, and worked from above. They are both carried through the concrete foundation below the main enclosing wall. Sluice-valves are fixed on the main, so as to admit of a supply from either reservoir being cut off when water is being pumped into the other. Frequent air-valves, along the line of piping, and a reflux-valve, situated close to the northern gate of the town; about 3000 feet from the pumping station, are also provided. Upwards of 33,000 lineal feet, or about $6\frac{1}{4}$ miles of sub-mains and service-pipes, carry the water over all the principal parts of the town and suburbs, and are furnished with the necessary sluice-valves, so as to render each part of the distribution independent. The water is delivered to the inhabitants by means of numerous stand and pipe-posts, fitted with convenient push-cocks. The pipe-posts are each fitted with twelve taps, and are only placed in localities where the population is most dense, in order that a number of people may be able to draw water at the same time.

The Sholapur Waterworks were opened with some ceremony by the Governor of Bombay on the 22nd July 1881. The total initial cost of the project as completed was £21,718, or £161 short of the original estimate.

CHAPTER III

MADRAS AND NAGPUR

Madras Waterworks—The Seven Wells supply—The City Waterworks—Outline of projects—The Red Hills reservoir and feeders—Details of Madras City water-supply—Injuries from floods—Insufficiency of scheme—Opening of works, and improvements suggested—The Nagpur Waterworks—Population of Nagpur—Old sources of water-supply—Native reservoir at Ambajhari—The new project—Details of execution—Puddle trench and wall—Earthworks of new embankment—Waste weir—Arrangements for withdrawing water—The straining and regulating tower—The syphon discharge pipe—The main to the city—Completion of works—Later supplementary supply for higher parts of the town, and for civil station—Principal details and particulars of the new project.

Madras Waterworks, 1866 to 1872.

By the census of the year 1891 the city of Madras and suburbs contains a population of 452,518 persons. It depends for its water supply on two separate and distinct sources,—one being the ‘Seven Wells’ Government Waterworks, supplying Fort St. George, the shipping, and various Government institutions and offices,—the other being the ‘Madras Water-works,’ which is the main supply of the city, and is under municipal control.

The Seven Wells waterworks is a very early project, having been initiated 120 years ago, or in the year 1772, by a Captain Baker, who constructed it under a contract with Government, by which he undertook for a period of seven years to supply, and keep always full, certain reservoirs in the fort, containing sufficient water for 6000 men for four months, at the rate of three quarts per man per day. In the year 1782, the works were purchased by Government for the sum of £10,500. Including this sum the total cost of the Seven Wells water-supply amounted to £42,492. As originally constructed the supply was confined to the garrison of Fort St. George, but it

has since been extended to nearly all the military institutions and buildings in the Presidency town.

The Seven Wells premises or 'compound' is situated about a mile from the sea, and nearly two miles from the Fort and Penitentiary, which are the farthest points to which the supply extends. On these premises there are now 10 wells, each 16 feet in diameter, varying from 23 to 29 feet deep, from which the water is raised by means of 'Picottah' levers into cisterns, and passed through a filter, measuring 48 feet by 30 feet by 6 feet. From the filter the water is again raised into two main cisterns, each holding about 2000 cubic feet, and thence is conveyed by gravitation through lines of cast-iron pipes, varying from 5 to 3½ inches in diameter, to the various points of distribution, the principal of which are the gunpowder factory, clothing and medical store, arrack distillery, bullet factory, Commissary-General's office, Fort St. George, the Ordnance Lines, and Penitentiary. The Seven Wells waterworks discharges over 140,000 gallons a day, or 51½ million gallons a year, at an annual cost of about £1200. During the long period that the Wells have been in operation they have shown no signs of failure, and it is estimated that should a further supply of water be necessary it could easily be augmented to three times its present amount.

The inception of the Madras City Waterworks, under the control of the Municipality, dates as far back as the year 1866. Long before that year, however, the great impurity of the drinking water obtained from the numerous wells scattered all over the town, which formed the only source of supply, was fully recognised. In the year 1855 an extensive irrigation improvement scheme, estimated to cost nearly £434,000, was proposed, and in combination therewith the surplus water from a number of large irrigation tanks or reservoirs was to have been stored in a reservoir situated about 8 miles from the town, and conveyed by an open channel or canal into two basins in Madras, from whence it could be pumped into settling reservoirs and thence passed into the mains for distribution. No action was taken on this proposal, but in the year 1861 a somewhat similar project was brought forward, and an engineer officer was appointed to report on it. without, however, leading to any practical results.

By the year 1863, in accordance with orders from the Madras Government, plans and estimates were elaborated for an improved scheme which had for its object the enlargement of two already large irrigation reservoirs, with a view to increasing their storage capacity for irrigation purposes, as well as to provide the city of Madras, its garrison and public establishments, with an abundant and wholesome supply of water. The Government portion of this scheme was originally estimated to cost £61,176, and provided for the construction of an open channel about $7\frac{1}{2}$ miles long to deliver the water from the nearest of the two reservoirs to a point near Madras, the Municipality being left to provide for and construct the necessary distribution works, estimated to cost £128,000. The general scheme was approved by the Government of India in 1866, and subsequently sanction to a municipal loan for the construction of the distribution works was accorded; the municipality being required to pay for the supply of water delivered from the reservoirs at a fixed rate.

The City Waterworks, as carried out, has for its immediate source a large irrigation reservoir known as the 'Red Hills Tank,' situated about 8 miles north-west of Madras. This reservoir is fed by a channel from the river Kortalayar, which passes through a reserve reservoir called the 'Cholaveram Tank,' before reaching Red Hills. The Kortalayar river itself has its origin in the surplus escape of the huge 'Kaveri Pauk Tank,' which is fed from the river Palar.

At a point on the Kortalayar river, about twenty-two miles from the sea, an *anicut* or weir is constructed, diverting the water into a channel which, after a course of about eight miles, enters the Cholaveram reservoir, and issues at a point two miles distant from its entry by another channel over two and a half miles long, which conveys the water into the Red Hills reservoir. The water for the city supply is drawn from this reservoir through six sluices, three of which are at the lowest level, the remaining three being placed above at 4 feet intervals. The discharge is received into a circular basin 80 feet in diameter, and, falling over a shutter-weir, passes into an open canal 3 feet 6 inches deep, originally calculated to deliver about 24 gallons per head per day for a population of 545,000

persons. This channel passes in a south-easterly direction through cuttings, and on embankments, for a distance of nearly seven miles, with a fall of only 3 inches per mile, and delivers the water into a circular well, 22 feet in diameter, situated near Madras. From this well, or 'masonry shaft,' a 42-inch main-pipe extends towards the city for 4455 feet, and then divides into two mains of 36 and 30 inches respectively. The water is distributed to the population by means of numerous cistern fountains, public standards, and wall taps, as well as into the houses when demanded.

In preparing its distribution scheme, the Municipality decided to adopt the principle of distribution by natural gravitation in order to avoid the permanent expense entailed by the use of steam-power for raising the water, and delivering it under artificial pressure. This economy, however, was only gained by a considerable sacrifice in the quantity of water, the latter having to be drawn off from the Red Hills reservoir at a much higher level than that originally contemplated. The settling tanks originally proposed were also discarded. It had been intended that the open channel should have a permanent current; but owing to the intermittent system of supply which the altered circumstances imposed, the water in the channel was frequently dammed up for long periods of twelve hours at a time, the bed of the channel being thus virtually converted into a settling tank, with a consequent rapid silting up, and noxious growth of vegetation, together with numerous other attendant evils.

The supply portion of the project appears from the commencement to have suffered severely from the effects of floods of unexpected severity, and from original errors in the methods of construction employed in raising the older embankments of the Red Hills and Cholevaram reservoirs, which entailed very heavy outlay to render the new work secure.

Water was first supplied to the city from the Red Hills reservoir in May 1872, but it was soon universally admitted that the supply system was far from satisfactory, and that the works needed considerable remodelling. The principal improvements suggested appear to be, an off-take from the Red Hills reservoir at a lower level; a closed pipe line to Madras

in place of the open channel, together with the much needed pumping and filtering works. A project for placing the water-supply works of Madras on a more satisfactory footing was prepared in the year 1877, but the Municipality was not in a position to vote the necessary funds for the purpose. Up to the year 1881 the cost of the original water-supply scheme, for a consumption of about 325 million cubic feet annually, had amounted to £143,000.

Nagpur Waterworks, 1869 to 1873.

A water-supply scheme possessing many interesting features is that projected and carried out between the years 1869 and 1873 at Nagpur, the capital city of the Central Provinces. Previous to the completion of these waterworks the population of the native city, which then numbered over 80,000 persons, derived their supply of water from a large number of wells sunk in the basaltic and metamorphic rocks on which the town is built. The greater number of these wells yielded a brackish water, so impregnated with salt as to be absolutely unpotable. A considerable additional supply was obtained, first from the 'Jama Talao,' an old native artificial tank adjoining the city, the water from which was greatly polluted by the surface drainage of a thickly inhabited gathering-ground; and second, from an old reservoir situated at Ambajhari, four miles from the city, from which water was conducted by a line of stone piping; but the works in connection with which had in course of time become greatly decayed, and almost useless.

In 1869, after the nearly total failure of the rains of the previous year, the sufferings of the native population of Nagpur, from the scanty and impure nature of the water-supply, had become so great, that energetic measures were taken to ascertain the best means of furnishing the city with an abundant and wholesome supply of water, and, after careful study and examination of the available sources of the neighbourhood, it was eventually decided to remodel and greatly enlarge the old and decayed native reservoir at Ambajhari, and render it capable of supplying a permanent and sufficient quantity of water for the wants of at least the largest portion of the

native city. As this old work is a characteristic example of native water-supply engineering, and is, moreover, one which has been entirely obliterated and lost in the modern scheme which has superseded it, a brief description of its original essential features may be of interest.

The native reservoir at Ambajhari was constructed upwards of a hundred years ago, under the Bhonsla Rajahs of Nagpur. An earthen embankment, faced with a vertical wall of rubble masonry, was reared across the valley of the Nag river (from which the city of Nagpur derives its name), about $\frac{1}{2}$ miles south-west of the city, and near the small village of Ambajhari. This name, meaning the 'spring of the mango grove,' points to the probable existence of a considerable natural spring or springs at this place, which may have led to the choice of the site for the reservoir. The embankment across the Nag valley was 2568 feet long, 20 feet in extreme height, and of an average height of 12 feet. It was 40 to 60 feet wide on the top, with a back slope of $1\frac{1}{2}$ or 2 to 1. The vertical masonry wall on the water-face was built of basalt-stone, with numerous semicircular or octagonal projections, or bastions, of similar character.

Near the deepest portion of the reservoir, situated somewhat towards the northern end of the work, the water was withdrawn through a masonry passage, carried at a low level through the embankment. This masonry passage projected into the reservoir for some distance beyond the line of the face-wall, terminating in a series of steps. On either side of the projection a broad flight of stone steps led down to the water from the summit of the embankment. The discharge of flood-water was provided for by two escape or waste weirs, one 100 feet long, situated at the south end of the embankment, and a smaller one, 28 feet long, at the extreme north end. The reservoir, when filled to the escapes, had a water area of 237 acres, and contained about 80 millions of cubic feet.

The arrangements for regulating the discharge of water were as follows:—On the outer steps terminating the projection into the reservoir of the masonry discharge passage was a series of five holes at different levels, closed by wooden plugs. The highest submerged plug being withdrawn, the water

flowed into a well or chamber (situated in the body of the embankment), the water in which was maintained at a few feet lower than that in the reservoir by opening one or more of a series of seven issue holes; also placed at different levels in this chamber. These holes communicated through a vertical passage with the lower part of a second small well, placed immediately behind the first. From near the bottom of the second well the masonry passage through the main portion of the embankment issued, and by closing this single outlet, water could at any time be cut off from the main passage. The flow of water was further regulated by a third well or chamber, provided with another series of holes and wooden plugs, and an escape, situated on the discharge line, a short distance beyond the foot of the embankment slope. Provision also seems to have been originally made for collecting the water from the springs below the reservoir into this latter well.

The water, when clear of the embankment and regulating chambers, was conveyed to the city through a cut stone pipe, 4 miles in length, formed of a series of sandstone blocks, each 2 or 3 feet long, and 18 inches or more, square, with a hole, 9 inches in diameter, bored through it. The stone blocks were socketed together, the joints being laid with specially prepared mortar, and the whole was enclosed in basalt rubble masonry. Along the course of this pipe-line—which was somewhat irregular—frequent water-towers or cisterns acted as air-valves, and at the same time reduced the head of water, which was allowed to escape through openings, provided with plugs, in the sides of the tower. The water was delivered to the city on the intermittent system—into small cisterns, each provided with holes in the bottom (closed by the usual wooden plugs), which communicated with service-pipes of unglazed earthenware.

The design and construction of this old work exhibited considerable skill in many particulars—especially in the adaptation of the pressure of the water to the strength of the masonry and other piping employed. In 1869 these old constructions were in a very ruinous condition, and owing to heavy leakage on the pipe-line, together with evaporation from the small depth of water retained in the reservoir, the latter occasionally

ran dry during the hot months, so that as a source of supply for the city of Nagpur the works had become practically useless.

Among the reasons which influenced the selection of the old Ambajhari reservoir site as a suitable position for the contemplated new works, were the following: It was found that above the reservoir there was an uncultivated gathering-ground of over $6\frac{1}{2}$ square miles, consisting, for the most part, of only lightly covered trap and other basaltic rocks, thus furnishing a very clean and favourable surface from which to collect the rainfall. The elevation of the site of the old reservoir was moreover sufficient to command all but a comparatively small portion of the native city by means of gravitation works, and admitted in other respects of the construction of a very extensive supply scheme at a moderate outlay.

The new project, elaborated in 1869-70, and subsequently brought to completion in the year 1873, contemplated the following main works, viz.: A puddle-trench excavated through the heart of the old embankment, and cut for several feet into the solid rock beneath, filled in with good retentive puddle to prevent all leakage. An embankment raised about 17 feet higher than the old one, completely burying in its centre the whole of the old work, including the masonry face-wall. A new waste-weir, having an elevation and discharge section, adapted to the altered conditions. Suitable arrangements for withdrawing and controlling the exit of water from the reservoir—now greatly enlarged by the raising of the embankment and escape-weir—and in due connection therewith, a main of cast-iron pipes, about 4 miles long, from the reservoir to the city, together with a certain initial provision of distribution-pipes and self-closing standards, the whole being estimated to cost £36,554.

The execution of these works was commenced in the early part of the cold season of 1870. The centre of the puddle-trench through the old embankment was placed at a distance of $45\frac{1}{2}$ feet from, and approximately parallel with, the old masonry face-wall. This trench was 3099 feet long, with an average depth of 25 feet, and an extreme depth of 36 feet.

It was excavated with side slopes on each side, into which steps were cut, up which the numerous body of labourers employed carried their basket-loads of earth. A portion of the earth excavated was deposited to form a slope of 2 to 1 in front of the old face-wall inside the reservoir, and the remainder was placed so as to form the base of the new outer slope. The solid rock bottom was met with at depths varying from 3 to 14 feet below the natural ground-level, and into this rock the puddle-trench, 5 feet wide, was cut until everywhere a sound and impermeable strata was reached. During the execution of the work the water in the old reservoir stood from 15 to 20 feet above the lowest part of the excavations, and the leakage from the reservoir, or from underground springs, was kept down by steam-pumping. The puddle-wall was built up with clay brought from a distance of about 3 miles; the total quantity transported and utilised being 900,000 cubic feet, or 33,300 cubic yards. The clay was deposited in the trench in thin layers of 6 to 8 inches thick, and was well kneaded and worked up with water, to ensure a perfect consistency throughout the mass. The width of the clay-wall—which was brought up through the entire height of the embankment—was 5 feet both at top and bottom, widening out gradually to a maximum width of about 10 feet on the line of natural ground-level.

The earthwork of the new portion of the embankment was everywhere joined into the old work, by means of stepped trenches deeply cut into the latter, and above the line of the old masonry face-wall a *berm*, or horizontal bench of earthwork, 9 feet 6 inches wide, was constructed, in order to relieve the wall from too severe a pressure. The finished embankment is 7 feet 6 inches wide at the top, finished off with edge curbs of rough stone. The inner or water face—everywhere protected with a layer of hard stone pitching 1 foot thick—is formed of two slopes, of $2\frac{1}{2}$, and 2 to 1 respectively, separated by the horizontal *berm*, or flat, above alluded to; having its surface only a foot above the summit of the old masonry wall. The outer slope was made with an inclination of 2 to 1, and was turfed. The total height of the new embankment was 53 feet above the lowest bottom of the puddle-trench, and 17 feet 4 inches above the top of the old work. The new portion

contains nearly 3 million cubic feet, or 107,400 cubic yards of earthwork.

At the southern end of the work a new waste-weir, 13 feet 4 inches higher in level than that of the old reservoir, was constructed, consisting of a curved wall of masonry 200 feet long, protected by side walls 120 feet in length. The crest of the weir was placed 6 feet below the top of the embankment, and the flood-water flowing over it discharges itself through a rock-cutting, and is led for some distance into the valley below.

The arrangement finally adopted for withdrawing water from the enlarged reservoir was a syphon discharge-pipe, laid over the top of the old embankment and face-wall, but below the level of the new portion of the work. The syphon starts from the bottom of a straining and regulating tower built inside the reservoir, 30 feet distant from the front of the old masonry sluice, and terminates in a valve-house situated at the foot of the outer slope of the embankment. This expedient was employed as the expense of constructing a tunnel outlet in the natural ground round the end of the embankment, owing to the conformation of the valley, would have been great, and it was not considered advisable to interfere with or break through the continuity of the old face-work by carrying a discharge pipe through or below it.

The regulating tower, situated at the toe of the new slope inside the reservoir, was founded on the solid rock 12 feet below the old bed, and its internal dimensions are 15 by 6 feet. The outer wall of the tower has three openings at different levels, each 2 feet square, covered by iron sluices or vertically sliding doors, each protected by wire-netting and worked by a screw-gearing placed on the upper floor of the tower. By opening the sluice-door nearest the surface of the water, the latter is admitted into a straining chamber and passes through a set of copper wire-gauze strainers, having 30 meshes to the inch, before reaching the mouth of the syphon discharge-pipe. A valve commanding the entrance to the syphon pipe is also worked from the upper platform of the tower; which latter is covered in overhead, and is connected with the top of the embankment by a light wrought-iron footbridge. The nearest foundation of the water-tower is connected with the masonry

of the old native discharge sluice by a half-arch, so constructed as to carry the ascending portion of the syphon pipe. The latter is 2 feet in diameter and 184 feet long. It is supported throughout its length on masonry blocks and concrete, everywhere founded so as to be secure against any possible subsidence, especially where the syphon pipe is carried through the puddle-trench. The summit or crest of the syphon passes through a charging well, inside which, and connected with the syphon, is a vertical charging pipe 4 inches in diameter, having a funnel mouthpiece, through which the syphon is filled with water, after closing the terminal valves at each extremity of the main pipe. At its outer and lower end the discharge syphon terminates in a valve-house at the foot of the embankment. It is here turned upwards and carries an 8-inch air-valve, by means of which air from the main is prevented from entering the syphon. A branch pipe at right angles to the upturned end of the syphon is furnished with two 15-inch valves—one of which controls the entrance into the main supply-pipe leading to the city; the other opens or closes a short scouring outlet, by means of which the syphon and the bottom of the straining tower can be cleared out, or through which any available surplus storage water can be given out for irrigation below the reservoir.

The lift, or height of the syphon, from the bottom of the lowest sluice-door in the tower to its crest in the charging-well is 14·55 feet, but it is not contemplated to withdraw the water in the reservoir lower than 5 feet above that level, so that the working lift is not more than 9·55 feet, at which level the valves at the outer end of the syphon would be 5·2 feet below the water surface. The main pipe to the city is 13 inches in diameter, and four miles long. In addition, 10,500 yards or six miles of distribution pipes of various sizes were provided. These pipes work at an average head at lowest water of from 30 to 60 feet. The city service is for the most part a public one on the ground level, as common in India; the water being supplied from self-closing standards placed at frequent intervals along the public thoroughfares. Fire-cock air-valves are also provided at every 100 yards.

The new and enlarged Ambajhari reservoir, as completed in

1873, contained 257½ millions of cubic feet of water, with an available storage of 240 millions, calculated to supply the greater portion of the native city of Nagpur with 15 gallons per head per day of 24 hours, during years of minimum rainfall. The completed cost of the project, including all incidental charges and the distribution service as initially contemplated, was approximately £40,000, or at the rate of 9s. 5d. per head of population supplied.

The water-supply scheme as above outlined provided for the wants of the larger portion of the native city of Nagpur; but some of the higher parts of the town, together with the whole of the adjoining civil station, containing a numerous and increasing population, was not commanded by it; still remaining entirely dependent upon subsoil wells. After a severe outbreak of cholera in the year 1887, largely due to the scarcity of water attending the failure of these wells, an extension of the water-supply to those areas situated at too high a level to be supplied by gravitation from the reservoir was determined upon, and a project was drawn up for raising the additional water required for the higher levels by means of pumping.

The calculations undertaken showed that, including a liberal supply for the service of the Bengal-Nagpur Railway Company, the total daily requirements for the proposed high-level extension was 438,400 gallons, or 70,144 cubic feet, equivalent to a supply of 21 millions of cubic feet in 300 days, which was taken as the largest interval of continuous drought. This requirement it was estimated could be met from the existent Ambajhari reservoir; but, to allow for the natural increase of consumption in the city, and still to retain the lowest water level at the limit originally considered advisable, it was determined to slightly increase the storage capacity of the reservoir by raising the crest of the waste-weir one foot, in order to impound an additional 15 millions of cubic feet of water—a demand which it was shown the drainage area of the reservoir and the average monsoon rainfall could amply meet.

Under the new scheme, which was carried out and opened for service in the year 1890, the level of the original waste-weir was raised 12 inches, and its length was at the same time increased from 200 feet to 457 feet, so as to greatly increase

its discharge under a more limited head. The water for the high service was drawn from the original 13-inch city main, at a point situated $2\frac{1}{2}$ miles from the reservoir. Here a 13-inch branch pipe 735 feet long was connected, to convey the water to a large covered underground cistern, holding about a day and a half's supply. From this cistern it is pumped by powerful steam-pumps into a covered service-reservoir, situated on high ground at a distance of one and a half miles, from whence it is distributed over the new area by gravitation.

The pumping cistern or reservoir measures 150 feet by 40 feet, and provides for a full water depth of 17 feet 3 inches, and an available capacity of 95,000 cubic feet. The pipe or 'rising main,' 8000 feet long, through which the water is pumped to the high service-reservoir is 8 inches in diameter. The high-service reservoir itself is divided into two compartments, each measuring 75 feet by 40 feet by 16 feet. It has an available capacity of 82,500 cubic feet, and a level $70\frac{1}{2}$ feet above the crest of the weir at Ambajhari.

The utilisation of two and a half miles of the original 13-inch main for the new scheme was decided upon, after full consideration, solely from motives of economy; but it having been found that the pressure in the city in the hottest months is inconveniently affected, the municipality have since determined to incur the extra expense of a separate and independent 12-inch main from Ambajhari to the pumping reservoir. Thirteen miles of additional distribution pipes were required for the new high-service extension. These work under a minimum effective head of 13 feet, but an average effective head of 35 feet in the civil station and 24 feet in the city. The extension provides for the daily wants of 44,000 persons, at an estimated outlay of three lakhs of rupees.¹

¹ The data for the above outline of the Nagpur Waterworks, and the subsequent high level extension, is derived from vols. xxxix. and cx. of the *Min. of Proc. of the Institution of Civil Engineers*.

CHAPTER IV

LAHORE AND KARACHI

Lahore Waterworks—Situation of Lahore and population—Aspect of the city—Project for waterworks and drainage—Main features of the water-supply as carried out—Quantity of water—The supply-wells in the bed of the Ravi—The pumping-well—The service-reservoir—Particulars of the distribution—Failure of the service-reservoir—Intermediate arrangements—Rates charged for water—Karachi Waterworks—Peculiarity of scheme—Necessity for improved water-supply—Proposals made—Project as finally decided on—The Malir river—The supply-wells—Excavation of wells without pumping—The masonry conduit—Pipe and masonry syphons—The valve-house and service-reservoir—The distribution—Cost and success of the Karachi Waterworks.

Lahore Waterworks 1877 to 1881.

LAHORE, the capital of the Panjab, is a very ancient walled city standing on the alluvial plain formed by the Ravi, a river now passing about two miles to the north of the town, but formerly running close under its walls. Like all ancient cities on the plains of India, the accumulating *débris* of centuries has gradually and irregularly raised its area somewhat above the level of the surrounding country. The highest portion of the elevation in the case of Lahore, and marking probably its oldest seat, consists of a ridge running east and west on its northern side. The city walls form a parallelogram, enclosing a densely populated area of about 461 acres; the suburbs of the town having in recent times rapidly extended themselves outside the walls in every direction except to the northwards.

The total population within the walls, by the census of 1871, was about 92,000, and in the suburbs 36,000, giving a total population of about 128,000 persons. The only source of water-supply for this population was that derived from wells situated within the densely crowded city area, and sunk into a subsoil saturated

with the filth of ages ; yielding a water totally unfit for human consumption. The high and excessive death-rate of Lahore, which for so long naturally attended this condition of the water-supply, at length aroused the action of the authorities, and various proposals for improving it, as well as for the introduction of an efficient system of sewage drainage, were made and discussed, until in the early part of the year 1877 the existing water-supply scheme, which has been in operation since the 30th June 1881, was at length approved, and the municipal loan requisite for its construction was granted by the Government of India. The aspect of the city at this time is found thus officially recorded : 'The streets and lanes in the city of Lahore are peculiar, to say the least of it. If there ever has been an idea of alignment it has been lost sight of long ago, and at the commencement of the works they might nearly all be described as mere passages and water-courses, winding about in a most tortuous fashion, liquid sewage and storm water having been for a long time the only engineers, and sun and rain almost their only sanitary conservators. It is only lately that a cart could get into many of the streets, and where it did get in, the difficulty was to get it out again.'

'It had long been the desire of various civil officers connected with Lahore to ameliorate in some degree this state of matters, and to open out the city and widen some of the streets. It was, however, found impossible to alter their alignment, as they were the natural drainage courses of the city, the roads having their levels well below the sites on which the houses were built. When the water-supply and sewage-drainage schemes were being designed, the widening of some of the principal streets was considered one of the objects to be held in view. There were, however, many difficulties to contend against ; amongst the greatest being the prejudice of the inhabitants against any attempt to alter the existing state of things—by far the most serious, however, was the question of taking up land in the streets. The houses were huddled close together, and each house occupied a very small base area, although built many stories high ; and in any street improvement requiring widening, the great number of tenements to be taken up, and the many inhabitants thus left houseless, became a serious

consideration. The Government and the municipality, however, recognised the fact that the introduction of water-supply and of drainage schemes made it imperative to do something towards widening the streets ; it was in fact compulsory to make a re-alignment where the principal mains had to be laid. To avoid taking up more land than was absolutely necessary it was decided to re-align that side of the street only on which the pipes would be laid, and this was adhered to.'

The main features of the water-supply scheme actually carried out at Lahore are the following : The supply of water is taken from wells sunk, practically speaking, in the bed of the Ravi river, from which it is lifted by pumps into a service reservoir placed at such a height that every part of the city and suburbs are supplied with pure water under a head of pressure ; the distribution being by means of cast-iron mains and service-pipes. On the northern side of Lahore, in the form of a horseshoe, extends the plain of the Ravi. It is well known that the valleys through which the Panjab rivers flow afford a constant and never-failing supply of water. Below their surface run, in fact, clear and sparkling underground rivers, whose flow is continuous and inexhaustible at all seasons, and it is this underground Ravi that has been laid under contribution for the water-supply of Lahore. The northern plain, selected as the most favourable and convenient position for the supply-wells, was practically virgin soil, free from all organic impurities, and as during heavy freshets it is liable to be flooded by the river, there was no probability of the city ever being extended on that side.

The quantity of water required for the daily service of the city population, taken at 130,000, was 1,300,000 gallons, or 208,000 cubic feet, at the fixed rate of 10 gallons per head in twenty-four hours, and from the result of some experimental trials made on the site selected for the wells, it was estimated that a series of six—afterwards reduced to four—connected wells, each 20 feet in internal diameter, sunk to a depth of 32 feet, and placed 300 feet apart, would yield this supply, as well as a surplus quantity ample for the city demands for some time to come ; a supply, moreover, which could at any time be augmented by sinking additional wells.

As the current of the underground river flows from east to west, the wells are placed in a straight line north and south, at right angles to the stream. On the up-stream side of the line of supply-wells two rows of 16-inch pipes, 3 feet 6 inches apart—placed at a depth below the lowest limit of pumping—connects the wells with each other, and with the sump, or pump-well, by means of 12-inch connecting pipes; joined and controlled by valves in such a manner that the supply of water from each can be carried into the pumping-well independently. To the connecting pipe inside each supply-well is fixed a vertical pipe, also 12 inches in diameter, provided with horizontal arms for drawing off the water, at either 10 or 20 feet below the normal water level. On each of these arms a valve is fitted, worked from above by a screw-down rod, by means of which the water can be either cut off from one or other of the arms, or the supply from any one well can be completely cut off. The connecting pipes are carried through a continuous line of trench-wells, each 7 feet square, running parallel with the line of supply-wells, all being provided with large openings through their sides for the passage of the pipes, which are supported on the well curbs. The cavities at the bottom of the trench-wells are filled up with broken bricks, so that the pipes rest on a firm foundation throughout. After the pipes were laid the masonry of the small wells was brought up to a level of 3 feet above the water-line, and the whole line was then arched over and filled in to ground level; manhole doors being left at 50 feet intervals to facilitate future inspection of the piping.

The sump, or pumping-well, is 15 feet in internal diameter, and is situated on the line of supply-pipes at a distance of 65 feet from the first supply-well. It is completely closed at the bottom with solid blocks of masonry, the joints of which are filled in with hard-wood wedges to prevent the entry of water, which might disturb the sandy soil when the pumps are at work. The bottom of the well is 32 feet below water-level, and the pumping is effected by two horizontal condensing engines with double acting bucket and plunger pumps, each capable of raising 1,300,000 gallons of water in twelve hours to a height of 150 lineal feet, and forcing this quantity through a 20-inch main, 3200 feet in length, when working at forty revolutions a minute.

The service-reservoir, 265 feet in length and 150 feet in width, divided into two compartments by a division wall, was constructed on a site selected on the highest part of the city ridge. Its capacity was calculated for a two days' supply, when full to a depth of 11 feet 6 inches. The ridge within the city on which the reservoir is erected, was the only site sufficiently high to allow the water to be delivered under an average head of about 40 feet of pressure throughout the main distribution. There were, however, some elevated portions of the same ridge where the pressure would only admit of a street service, but as it was deemed desirable that the houses in the highest parts should be supplied, as well as an efficient fire-service, three stand-pipes were erected on the north side of the reservoir, of sufficient height, when water was passed over them, to effect the object desired. This high service is capable of exerting a pressure on the mains and service pipes of 50 feet over the highest water-level in the reservoir, or a total pressure of about 90 feet.

The city area supplied was divided into five separate districts, each having its own main, and system of street service-piping, supplied directly from the reservoir, or high service stand-pipes. The service pipes of each district are, however, connected with the main pipe of the adjoining system, so that in case of a stoppage of one main, the pipes can be supplied from another by opening the necessary connections and closing the stopped main. By this means also the water can be confined to any one or more districts; it can be made to circulate freely throughout the entire system, and thereby establish a better equilibrium of pressure, or in case of any abnormal demand in one district, the adjoining mains can give it an auxiliary supply. Altogether nearly twenty-two miles of main and service piping, varying from 20 inches to 3 inches in diameter were initially provided. Provision is everywhere made for direct communication between the street service pipes and the houses, into which water is delivered whenever desired, in preference to drawing the supply from the street stand-posts, of which 300 were originally erected at convenient intervals. One hundred and eighty street fire-hydrants of 2 inches diameter, were also furnished at convenient sites, so as

to be available in cases of fire, as well as for sanitary purposes. The pipe laying was a work of great difficulty, requiring great care, owing to the narrow and tortuous nature of the streets and lanes, and to the bad soil.

Soon after the first opening of the Lahore Waterworks a settlement in the foundations of the service-reservoir occurred, which compelled its disuse until a new reservoir could be built. In the interval, arrangements were made to carry on an intermittent supply system by making use of the high service stand-pipes; provision being made for the overflow by a special outlet, instead of allowing it to pass through the reservoir. In order to avoid the needless expense of pumping the whole water to an unnecessary elevation, the height of the stand pipes, was, as a temporary measure, reduced to nearly the same level as the ordinary pressure of the disabled reservoir. The new service-reservoir on the original site was completed in the year 1883, and has been entirely successful. It consists of four large iron tanks, each 60 feet by 60 feet by 12 feet containing a supply of a million gallons.

The rates charged by the municipality are 8 annas per 1000 gallons when supplied retail, and 6 annas for manufacturing purposes. It is satisfactory to find it recorded that 'any caste prejudices against using the water has long since broken down, and the people fully appreciate the pure water, with as genuine a feeling of satisfaction as those who are considered more advanced in civilisation.' The total initial cost of the Lahore water-supply project, as above sketched, is given as rupees 15,00,935 or £150,093 at par.

Karachi Waterworks, 1880 to 1884.

The peculiarity of a gravitation scheme of water-supply derived directly, and without intermediate pumping from wells, is met with in the case of the sea-coast town of Karachi, the capital of the Province of Scinde. The works in connection with this scheme were commenced early in the year 1880, and were brought to completion in 1884, having been partially opened in 1883. The necessity, on sanitary grounds, for an improved water-supply for the rapidly rising commercial town

of Karachi, had already for many years been admitted, and several proposals for its improvement had been made and rejected on various grounds, when, in the year 1868, careful experimental trials were made to ascertain by means of pumping: at what level 1200 gallons of water per minute could be obtained from the underground flow of the Malir river. The experiments made proved that the above quantity of water—which was that necessary to supply the town of Karachi with twenty-two gallons per head per day for a population of 80,000 inhabitants—could easily be obtained at no great depth. A project was accordingly elaborated for supplying the town with water to be derived from wells sunk on the banks of the Malir river, and carried across the intervening country by means of a main of cast-iron pipes, to a reservoir to be built near the town. The total estimated cost of this project was £152,000. Owing, however, to a great rise in the price of iron in England occurring before the works were put in hand, the scheme was indefinitely postponed, the money at the command of the municipality not being sufficient to meet the increased outlay.

In the year 1873, the question of the water-supply was again taken up, and in order to reduce its initial cost—the price of iron being still high—it was proposed, in view of the cheapness and excellence of the stone available in the neighbourhood of Karachi, to substitute a masonry conduit, built underground, in place of a cast-iron main. A new scheme, embodying this substitution, estimated to cost £120,000, was prepared, but the available means of the municipality—without recourse to a loan, which was not desired—being limited to about £85,000, the cost of the project was further reduced to that amount, by a curtailment of the distribution system. On the completion of the reduced scheme, however, the public appreciation of the pure water, and the demand for it at remunerative rates was so great, that the municipality at once applied for, and were accorded permission to raise a loan for the execution of the curtailed portion of the project, which was then carried out with little or no delay.

The Malir river, which rises in the mountainous district between Karachi and Sehwen, drains a sparsely populated

country about 600 square miles in extent. At the point selected for the supply-wells, it is about 2100 feet wide, and when in flood it discharges a vast body of water. For the greater part of the year, however, the bed of the river is perfectly dry, but water is everywhere to be found by digging a few feet below the surface of the sand. About 1000 feet from the near bank of the Malir, which is well defined, two wells, each 40 feet in internal diameter, 36 feet deep and 400 feet apart, were sunk. These wells supply by gravity, through a conduit over 18 miles in length, and principally constructed in masonry, a service-reservoir situated close to the town of Karachi. From the service-reservoir and inlet-well in connection with it, water is delivered by gravitation to all parts of the town, port, civil lines, and military cantonment, through cast-iron pipes; numerous public street services being also established. The two supply-wells were excavated to their full depth of 36 feet without the aid of pumps of any kind. About 3 miles from the Malir, the line of conduit crosses a smaller river called the Thudda, and as the bed of this stream, at the point of crossing was at a lower level than the bottom of the wells, the excavation of the trench for the conduit was commenced at this point, and carried onwards to the site of the wells. By this means all the water found, both in the conduit-trench and the wells, was drained off into the Thudda. An enormous extra expense in pumping was saved by the possibility of this expedient, as it was found that for a period extending over many months, the volume of water drained through the conduit-trench excavation amounted to two million gallons of water per day. As soon as the excavation of the conduit-trench and the two wells was completed, the latter were 'steined' or lined with masonry 3 feet thick, consisting of large blocks of stone, laid dry; the joints being everywhere left rough and open, so as freely to admit water. Above water-level the lining-wall is set in mortar, and is carried to a height of 23 feet above ground-level; the work being finished off with an ashlar cornice and coping.

In the centre of each well—on a secure foundation—is erected a cast-iron valve-shaft, 4 feet in diameter, provided with three sliding sluice-doors, worked from an upper platform, through which water is admitted into the shaft at different

levels. Near the bottom of the valve-shaft a 24-inch main pipe, fitted with a regulating valve (also worked from the upper platform) issues, and connects the valve-shaft with a junction tank or chamber 22 feet deep, and 10 feet in diameter, situated nearly a mile from the Malir wells. At this junction tank the masonry conduit commences.

The masonry conduit, including the length of several cast-iron pipe-syphons, constructed to pass the water under the natural streams intersected in its alignment, is over $17\frac{1}{2}$ miles long. For the first $10\frac{1}{2}$ miles of its course from the junction tank its internal section is 3 feet 3 inches wide and 3 feet high, with a fall of 2 feet per mile; for the remaining part of the length the internal section is 2 feet 6 inches wide and 2 feet 3 inches high, the fall varying from 3.9 to 9 feet per mile. From the level of the bottom of the 24-inch pipe issuing from the valve-shaft in the supply-well, to the bottom of the masonry conduit at the first point where it terminates in the inlet-well, adjoining the service reservoir, the total vertical fall is 69.02 feet. The conduit is built of rubble masonry coated on the inside with Portland cement plaster half an inch thick. The top is slabbed over with stone 8 inches in thickness, over which is laid a covering of concrete, any remaining depth of the trench being filled in with soil.

Along the course of the conduit, the water is passed under five intervening *nalas* or streams, by three pipe and two masonry syphons, the largest being the pipe-syphon carried under the Thudda river. Ventilating shafts, 5 feet by $2\frac{1}{2}$ feet in section, are provided at intervals of $\frac{1}{2}$ a mile to 1 mile apart, foot-irons being fixed in each shaft to enable an inspection of the conduit to be made when desired. The water is discharged by the masonry conduit into an inlet-well, 20 feet in diameter, which, together with the valve-house, is built adjoining the service-reservoir, and acts as a second chamber to it. The walls of the inlet-well are carried up to a height of 24 feet above ground level, and carry a concrete roof and an ashlar battlemented cornice. The distributing or service-reservoir is 200 feet long and 150 feet wide, and contains a maximum depth of water of 10 feet 9 inches. The total capacity is nearly 2 million gallons. The reservoir is built in excavation, and is

roofed over with rubble masonry, concrete, and earth, supported on lines of archwork. A partition wall runs for nearly the whole length of the reservoir, and separates the inlet-pipe from the main delivery-pipe, thus ensuring a complete circulation of the water. The water-level in the reservoir is 55 feet above the average ground floor-level of the houses in the native town.

A cast-iron inlet-pipe, 24 inches in diameter, controlled by a valve at the well-end, connects the inlet-well with the reservoir, where it terminates in a bell mouth. The main delivery-pipe, also 24 inches in diameter, has two branches, leading, one from the inlet-well, and one from the reservoir. These are fitted near each inner end, with 24-inch sluice-valves, so that water can be supplied to the town direct, either from the inlet-well or from the reservoir, as occasion may require. A cleansing or scouring-pipe, which communicates with a built drain, is laid 2 feet below the level of the main delivery-pipe, and, like it, has one branch from the well and one from the reservoir, ending in each case with a sluice-valve.

The distribution throughout the town, port, civil lines and military cantonment of Karachi, is effected through main and service-pipes of cast-iron, varying from 24 inches to 2½ inches in diameter, having an aggregate original length of nearly 32 miles (now probably much more). A 5-inch pipe was laid down for the special supply of the main railway station, and a 6-inch pipe was carried to Keamari, a distance of over 5 miles from the civil lines, for the supply of the shipping and engine-house at Merewether pier. In the town, hydrants are placed, at intervals of 200 feet in the principal thoroughfares, to facilitate street-watering, and in other streets at 400 feet intervals. A neat and ornamental pattern of *bhisti* (i.e. water-carrier) service, delivering water from overhead, as well as a roofed-in public street service, each containing twelve self-acting bib cocks and drinking-trough for cattle, is adopted at Karachi. Of these forty, and twenty-eight, respectively, were originally provided, distributed over the more thickly-populated parts of the town.

The total cost of the Karachi Waterworks, as completed in 1888, amounted to nearly £115,000, and the maximum possible

daily supply of water was 2,500,000 gallons, or 25 gallons per head per day for a population of 100,000 persons. The rates charged for private supplies, after the opening of the works, varied from 5 to 1 Rs. per month, according to size of connection, or from 6 to 10 annas per 1000 gallons by meter. As the water flows by gravity from the supply-wells to the distributing reservoir, there is no expense for pumping; whilst the cost of maintenance, repairs, and establishments is at a minimum. The scheme, therefore, should be a remunerative one to the inhabitants and municipality. The Karachi Water-works were formally opened to the public on the 21st April 1883, but were not fully completed until the year 1884.

CHAPTER V

JUBBULPORE—CONCLUSION

Jubbulpore Waterworks—Scarcity and impurity of the former water-supply—Population of Jubbulpore—Outline history of the scheme—Main features of proposed works—Provision of funds—Preliminary operations—Construction of the masonry dam—Escape weirs—Straining and regulating tower—Pipes, valves, and supply main—Arrangements for future extension of the water-supply—Concluding observations—Other water-supply projects—Water-supply of Lucknow—Artesian well—Failure to obtain water—New scheme—Outline of project—Water-supply of Delhi—Conclusion.

Jubbulpore Waterworks, 1881 to 1884

A VERY thorough and well-considered scheme of water-supply for the provincial city of Jubbulpore, in the Central Provinces, was carried out between the years 1881-1884. This rapidly rising city and important railway centre, previous to the construction of the water-supply works now to be outlined, was dependent on the supply afforded by numerous shallow wells, for the most part sunk in the hard granitic rock with which Jubbulpore abounds. The water derived from these wells, at the best of times, was uncertain in quantity and of indifferent quality; but in years of short rainfall it was extremely scanty and impure. By the census of 1881, the population of the native city and military cantonments of Jubbulpore numbered nearly 63,000. In the city proper, numbering about 47,500 souls, there existed 1058 wells; but less than 200 of these furnished water suitable for drinking purposes, and even in years of average rainfall a large proportion of the latter ran dry.

In the year 1874, the scarcity of water was so great that it sold in the city at from 2 to 4 annas per *ghurra* (a vessel holding about 2 gallons); and this is stated to have been a customary experience in the hot season, except after years of heavy rainfall. A large number of the wells in the city were

also contaminated by the neighbourhood of small tanks fed by the surface-drainage of the streets; for many years, therefore, an improved water-supply for Jubbulpore was a most urgent want.

The history of the scheme carried out in the years 1881-84 may be shortly told. As far back as 1872, a special engineer was deputed by Government to examine and report upon the available sites—within a reasonable distance of the city—offering facilities for the storage of water. A number of sites were at that time reported on; but all proved in one way or another unsuitable. In the following year, the Government engineer then attached to the Jubbulpore Division, was instructed to make proposals for a water-supply scheme, and he shortly afterwards submitted sketches of two projects to supply the city by gravitation.

Of these proposals, one was rejected owing to the very limited head of water available. The remaining scheme, which formed the basis of that afterwards carried out, was to construct a reservoir on the Khandari nulla, at a favourable site situated about 7 miles from the city, and convey the water the whole distance by means of pipes. The head of water in this scheme was sufficient to command at good pressure all parts of the native city and cantonments; but its estimated cost amounted to five lakhs of Rs., or £50,000 nominal, and the finances of the municipality would not admit of so heavy an outlay. The scheme was, therefore, in abeyance for some years. The privations undergone by the city population in consequence of the deficient rainfall of 1878 were so great, that the improved water-supply scheme, and especially the means by which the necessary money could be raised, was earnestly taken up by the local civil officers, with the result that arrangements were shortly afterwards entered into with a local firm of wealthy bankers, through whom the funds were obtained on fairly easy terms. It is owing to the public spirit and liberality of this firm that Jubbulpore is in great measure indebted for the excellent water-supply which it has now enjoyed for more than a decade.

The question of funds having been satisfactorily settled, the necessary surveys and studies for the proposed water-works

were commenced towards the end of the year 1879, and a detailed project was elaborated. The new census of the early part of the year 1881, however, showed so considerable an increase of population that a revision of the project as originally prepared became necessary, and the details of an enlarged scheme, providing for the supply of 100,000 persons, were rapidly drawn up. This scheme was sanctioned by Government towards the end of the same year. Preliminary work had, however, been commenced early in 1881, enabling the construction of the reservoir dam to be put in hand before the close of the year. From this time operations were carried on vigorously up to the beginning of the year 1883, when the works were formally opened, with some ceremony, by the Chief Commissioner of the Central Provinces on the 26th February, although it was not until about a year later that the full scheme was entirely completed.

The preliminary operations, commenced in April 1881, comprised excavations for the foundations of the masonry dam of the intended reservoir; the construction of service-roads, and accommodation for the supervising establishment and for the work-people. Owing to the great scarcity of water during the hot season, provision was made for the temporary storage of a certain supply by the construction of a small tank within the reservoir area. The important matter of conservancy was also attended to, and so efficient were the arrangements made to preserve the coolie lines in good sanitary condition, that notwithstanding the small army of labourers—numbering nearly 3000 persons, which was collected at the site—no epidemic occurred during the entire progress of the works. The quarrying of the necessary stone for the main works, and the provision of the other various materials, as well as plant, required, was rapidly pushed forward, so that by the month of December 1881 the construction of the masonry dam could be commenced. The site for the dam was chosen at a point on the Khandari nulla, situated about 8 miles east of Jubbulpore, at an elevation of 1390 feet above mean sea level. The foundation material met with along the whole alignment of the dam was of a most favourable character; a good description of basalt rock being everywhere found at moderate depths.

Excellent basalt stone for building purposes was also procurable close at hand, so that the site offered great natural advantages for the construction of a masonry dam.

The dam, as constructed, is 1680 feet long, and has a maximum height of $71\frac{1}{2}$ feet above foundations. The maximum thickness is 52 feet at the bottom, and it is everywhere 9 feet thick at the top; the finished structure containing about 1,111,200 cubic feet, or 41,155 cubic yards of rubble masonry, with about 53,000 cubic feet, or 1963 cubic yards, of concrete in foundations. For the whole length of the dam a trench, 3 feet broad and from 3 to 2 feet in depth, below the general level of the foundations, was cut into the rock, and filled with concrete, and wherever faults or fissures were encountered, these were carefully and completely opened out, until firm rock was reached, the void spaces being filled in with concrete. Thus the work was everywhere rooted into a solid and impervious strata, and rendered perfectly secure against all leakage along the line of junction.

A flood-escape, 300 feet long, with cill, or crest, placed at the top level of the stored water, or $61\frac{1}{2}$ feet above the lowest bottom of the reservoir, is provided on the right flank of the dam. Immediately adjoining this—which may be called the normal escape-weir—an additional length of escape, 437 feet long, is placed, having its cill 3 feet higher, whilst in continuation of the latter a further length of 628 feet has the cill level 4 feet above the normal escape; the remaining flank of the dam, 315 feet in length, being 5 feet above the same level. The combined discharging power of the escapes is estimated at 18,450 cubic feet per second: this is equivalent to a rainfall of 5.44 inches in an hour over the whole catchment of $5\frac{1}{2}$ square miles, reaching the escape at a uniform rate in the hour. The water is discharged directly on to the solid basalt rock below the dam, without the intervention of steps, or precautions of any kind; the height of the fall at the normal escape being 23 feet. On the left of this escape, a long guard wall, 326 feet in total length, cuts off the water from access to the lower part of the valley, and a short guard-wall, 80 feet in length, affords protection to the base of the hill on the right flank of the dam. These guard-walls are set well back from the extremities of the

escape, so as to be clear of the falling water. The crest of the escape-weir is protected with ordinary concrete, finished off with 2 inches in thickness of fine Portland cement concrete, instead of with cut stone.

A solidly built masonry water-tower, securely founded on the solid rock, is constructed at a distance of 10 feet from the inner or reservoir face of the masonry dam, and is connected with the top of the dam by a flight of steps carried by an arch. The tower is circular in plan, with an octagonal covered-in chamber at the summit. It has an internal diameter at bottom of 6 feet, and an external diameter throughout of 18 feet. At the top, the internal diameter is 11 feet, and the height of the tower from bottom of foundations to the battlemented summit of the octagonal chamber is $87\frac{1}{2}$ feet. Attached to the outside face of the tower is built a rectangular chamber, 10 feet by 6 in plan, carried up from the floor level (which is 10 feet above the lowest bottom of the reservoir) to a short distance above high-flood level. Into this chamber the water of the reservoir is admitted through a set of wire-gauze strainers, having forty meshes to the inch. There are two sets of these strainers, placed a short distance apart, and fixed in wooden frames, which work in grooves provided in the outer wall of the strained-water chamber, and either set can be hauled up for cleaning or repair, by special tackle fixed above for the purpose. The object of these strainers is to prevent fish or any solid matter from the reservoir entering the pipes.

From the strained-water chamber the water passes into a vertical stand-pipe, fixed inside the water-tower, through three radiating inlet pipes, which are carried through the intervening wall at three different levels. The entrance of water is controlled by valves placed on the inlet-pipes near their junction with the stand-pipe inside the tower, where they are at all times accessible. The outer ends of the inlet-pipes inside the strained-water chamber are turned upwards, and are bell-mouthed, so that whenever repairs to the inside valves are required, the outer ends of the pipes can be closed by a ball of wood, or other stopper of proper diameter. A small pipe, provided with a stop-cock, connects the interior of each inlet-pipe with the outside water, so that when it is desired to remove

the stopper, the pressure can be equalised by the admission of water below it. In addition to the three inlet-pipes, a fourth pipe placed on the bottom floor of the tower, passes from it through the strained-water chamber into the reservoir, terminating in a hinged flap-valve worked from above. The pipe, which is provided with a large valve in the interior of the strained-water chamber (worked also from the top floor), and with an ordinary screw-down valve inside the tower—is called the ‘scouring-pipe,’ and its object is to remove any sediment which may collect in front of, and inside, the strained-water chamber, which is done by the scouring action set up when the valves are opened. The vertical stand-pipe within the tower is connected with the main supply-pipe, and this, together with the scouring-pipe, both pass from the bottom of the tower through a culvert, which is carried underneath the dam. The scouring-pipe ends at a short distance beyond the outer toe of the dam, and the main supply-pipe, 16 inches in diameter, carries the water to the town of Jubbulpore. No arrangements are required for filtering the water, but special precautions are taken to prevent any fouling of the catchment area of the reservoir.

The 16-inch main pipe between the reservoir and the town is provided with frequent stop-valves, and on all the pipe systems air-valves on the summits, and scour-valves in the depressions are fixed. The pipe system conveys water to all parts of the native city, where it is supplied free at all the numerous public standards. A supply is also furnished to the cantonments and civil station, to the central jail, railway station, and other public buildings, as well as to private houses at agreed rates.

The total original cost of the project amounted to 6,91,140 rupees, or £69,114 at par of exchange. It was arranged that the money borrowed for the construction of the works should be repaid in a period of twenty-two years, the yearly instalments to be met from the annual income of the municipality. As actually carried out, the Jubbulpore waterworks are designed to supply 88,423 persons at the rate of 15 gallons per head per day of twenty-four hours, or nearly 59½ millions of cubic feet per annum, which is reckoned, exclusive of the

monsoon, at 280 days. The full capacity of the reservoir up to the level of the normal escape-weir is 203 millions of cubic feet. The thickness of the masonry dam, moreover, has been made so as to allow an extra height of $3\frac{1}{4}$ feet being added whenever it may become necessary to increase the storage capacity. By thus raising the dam, additional water, to the amount of 36 millions of cubic feet, can be stored. In estimating the quantity available for the wants of the city, the bottom 10 feet in depth of the reservoir, which amounts to 548,418 cubic feet, is neglected, this space being left for deposit of silt. A vertical depth of 6 feet, taken on a mean area of the stored water, and amounting to about $47\frac{1}{2}$ million cubic feet, is also allowed for evaporation and absorption. These volumes added to the calculated yearly draw-off from the reservoir of $59\frac{1}{2}$ million cubic feet, amount in all to $107\frac{1}{2}$ millions of cubic feet of water. The available annual flow from the catchment basin of the reservoir, calculated on the lowest observed rainfall during a period of thirty-five years, is taken at $119\frac{1}{2}$ millions of cubic feet, giving a lowest surplus volume of over 12 millions. In average years the quantity available for storage is of course much greater, and it is calculated that the reservoir will practically store sufficient water to meet the requirements of two consecutive seasons without replenishment.

The foregoing examples of town water-supply schemes in India, include among them some of the largest of these undertakings which have been carried out in that country; they have, however, been partly selected from the large total of such works, with a special view to illustrate distinct types and varieties of construction, one or other of which, merely modified in size and detail according to local necessities and conditions, will be almost certainly found repeated in the majority of the remaining works of this class, which of late years have been called into existence by so many municipalities throughout the country, but which it will be unnecessary for the purposes of this volume to further particularise. The gradual loosening of caste prejudices, and the growing public appreciation of the practical benefits and advantages derived from a pure and un-failing water-supply, is now sufficiently apparent, and for many years to come the provision of an adequate supply of whole-

some water to the town populations of India, must everywhere be one of the chief concerns of the urban authorities. That a vast number of such works urgently call for construction does not require assertion, nevertheless no inconsiderable progress has already been made. Besides the particular works which we have arbitrarily selected as illustrative examples, water-supply schemes of considerable importance have been carried out at Burdwan, Dacca, Mhow, Poona and Kirkee, Satara, Jalgaon, Maraj, Pandapur, Thana, Kolapur, Secunderabad, Bangalore, Ootacamund, Wellington, and Hyderabad in Scinde, as well as in the case of a large number of the smaller towns throughout the country.

Projects for the water-supply of most of the larger cities of the North-west Provinces—such as Lucknow, Cawnpore, and Benares, are either in active construction, or under preparation. In the case of Lucknow, the great necessity for introducing a supply of pure drinking-water, has occupied the serious attention of the Government and Municipality for many years. In the year 1881, a special engineer officer was appointed to report on the subject, and after some discussion it was determined to sink an Artesian well. The boring was commenced in the year 1889, and by May of the year 1890 had reached a depth of 1336 feet, at a cost of 93,000 rupees (£9300 at par) without result. The boring was then abandoned, and it was decided to adopt a scheme for the supply of water by pumping, and the formal inauguration of this project—by the Lieutenant-Governor of the North-west Provinces—took place in November 1892.

The main features of the new Lucknow water-supply are, an intake pumping station at a spot above the city on the right bank of Nagaria Nala: a service-reservoir, with settling-tanks, filtering beds, etc., and a distribution of the filtered water through thirty-three miles of iron piping, and 351 standposts in the native city and civil lines, and through nineteen miles of piping and 100 standposts in the military cantonment. The scheme is calculated to supply two million gallons of pure drinking-water per diem to the population of the native city and civil lines, and 200,000 gallons to the cantonment; the estimated capital outlay amounting to 15½ lakhs of rupees

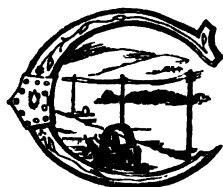
(£155,000) with an annual expenditure of 1,40,000 rupees (£14,000) in interest and cost of maintenance.

On November 4th, 1892, a water-supply scheme for the capital city of Delhi, which was begun in the year 1890, was formally opened for the public service. A reservoir 300 feet long and 150 feet wide has been constructed on the highest part of the famous ridge, close to the city, and a supply of ten gallons per head per day for a population of 173,000 persons in the city, fort, and cantonments has been provided for. In numerous other parts of India water-supply projects are being mooted, or are in active prosecution, and everywhere a practical recognition of the immense value of this special class of public works, so necessary to all real progress in sanitation and civilisation, can be noted as one of the most wholesome and valuable products of the comparatively recent development and progress of municipal institutions in India.

THE ELECTRIC TELEGRAPH IN INDIA

THE ELECTRIC TELEGRAPH

Introductory observations—Electric telegraph apparatus—Varieties of signals—Origin of the electric telegraph—Outline of early history of the invention—Statical electrical apparatus—Dynamic electricity—Deflection of magnetic needle—Wheatstone and Cook—First telegraph line in England—First experimental line in India—Dr. O'Shaughnessy—India a pioneer in electric telegraphy—Telegraphic communication between England and India—Statistical details of modern electric telegraphs in India—Extent of the system—Capital outlay—Revenue—Number of messages—Establishments—Classifications and working—Concluding observations.



COMMUNICATION by means of the electric telegraph is a practically indispensable adjunct to the effectual and safe working of railways, and it was principally, in rapid correspondence with early railway necessities, that this exceedingly useful invention assumed a practical and

workable shape. In every civilised country in the world, the electric telegraph is now so common and familiar an agent, and its use, and numberless public and private conveniences,—altogether apart from railway service—forms so integral a part of all civilised life in modern times, that it has become difficult to realise that its practical use extends only over a single half century. It is unnecessary here to enter into any detailed description of the essential principles of an invention so well known, and in its main features so familiar to every section of the community. It will suffice to say that, proceeding upon the principle that an electro-magnetic current can pass along a conducting wire to a great distance, and can be made to move a magnetic needle at any point of its course—signals—according to any established code, can be readily conveyed,

with almost incredible speed from one end of a wire to another; the signals being sufficiently varied to express letters of the alphabet and the ten numerals, or particular combinations of letters, words, or phrases, so that communications can be made at any one place, and can be read off at another, even although many hundreds of miles apart.

The apparatus of an ordinary aerial electric telegraph consists of a line of conducting wire, or wires, of galvanised iron, suspended on earthenware tubes or 'insulators,' carried on poles which are spaced at certain distances apart from station to station. A single wire will serve for one circle of the electric current; it being found that the earth itself is a conductor, so that if a current pass along a wire above ground, it will return through the earth, provided the wire at each end is carried into the ground, and is attached to a mass of buried metal. Each aerial wire will therefore form a circuit, and carry a distinct set of signals. The electric current is generated and is maintained by the use of galvanic batteries,—of which several forms are employed,—the strength of which requires to be proportionate to the distance between the extreme stations. Many varieties in the kinds of signals, and in the methods by which they are produced, have also from time to time been introduced, and the rate of transmission of messages has been greatly increased.

It is hardly possible to assign to any one person the merit of originating this very valuable invention. Like many others of like importance, it has been perfected by degrees from small beginnings, and a considerable number of scientific men and practical workers are each entitled to their due share of merit. The following brief *résumé* of the early history of the electric telegraph, abbreviated almost entirely from an interesting and valuable paper read before the Institution of Civil Engineers on March 2nd, 1852 (vol. xi. of *Proceedings*), will convey a sufficiently clear idea of the early steps by which the infant electric telegraph arrived at practical maturity.

The electric telegraph has its origin in the combination of three separate yet correlative physical forces, viz., electricity, galvanism, and magnetism. Its history is divisible into two distinct eras; the first era comprises all telegraphs in which

statical electricity (or electricity produced by friction) was the exciting agent, the second era comprehends all telegraphs in which *dynamic* electricity (or electricity produced by chemical affinity) is the acting principle. The employment of magnetism for telegraphic purposes appears to have been thought of as early as the sixteenth century. The Jesuit 'Famianus Strada,' professor of rhetoric at Rome, states in his *Proclusiones Academicæ*, published in the year 1617, that Cardinal Bembo, who died in Rome in 1547, was possessed of a plan for corresponding at long distances by magnetic electricity, *i.e.* by the '*occult sympathy*' of two needles—a notion said to be alluded to by Galileo, and also by Sir Thomas Browne. In 1774 Lesage, at Geneva, constructed an electric telegraph, composed of twenty-four wires, between two rooms. On exciting an electric machine and joining it to one of the wires, the pith ball of an electrometer belonging to it was repelled, and the motion signified a letter of the alphabet. This invention was submitted to Frederic the Great, but was never carried into execution.

In 1787, Lomond improved upon Lesage's plan and reduced his twenty-four wires to one, and various other modifications were made down to the year 1826. Amongst other inventors, about the year 1819 a Mr. Ronald, of Hammersmith, is stated to have applied electricity for the purpose of effecting telegraphic communication, and succeeded so far as to complete a current through eight miles of wire. In 1826 the first registering telegraph is said to have been constructed by Mr. H. G. Dyar, of Long Island, in America. He 'used the decomposing power of a spark, acting upon a fillet of paper moistened and stained with litmus, and moved by hand, or by clockwork. The passage of each spark from a conductor to the paper produced a discoloration, and by the different combinations of marks thus made any signal could be transmitted and registered.' This is the main principle of one of the subsequent printing telegraphs. So far, *statical* or frictional electricity had been the agent employed, but from about the year 1800, when Volta made his celebrated discovery of the pile now bearing his name, the dynamic era of telegraphy may be said to have commenced. The distinguishing characteristic of the new voltaic current was, that it flowed in a continuous stream, instead of in sudden flashes or gushes, and

the minds of inventors were directed into a new channel. In the year 1811, Sömmering—who appears to have made the first electro-dynamic telegraph—described before the Academy of Sciences at Munich his plan of a telegraph, based on employing as the means of indication the decomposition of water by a battery. He used 35 wires, which signified the 25 letters of the alphabet and the ten numerals. Soon afterwards Schweiger suggested several important improvements in Sömmering's device, and proposed a considerable diminution in the number of signals, by employing two batteries of different powers, and reduced the number of wires to two. About the same time also, Professor Coxe, of Philadelphia, devoted much time to the subject, and confidently predicted the future success of the electric telegraph.

In the year 1819 a great impetus was given to the science of electro-magnetism by Professor Oersted, who discovered that when a magnetic needle was placed above or below a wire, and a current was passed through the latter, the needle had a tendency to place itself at right angles to the current. Schweiger soon after improved on this discovery, and found that by taking a silk covered copper wire, and coiling it round several times, the deflections of a magnetic needle suspended about it became extremely sensible. Fechner conceived the idea of adapting Oersted's discovery to telegraphic purposes, but was forestalled by Ampère, who, on the 2d October 1820, read before the Academy of Sciences a description of an electric telegraph on this principle. About this period, Arago observed the magnetic properties of the electric current, and discovered the attractive power of soft iron, while Sturgeon, in 1825, constructed the electro-magnet, and noticed the increased power to be obtained from it. It is stated that Baron de Schilling of St. Petersburg, about the year 1832 or 1833, constructed an electric telegraph consisting of five magnetic needles placed in the centre of coils or multipliers, and set in motion by keys.

The main elements of the electric telegraph were thus complete, nothing was wanted but a master mind, or minds, to combine the discoveries made, and mould them into practical and workable shape. In the annals of the year 1837 four names

stand pre-eminent as claimants for the honour of inventing long-distance telegraphy, viz., Wheatstone, Alexander, Steinheil, and Morse. There appears to be no doubt of Wheatstone's priority, whose discovery was announced in the *Magazine of Useful Science* on 1st March 1837. On the 12th June of the same year, Messrs. Wheatstone and Cooke sealed their first patent 'for improvements in giving signals, and sounding alarms in distant places by means of electric currents transmitted through metallic circuits.' The five needles at first used were soon afterwards reduced to two, and numerous other patents were taken out by the same gentlemen. In July of 1837, M. Steinheil of Munich made an electric telegraph consisting of magnetic needles and coils of very fine insulated copper wire. Signals were obtained by the action of a magneto-electric machine, and he employed the earth to complete the circuit, but the apparatus was of a very complicated nature.

Professor Morse in America (one of the great names of electric telegraphy) also patented in the same year an electro-magnetic registering telegraph, employing only one wire, and consisting of an electro-magnet, the coiled wire of which forms the continuation of the line wire. The armature of this magnet was attached to the end of a small lever carrying a steel point at its opposite extremity. Under this point was a roll of paper set in motion by the aid of wheelwork. When a current was transmitted, the magnet attracted the armature, which caused the pen to press against the paper. This principle has developed into the well-known Morse registering telegraph. If the contact is rapidly made and broken by the finger-key, simple dots only are made on the paper. If the circuit is kept closed for some time, the pen or style traces a line proportionate in length to the time the circuit is closed. If no current is transmitted for some time the paper exposes a blank surface, and the combination of these dots, lines, and blank spaces, forms a symbolic alphabet.

The original system of signals employed by Messrs. Wheatstone and Cooke, consisted of a dial, on which various symbols were depicted, to which the needles—deflected by the current—were made to point. The first telegraphic line in England upon Wheatstone's plan was erected in the year 1839, between

London and Slough, on the Great Western Railway, a distance of 18 miles. In the *Journal of the Asiatic Society of Bengal*, for September 1839, is a very interesting account of Dr. O'Shaughnessy, M.D., F.R.S.—afterwards Sir William Brooke O'Shaughnessy—of a series of results obtained in April and May 1839, on a line of wires 21 miles in length constructed by him in the vicinity of Calcutta, suspended on bamboo poles. In that paper, the one-wire system, the earth circuit, the use of the induction machine, and the traversing of rivers by means of insulated wires, were prominently set forth, and accurately described, and the importance of the introduction of the electric telegraph into India was strongly urged. This appears undoubtedly to have been the first *long* line of telegraph ever constructed in any country. Interesting details relating to the construction of this line of telegraph—which presents an important if not solitary instance, of the practicability on a large scale of a great invention being first demonstrated on Indian soil—will be found in the Preface to *The Electric Telegraph in British India*, by W. B. O'Shaughnessy, M.D., F.R.S., Surgeon, Bengal Army, Chief Superintendent of Telegraphs to the Honble. East India Company, London. Printed by order of the Court of Directors, 1853, from which the following is quoted. 'In April and May 1839, the first *long* line of telegraph ever constructed in any country was erected by the writer of these pages in the vicinity of Calcutta. The line was 21 miles in length, embracing 7000 feet of river circuit. The experiments performed on this line removed all reasonable doubts regarding the practicability of working electric telegraphs through enormous distances, a question then, and for three years later, disputed by high authorities, and regarded generally with contemptuous scepticism. It is never too late to acknowledge an obligation. In the experiments then carried on I received the warm aid and support of Dr. Wallich, then Superintendent of the Botanic Gardens, Calcutta, now Vice-President of the Royal Society, London. One terminus of the line was placed in his house, and all the resources of his establishment and library were held at my disposal. He saw at a glance the marvellous future which these and simultaneous experiments in other countries foretold, and with his high name he

protected the experimentalist from much of the derision which his attempts excited in the community of Calcutta. The experiments having been completed, and the results published,¹ the line was taken down.'

It will thus be seen that India has been a pioneer in electric telegraph development. Dr. William Brooke O'Shaughnessy was afterwards intrusted with the first public lines of telegraph laid down in that country. Under his direction working lines of telegraph were rapidly established over the whole of Hindustan, the first line constructed being one 30 miles in length between Calcutta and Diamond Harbour, opened in December 1851. By the year 1858, all the seats of Government were connected by wires aggregating 3000 to 4000 miles in length, and additional telegraphic lines—at least equal in extent—were in course of construction.

By the year 1872, every important place in India was connected by telegraph, which was also in working order along the whole 5373 miles of railway then opened. Three alternative lines of cable telegraph also connected the great dependency with England. A complete system of telegraphic communication between India and Europe *via* Turkey, 'was planned and carried out by the late Lieut.-Colonel Patrick Stewart of the Bengal Engineers, on the failure, a few days after completion, of the original cable laid from Suez to Bombay in 1857; capital for which had been raised by a company on a twenty-five year guarantee from the Government of India. Colonel Stewart did not, however, survive to see the successful result of his labours. He died at Constantinople in January 1865, from the effects of exposure and over-exertion, a very short time before the lines were formally opened.'²

This Turkish line remained the principal means of telegraphic communication with India until the year 1870, when a new era dawned on the history of Eastern telegraphy. Almost simultaneously with the successful laying of the new Red Sea cable, the Indo-European Telegraph Company's line was opened to Teheran, and was carried to London by way of Tiflis, Warsaw,

¹ *Vide* No. 714-731 of the *Journal of the Asiatic Society of Bengal*, September 1839.

² *Moral and Material Progress Report*, 1873-74.

and Berlin. The Anglo-Persian line from Teheran to Bushire had previously been much improved, and a second wire erected. An alternative cable had also been laid from Bushire to Cape Jask, whence it was continued by land wires to Gwadar, and the Turkish Government, stimulated by the competition, took steps to improve the older service. Between the years 1862 and 1872, the Indian Government expended upwards of £1,150,000 on telegraphic communication with Europe, in addition to a sum of £18,000 annually—or half the guarantee on the original Red Sea cable. By the various routes now open, the English and Indian public enjoy the utmost facilities for the rapid transmission of intelligence from the one country to the other.

The length of inland telegraph lines opened in India under the administration of the Indian Government Telegraph Department, reached, at the end of the year 1891-92, the great total of 38,625 miles, and the capital outlay on these lines—deducting receipts on capital account—reached 521,82,804 rupees, or £5,218,380 at par of exchange. The aggregate number of telegraph offices throughout the country open for the despatch of paid telegrams at the end of the same year, was 1001 departmental and postal offices, and 2245 offices on railways and canals, or 3246 offices in all. Some of the more interesting statistics of the Indian system of electric telegraphs, during the last year for which the information is available, viz., the official year 1891-92, are as follows. The capital expenditure during the year was Rs.19,42,128, of which Rs.15,47,523 were expended on new lines. The working expenses were Rs.48,34,295, whilst the revenue derived from all sources reached a total of Rs.74,30,092, leaving a surplus of Rs.25,95,797, representing a dividend of 4·97 per cent. on the capital account. If, however, the charges for State messages, and ‘news free’ and other *pro forma* revenue be deducted, the net receipts by Government equalled Rs. 10,43,697, representing a net return of 2 per cent. as compared with 0·37 per cent. nine years earlier, and 2·193 per cent. in the maximum year 1889-90. The revenue receipts on account of State messages may, however, be legitimately included in estimating the return on capital outlay—including these, therefore, but deducting the ‘news free,’ and other *pro*

forma revenue, amounting to Rs. 49,807 only, the net receipts were equivalent to 4·85 per cent. on the capital expenditure.

During the year 1891-92, 3,808,998 messages were booked in the Telegraph Offices of the Department, to the value of Rs. 56,82,729. Of these, 3,140,690 were *private* inland or foreign messages (the number of private inland messages alone being 2,627,408). As compared with the previous year, this represents an increase of 262,380 in number, and Rs. 2,42,140 in value, equivalent to 11·09 and 9·87 per cent. respectively. During the last ten years the number of private messages has increased by about 120 per cent., and their value by nearly 100 per cent., and in the same period the number of telegraphic offices has increased 218·7 per cent. These figures show how greatly the use of the telegraph is appreciated, and how rapidly it is extending among the people of India.

At the end of the year 1891-92, the strength of the signalling establishments of the Indian Telegraph Department amounted to 2842 persons, of whom 1550 were departmental officers, 357 were British military signallers, and 935 were postal clerks. Over the enormous total of telegrams transmitted and received during the year, the number of complaints made was 1045, or 0·025 per cent. of the total number of messages. Of these about one-half, or 542, were admitted. The number of telegrams that from various causes could not be delivered amounted to 13,899, equal to 0·308 of the whole number received for transmission, the latter figures illustrating a peculiar phase of Indian civilisation.

Inland telegrams in India are classified under three main heads, viz., 'State,' 'Private,' and 'Press'; and under each of these heads the messages are sub-classified as 'Urgent,' 'Ordinary,' and 'Deferred,' subject to a decreasing scale of charge in the order named. 'Urgent' telegrams take precedence of all others; 'Ordinary' telegrams are forwarded next in order, and 'Deferred' messages are a cheap class of telegram transmitted onwards whenever the wires are clear of urgent and ordinary traffic. The year 1891-92 is the decennial year of the existing tariff with these classes: it will be interesting, therefore, to note in the case of *private* telegrams, the relative popular appreciation of the three kinds of message. During

the ten years, Urgent telegrams have increased in value by 92 per cent., Ordinary telegrams by 59·1 per cent. (sharing the fate of almost every *second* class) and deferred telegrams by 247·3 per cent. The latter cheap form of message, in fact, amply satisfies the needs of all the less important concerns in business and domestic life, and its greater relative use may be expected to steadily continue. In the 'State' and 'Press' class, the percentage of deferred telegrams during the year 1891-92 is even higher than in the case of private messages.

The net additions to the system maintained by the Indian Telegraph Department during the year were 1555 miles of line, 6647 miles of *wire*, and about 2 miles of cable. The total mileage of wire on the 38,625 miles of open lines was 120,159 miles (or sufficient to go more than five times round the circumference of the earth), of which 40,999 miles were in connection with the railway system, 76,819 miles belonged to imperial lines, and only 288 miles were maintained for native States; the remaining mileage being classed under private or provincial lines, or maintained in connection with canal systems.

Among the more important of the electrical improvements recently subject to careful experiment in India, are the use of 'dry' batteries to test their suitability under the varying and trying conditions of the Indian climate. The experiments with this form of battery have been attended with a promising degree of success, its chief merit being that it requires no maintenance. The application and extension of the system of duplex and quadruplex telegraphy over unusually long distances, has also made considerable progress, and the practicability of working duplex *direct* through an iron wire between Calcutta and Bombay, a distance of 1346 miles has been proved.

SEA AND HARBOUR WORKS IN INDIA

SEA AND HARBOUR WORKS

Introductory—Paucity of harbours on Indian coasts—Principal ports—Bombay—Early improvements and development—Karachi harbour—Description of port—Harbour works undertaken—Object in view—Outline of principal works—The Manora breakwater—Details of construction—The port of Karwar—Improvements effected—The open roadstead of Madras—Extract from report of a committee in 1868—Proposals for improvement of the port—Breakwater project—Enclosed harbour scheme adopted—Description and construction of the works—Main features as carried out—Disastrous effects of a cyclonic storm in 1881—Proposals for restoration of the harbour—Committee of eminent harbour engineers—The port of Calcutta—Kidderpore docks—Lighting the coasts of India—Important lighthouses—Coasts of Burma—Alguarda lighthouse—Double Island, Cocos and Khrisna shoal lighthouses—The Great Basses, and Tuticorin lighthouses—The ‘Prongs’ lighthouse, Bombay—Concluding remarks—Summary of aim of volume.



For all the many necessities for the carrying out of a great export and import trade in any country, secure harbours, liberally provided with suitable accessories, whether for the safety and guidance of ocean-going vessels entering or leaving them, or dry and wet docks for cleaning and repairing, or for the rapid and convenient loading and unloading of their cargoes, are as important as improved internal communications; harbours and docks being, in fact, the great transfer stations of outwards and inwards traffic from sea to land carriage, or *vice versâ*, on the road to the final destination of the merchandise. It is necessary, therefore, in this concluding section to indicate the main features of some of the chief sea and harbour works carried out on the coasts of India, although the space available will only admit a brief reference to the more important examples.

Important as harbour accommodation really is as a link in the chain of inter-communication between India and the outer world, the ports, harbours, and anchorages of the Indian coasts are singularly few in number, and have, moreover, until comparatively recent years, received a far smaller degree of attention than has been so largely devoted to the internal communications of the country. Much, however, has been done, not only in the matter of surveys, and thorough scientific investigation into the capabilities of all those places presenting the most promising features for the construction of artificial harbours,—whether as commercial ports, or as harbours of refuge, and in the gradual improvement of many of them, but also in the development on an extensive scale of the more important of these places by means of heavy and costly works. It is to these latter only—where works of especial consequence have been undertaken—that we can here refer.

Unlike most of the other great peninsulæ of the world, India, although possessing upwards of 3600 miles of coast line, is remarkably destitute of natural harbours affording accommodation and security to large ships. This disadvantage is, moreover, augmented by the circumstance that at certain seasons of the year the neighbouring seas are peculiarly liable to furious tempests and cyclones, of exceptional severity. Along the whole eastern coast of the peninsula—facing the Bay of Bengal, from the head of the bay to Cape Comorin, absolutely no really commodious natural harbour exists, although at a few places, greater or less facilities for the improvement of natural features, and the formation of artificial harbours are to be found. The Presidency city of Madras, the most important centre on this wide stretch of coast, lies on an exposed and open roadstead, and, until quite recent years, has possessed no accommodation or protection whatever for shipping.

At the head of the Bay of Bengal—in the Gangetic Delta, the port of Calcutta is situated 100 miles inland, on one of the mouths of the Ganges called the Hooghly, through which the navigation is tortuous and difficult, and affords a certain degree of accommodation for large ships. The port of Colombo, on the west coast of the island of Ceylon, has been

vastly improved of late years; Ceylon, however, being a Crown colony, is outside the limits of this volume. On the western coast of the peninsula—facing the Arabian Sea, the two principal commercial harbours are Bombay,—taking rank as the first and most important natural harbour in India—and Karachi, situated not far from the mouths of the Indus; the capabilities of which place are only of a moderate kind. On this coast also, the small natural harbour of Karwar—the port for North Canara and the cotton districts of Dharwar, affords some degree of protection, and has been artificially improved. Along the whole seaboard of India small seaports, chiefly situated in the mouths or estuaries of the principal rivers, are very numerous, and are largely used by native and English-coasting craft. Most of these have from time to time received attention in the way of dredging and deepening their available areas, or have been protected by the provision of groynes or small breakwaters. Many have been provided with wharves, quays, or landing-piers (as at Calicut)—for the convenience of the shipping, so that the aggregate amount both of work and expenditure, from local or imperial funds, on the improvement of the smaller ports along the Indian coasts, must be very considerable; a few of the smaller ports, such, for instance, as Mangalore, are said to be capable of great improvement, and in at least two cases, viz., the backwater of Cochin on the west, and the so-called ‘Blackwoods’ Harbour on the east coast, natural facilities appear to exist for the formation of semi-artificial harbours of some considerable importance: Cochin has, in fact, been reported of as capable of being made one of the finest close harbours in India, when it might become the outlet for the whole trade of the Southern Peninsula.

Bombay, the western sea-gate of India, and by far the best natural harbour in the country, was for a long period destitute of any suitable accommodation to enable ships to load and unload alongside quays or wharves. From about the year 1855, considerable improvements were initiated in buoys and lighting the entrance-channel. The long spit of land called the ‘prongs,’ running out from Colaba—which for many years was a fruitful source of danger to ships, owing to the original lighthouse having been built on Colaba Island, too far

inland from the point of danger, was protected by a new light-house, erected at great expense $1\frac{1}{2}$ miles farther out to sea. The old Government dockyard and docks at Bombay were supplemented by a fine dry dock at Mazagon for the Peninsula and Oriental Company's steamers, on ground reclaimed from the sea on the eastern side of Bombay Island. This dock was constructed 382 feet long inside gates, $53\frac{1}{2}$ feet wide at bottom, 79 feet wide at top, and $26\frac{1}{2}$ feet deep, but approachable only by large vessels at spring-tides. The increasing need of wet-dock accommodation at Bombay gradually led to the construction of extensive works of this character, on the site known as the Elphinstone Estate, which was reclaimed from the sea by the Elphinstone Land and Dock Company, and dock construction at this port has greatly extended, so as in great measure to keep pace with the growing necessities of the sea-borne trade.

The harbour of Karachi, situated near the mouths of the Indus, and slightly nearer in a direct line to the entrance of the Red Sea at Aden, than is Bombay, is the port of Scinde, and—through the Indus river and valley railway—of the whole Punjab. It thus occupies a very important position, and has now for some time enjoyed a large and growing prosperity. The harbour, which in point of accommodation can never seriously rival Bombay, is essentially a backwater, having an area at high tides of 15 to 18 square miles; but a very considerable portion of this is only very lightly covered by the tidal flow. The range of the tide is rather over 7 feet at main springs, and sometimes 10 or 12 feet at extraordinary springs. The western half of the harbour is formed by a long narrow strip of sand, ending in a rocky promontary at Manora Point, and the eastern side is formed by the low sandy island of Keamari. The main entrance for ships is between the western side of Keamari and Manora Point. Across this entrance a sand-bar had formed nearly 3000 feet in width, with a depth over it at low water spring-tides of $1\frac{1}{2}$ to 2 fathoms only; the bar having been formed by the action of the south-west monsoon current driving forward the loose sand lying immediately off the extremity of Manora Head. It was to remove this bar, and preserve a permanent and deep-entrance channel that the works carried out at Karachi were mainly undertaken.

The chief objects in view were, to increase the volume of water passing through the entrance at each tide; to give the current a proper direction, and to shut out as much as possible the heavy south-west seas from the mouth of the harbour. A secondary entrance was originally situated between the mainland and Keamari Island, called the Chinna Creek, and the first object was gained by blocking up this entrance, so as to force all the water through the main entry—and by opening a passage through a long mole or dyke which had been previously constructed by Sir Charles Napier, from Karachi town to Keamari Island, but without any opening. The second object was secured by running out a long groyne from Keamari Island to seaward, so as to direct the whole force of the tide on the bar; and the third, and the principal operation, was the construction of a breakwater extending to seaward from Manora Point, to break the force of the heavy seas. These works were aided by continuous dredging on the bar to assist the tidal scour, and the removal by blasting of a rocky obstruction at 'deep-water point,' on the west or Manora side of the harbour.

The blocking of the Chinna Creek, or eastern inlet entrance—including the construction of an iron screw-pile bridge 1200 feet long, over the opening made in the Napier mole, together with the principal subsidiary operations in the deep-water channel, cost altogether nearly £130,000. A new jetty near the town-end of the harbour, where goods could be landed and shipped by the smaller craft, cost £43,000; and the Keamari groyne, which was commenced in November 1861, and completed in 1865, cost over £48,000. The closing of the Chinna Creek, 980 feet across, was completed in the year 1873.

The construction of the valuable Manora Point Breakwater was commenced in 1869, and it was completed in the year 1873, at a cost, including plant and establishment, of rather under £100,000. This breakwater is of especial interest, both on account of the novel features of its design, and as being the first that was constructed in deep water with a view to break the force of the heavy seas raised by the south-west monsoon on the west coast of India. It runs in a SSE. direction from the southern extremity of Manora Point, for a distance of

1503 feet beyond low-water mark, terminating in a depth of 5 fathoms, or 30 feet at low water. For the first 500 feet of its length the water at low tide is 2 to 2½ fathoms only, and the irregular sea-bottom consists of conglomerate rocks, wholly or partially imbedded in sand: the bottom along the remaining outer portion consists of sand resting on a bed of clay. The base of the breakwater is formed of a heavy bank of rubble stone thrown to the sea-bottom from boats; and the top surface of this bank was levelled off by divers at a height of 15 feet below low water in the deeper, and 10 feet in the shallower portion towards the shore end. Upon this rubble bank, made with ample width, and side slopes of 1 to 1, was raised a solid superstructure, consisting of a vertical double wall built up of huge concrete blocks, each 12 feet long, 8 feet high, and 4½ feet thick, weighing 27 tons. These blocks, which were placed on edge, with a backward rake or inclination towards the shore of 3 inches to the foot—to prevent movement during the progress of the work—form a wall 24 feet high and 24 feet wide. The cross section of this wall presents six blocks, two, without bonding, forming the width, and three the height.

The manufacture of the large concrete blocks was carried on on shore by the aid of concrete mixing machinery: they were made in moulds of the requisite dimensions, and contain one-eleventh in bulk of Portland cement, mixed with conglomerate and sand. After being allowed a suitable interval to dry and harden, they were—by means of a special machine—lifted on to trucks, and run out to the breakwater, where they were deposited in place by the aid of a powerful ‘Titan’ or travelling crane, with projecting arm of special construction; the lifting and lowering tackle being worked by a powerful steam-engine.

The Manora breakwater was virtually completed in 1873, at the very moderate cost, exclusive of establishment, of £69,489. The total cost of the Karachi Harbour improvement works, up to the year 1873-74, was about £450,000; their united effect has been entirely satisfactory. A new direct entrance channel, preserving a depth of 20 feet at low water, was formed, and the harbour was rendered accessible to vessels of the largest size, whilst at the same time the

capacity of the anchorage was considerably increased. The breakwater, which has sustained no serious injury from the violence of the sea to which it is exposed, permits the use of the port at all seasons, and allows the regular arrival and departure of the mail-steamers. At Keamari—no longer an island—a landing-pier, and extensive wharfage, has been constructed, to which the railway has now for many years been extended, and the possession of an excellent, though moderate-sized harbour, out of the track of cyclones, and situated 500 miles from the nearest good harbours on either side of it, ensures to Karachi a continuous growth of trade, and commercial as well as military and naval importance.

The port of Karwar, on the west coast, about 50 miles south of Goa, consists of a bay or cove, partially protected from the south-west monsoon. In the year 1858, an English harbour engineer of eminence was deputed to report on its capabilities as a harbour of refuge. He reported that the bay was in great measure protected from the most violent south-west winds, but was exposed to the west and north-west, and recommended the construction of breakwaters, aggregating a mile and a half in length, by means of which a perfectly quiet harbour, of upwards of 4 square miles in area, would be formed, with a depth varying from 14 to 32 feet at low water. In 1860 it was determined to effect some improvements in this natural harbour, in order to render it available as a port for the shipment of cotton from Dharwar. A road was constructed to connect it with that district:—Along the east side of the bay a wharf-wall of masonry, 845 feet long, was built, and a landing-place was formed by excavating the hill-sides, which here descend nearly to the water's edge. It was at first intended to construct a screw-pile pier 200 feet long, with a T head of 90 feet, and the necessary materials for this pier were obtained from England in 1864, but, owing to unexpected difficulties met with in securing the piles in the treacherous soil, the pier materials were utilised in the construction of a landing-stage, about 100 feet square, commanding $7\frac{1}{2}$ feet at low water, and extending 45 feet beyond the wharves. A lighthouse was also built on the Oyster rock, westward of the port, the light of which is 205 feet above the level of the sea. The harbour improvement

works at Karwar were estimated to cost £115,000, including a wharf road and iron bridge costing £65,000.

The condition of the Madras open roadstead, as a port of call for vessels, was thus referred to by the members of a committee appointed by Government in the year 1868 to report on the best method of improving the facilities for the sea-borne trade at that place. They say:—‘The port of Madras at the present time, so far as the facilities for trade are concerned, differs very little from what it was nearly 250 years ago, when, as a small fishing village, it first attracted attention. It remains an open roadstead, destitute of any natural shelter, and still unprovided with any artificial substitute; and its surf still offers an insurmountable difficulty to the passage of boats of every kind, except the primitive Masulah boats. But though manned by thirteen trained men, a Masulah boat carries only $1\frac{1}{2}$ tons as an ordinary load in the finest weather, and often less than half a ton in heavy weather. The very skill of the boatmen is one of the difficulties of the port, for their numbers being limited, they are able to set regulations at defiance, and to charge pretty much what they like—twice, four, and six times the legal hire being a common rate, and ten times by no means uncommon; well knowing that the course which would elsewhere be followed of importing additional men from other localities would be inoperative at Madras, for in consequence of caste prejudices, and the disinclination of natives to adopt customs, or to follow trades which have not been followed by their fathers before them, the ordinary laws of political economy cannot be applied in their integrity in this country, and it does not follow that because there is a greater demand than supply of Masulah boatmen, and a very handsome profit to be reaped by those who might qualify for the occupation, that outsiders will qualify for it, and come forward to break the monopoly. The great objections then to the port of Madras are—First, That it is an open roadstead, destitute of shelter, which renders it necessary on the approach of a gale for ships to put to sea for safety; or if out of trim and ballast, and unable to put to sea, to incur the imminent risk of dragging their anchors, or of parting from them and going ashore complete wrecks. Secondly, That owing to the com-

munication between the shipping and the shore being for the most part by Masulah boats, only carrying $1\frac{1}{2}$ tons at a time, the delay in loading and unloading is so great as to deter many ships, to which a preference would be given, from coming to the port at all. Thirdly, That the actual cost of landing and shipping cargo, even at legal rates, is needlessly great, while the much higher rates which the mercantile community pay on demand, rather than incur the inconvenience and odium of prosecuting the boatmen, enhances the cost so much as to become a formidable addition to the charges of a port otherwise regarded as a cheap one. Fourthly, That, notwithstanding the skill of the boatmen, the damage to goods from spray, and from shipping seas in crossing the surf, is a very serious consideration.'

Some time before the date of this report, a screw-pile pier, projecting some 300 or 400 yards from the shore, had been constructed with a view to lessen the evils above depicted. The committee recommended the construction of a breakwater 2000 yards long, lying parallel with the shore, and distant about 1200 yards from it, in 7 or 8 fathoms of water, the cost of which they considered might reach about $1\frac{1}{2}$ million sterling. They were of opinion that a closed harbour would be preferable to a breakwater, but the majority of the members believed that the danger of shoaling from the advance of sand—the long shore movement of which would be arrested by the projecting piers of a closed harbour—would be an insuperable objection.

From this time numerous proposals were made and lengthily discussed, until, in the year 1872, a project for the construction of a closed harbour was submitted by an experienced English harbour engineer, whose services in the following year were secured for a period of twelve months, in order that he might fully investigate the subject. The scheme proposed was, the construction of two piers to be run out for 1200 yards at right angles to the foreshore, and placed about 500 yards north and south of the existing screw-pile pier. These side piers to be connected at the ends by a cross-pier or breakwater, running parallel with the shore, with an opening, 150 yards wide in the centre, as an entrance into the closed harbour which would

thus be formed. It was proposed that the piers should be constructed generally after the pattern of the Manora break-water at Karachi, viz., a rubble-stone bank or mound, brought up from the sea-bottom to a depth of 22 feet below low water, on which would be built a vertical wall 24 feet thick, of large concrete blocks—each weighing 27 tons—capable of resisting the force of the waves. The cost of this close harbour was estimated at £565,000, and the enclosed area available for ships would be a rectangle about 1000 yards long by 830 yards wide, or 170 acres, with a depth at low water of from 3 to 7 fathoms, with a further space of about a quarter of that area, with a depth of less than 3 fathoms for boats, lighters, and native craft. The question of the probable advance of the foreshore was discussed, and it was considered that the accumulation of sand would at first be heavy, but that when once the piers were extended into the deep water the further advance would be so slow as practically to remove to a very distant date any danger of the harbour shoaling up.

This scheme was generally approved by the Government of India in 1874, after much discussion of its details, and much opposition by the advocates of the breakwater alternative, but on various counts the Government raised the estimated cost from £565,000 to £776,000. In the following year the sanction of the Secretary of State to the construction of the proposed harbour was communicated, with the following liberal remarks on the estimates of probable expenditure :—‘The contingencies upon which the cost of constructing and repairing a harbour depends are so uncertain that it would be hazardous to express a confident opinion in respect to these conflicting estimates. But the question is too large to be dealt with only on financial grounds. Many human lives are sacrificed in the tempests which annually ravage the Coromandel coast, and it is possible that a large proportion of these might be saved if vessels which are now surprised in the roadstead could seek the shelter of a harbour. The material interests of a vast population that inhabits the Presidency of Madras are not less deeply affected by the unsheltered condition of the port. It can hardly be doubted that if a safe and regular access to the sea could be secured to them, their industry and trade would be greatly

stimulated. The public utility of a harbour can seldom be measured by the actual return in the shape of dues which it can be made to pay, and in the Presidency of Madras, where the destitution of shelter upon the seaboard is so remarkable, such a principle of valuation would be specially misleading.'

The work of construction on the North Pier was put in hand in December of the year 1876, the South Pier not being commenced until about a year later. In carrying these piers through the shoal water, much trouble and delay was occasioned in consequence of the rapid accumulation and advance of sand, but, as had been confidently anticipated, as soon as the 4-fathom line was reached, all difficulty on this head ceased, and the work was carried on without further interruption. The general features of the work as carried out were as follows:—The rubble stone base was made 78 feet wide at the top, with side slopes of 1 to 1; its height varied with the depth of water, being about 25 feet at the deepest part, where the top of the mound was 22 feet below the water. The rubble was deposited *in situ* from steam-hopper barges, and its surface was levelled by divers to receive the concrete blocks. The foundation blocks were 14 feet long, 6 feet wide, and $4\frac{1}{2}$ feet thick; those forming the remainder of the wall being 12 feet by 8 feet by $4\frac{1}{2}$ feet, weighing 27 tons each; upwards of 13,643 blocks were used; they were laid, with a backward rake of 3 inches to the foot, by the aid of powerful 'Titan' cranes with overhanging arms. The walls were constructed without bond, the width of 24 feet being made up of two parallel walls of blocks resting on, and in side contact with each other, each block having a tenon on its upper surface, and a corresponding mortice on its lower surface to prevent slipping. The greatest depth of water in which the piers were founded was 8 fathoms, or 48 feet. Towards the ends, forming the central entrance into the harbour, the pier-heads were widened out to about double width. The total length of the piers (those to the north and south being of nearly equal length) was 7856 feet.

With the exception of a small re-entering curve, which it was proposed to add at the pier-heads, the works were practically completed towards the end of the year 1881, when, on the 12th November of that year, a severe cyclonic storm occurred,

raising exceptionally heavy rollers and ground swell, although unaccompanied by any very violent wind. The result of this storm was to wreck nearly the whole of the outer, or breakwater face of the harbour, from the elbows, or turns of the pier-walls, where the injury was greatest, to the entrance on either side; the side piers, from the shore to the elbows, being but little affected. In the case of this storm, the action of the sea was sufficiently severe to undermine foundations at a depth of 22 feet under low water, an action far in excess of that hitherto held possible by harbour engineers in England, where a depth of 15 feet below low water was considered as safe against all possibility of disturbance by the worst waves.

This regrettable incident caused a suspension of operations for some time, and gave rise to a long discussion as to the most secure methods of restoring the harbour. The recommendations of a committee, composed of eminent harbour engineers, which was appointed in England in the year 1883, advising a certain remodelling of the works, estimated to cost £430,000, were eventually in the main adopted, after very considerable opposition had been offered by the local, nautical, and other authorities in Madras, who advocated the closing of the outer or easterly entrance to the harbour, and the construction of a new and wider entrance in the north-east angle. This proposal, after a long discussion, was, however, overruled, and the restoration of the harbour on the main lines recommended by the English committee was ordered. The final estimate for the restoration works reached a sum of £459,000, so that, with the original outlay up to the time of the storm, the estimated completed cost of the Madras harbour ranged not far short of a million and a quarter sterling.

There is little of general interest that need be here referred to in connection with the port of Calcutta. That portion of the Hooghly tidal channel abreast of the city, chiefly occupied by the shipping frequenting the port, is from 4 to 5 miles long, and averages about 300 yards in breadth. A considerable extension of wharves and jetties along this water frontage has from time to time been carried out by the port authorities, and the provision of wet dock accommodation, somewhere at or near Calcutta, is a question which in one form or another

has been under discussion for the best part of half a century. Much difference of opinion has existed as to the most suitable position for the construction of commercial docks (or even whether such docks were necessary at all), and numerous proposals have been put forward. Diamond harbour—situated about 50 miles lower down the river, or 31 miles by land from Calcutta—has been particularly favoured. Proposals for the construction of docks at this place were made so far back as the year 1839, and were again urged in 1847, when, chiefly on the opposition of Lord Dalhousie, the project was shelved. A special committee, appointed to consider the question of dock accommodation at Calcutta in the year 1883, was also favourable to the revival of this scheme, but an important and influential minority, composed of all the mercantile members, agreed in rejecting it. Another committee, subsequently appointed to pursue the investigation, came to a unanimous conclusion against Diamond harbour, and was in favour of the construction of docks at Kidderpore, on a site situated on the Calcutta side of the river, about $3\frac{1}{2}$ miles from the city. The estimated cost of these docks, including subsidiary works and interest, was 265 lakhs of rupees, or £2,650,000; the area of dock accommodation proposed being nearly 111 acres, consisting of a tidal basin of $9\frac{3}{4}$ acres, and two docks of $36\frac{1}{2}$ and $64\frac{1}{2}$ acres respectively. The approval of the Home Government in the year 1884 was, however, on general prudential grounds, limited to the tidal basin, and the smaller of the two docks only, and to the expenditure of a sum not exceeding 200 lakhs, or £2,000,000 sterling.

Considerable difficulty was experienced by the Port Commissioners in raising the necessary funds, and much discussion and differences of opinion as to the kind and degree of financial assistance to be rendered by the Government occurred. It was clear that the latter, as the owners and guarantors of so large a mileage of railways converging on Calcutta, were intimately concerned in the forwarding of all port arrangements promising facilities to trade, but from various causes it was not until the year 1886 that a final agreement between the Government and the Port Commissioners was arrived at, that the money required for the prosecution of the Kidderpore Docks should

be raised in India by Government loan, and lent as required to the local authority; the interest charged being the actual rate of borrowing—plus 1 per cent. for a sinking fund, to be invested at the end of four years after the completion of the docks. The work was accordingly undertaken, but whether, under the conditions of the port, the number of ships using the new Kidderpore Docks is likely to be such as to render them a financial success, it is as yet probably too early to determine.

Although the lighting of the coasts of India is by no means perfect, a great deal has from time to time been done, especially on the Burma seaboard, so that there are now probably upwards of seventy lighthouses or lightships stretched along the great extent of coast from the Manora light at Karachi to the Malay peninsula. Some of the more important of these lighthouses occur on the coast of Burma, such as that erected on the Alguarda reef, a short distance off the mouth of the river Negrais. This graceful tower is 120 feet high, showing a light $143\frac{1}{2}$ feet above high-water spring tides, and has a base diameter of $42\frac{1}{2}$ feet. It was completed in the year 1865, at a cost of about £100,000. The Double Island Lighthouse, situated near the mouth of the Bassein river, 56 feet in height, with a light 134 feet above high water, costing about £6000. The Cocas Island Lighthouse, $72\frac{1}{2}$ feet high, with light 195 feet above sea level, built on Table Island north of the Cocas, off the coast of Burma. This lighthouse is an iron-plated tower, and cost nearly £12,000. The Khrisna Shoal Lighthouse, in the Gulf of Martaban, is erected on iron screw-piles, screwed to a depth of 24 feet into the sea-bed in 3 fathoms of water at low tide, where it is exposed to the heavy seas raised by the south-west monsoon. The tower is 84 feet in height, and it cost upwards of £16,000. The Great Basses Lighthouse, off the coast of Ceylon, is a granite tower, containing 37,365 cubic feet of that stone. It is $97\frac{1}{2}$ feet high, and cost £64,000.

The 'Prongs' Lighthouse at Bombay, about $1\frac{1}{2}$ miles to seaward of the old lighthouse on Colaba Island, has already been referred to. This tower, owing to the nature of the bottom, was founded on a great thickness of concrete, enclosed

in a massive dam faced with concrete blocks of large size. It is built of hard grey trap, and is 42 feet in diameter at the base, and 16 feet at the top; the total height being 127½ feet. The central core of the shaft is 12 feet in diameter, divided into eight stories, each 12 feet high. The lighthouse at Karwar, also already mentioned, is built on the Oyster rock, about 3 miles westwards of the port, a rock which rises 160 feet above the sea. The lighthouse was finished in 1864; it consists of a circular tower 45 feet high, with the light 205 feet above sea-level. These various lighthouses are all provided with dioptric lights of the first order. Along the coast of the Madras Presidency there are numerous lights of all classes, including a fine tower 90 feet high, with a dioptric light of the second order at Alepy, and one 82 feet high, with a fixed white light at Tuticorin, first lighted in 1874. These are a few examples of prominent lighthouses erected on the Indian coasts.

CONCLUDING REMARKS.

IN the foregoing pages, all the principal fields of operation in connection with public works in India have been separately brought before the reader, and, although the large compass of the entire subject has compelled a very condensed treatment of individual departments, and especially of individual works, it is hoped that the main object of conveying to the mind of the reader a more comprehensive idea than he may have previously entertained of the immense extent and variety of Indian public works, and of their great importance and value to the country and to the Government, may at least have been partially attained. Statements exhibiting mere money expenditures on works of public usefulness, are necessarily a very imperfect expression of their real value, it has, therefore, been sought not only to interest the reader in the constructive details of Indian public works themselves, and to convey some idea of the dimensions and comparative magnitudes of the foremost examples; but it has been endeavoured at the same time to depict the astonishing manner in which as a whole, they have affected the general welfare; whether in ameli-

orating the material conditions of life by advancing the average wealth and wellbeing of the people, or by increasing industrial activity and improving the public revenues.

The enormous increase given to the productive capacity of the country by the labours of the engineer in India, is in truth incalculable, and the improvement, there as elsewhere, is plainly written on the face of the land, and in the wonderfully increased resources of the Government on every side. Scientific and practical engineers as a body, are commonly far too absorbed in the details of their multiform occupations, and too careless of the unconscious injustice and ingratitude with which their arduous and exceptionally responsible labours are so often requited by an unreflecting public, to go out of their way to assert the true greatness and importance of their profession in relation to the world's advancement. It is in backward and undeveloped countries that its true value is the most clearly exemplified, because it is in these, that the immediate springs and sources of progress are the most clearly visible to the public eye.

Mr. Alfred Milner, in his recent work on Egypt, relates that when a native statesman, and one of those most intensely opposed to British interference in the country, was asked by him how he imagined the country would get on without the English irrigation engineers, replied, 'You do not suppose that if Great Britain were to retire from Egypt we should let the engineers go?—I myself should be the first to do everything I could to retain them.' The true secret of the successful financial administration of Egypt under British guidance was here too patent to be overlooked or obscured, and found natural expression in the above remark. The same author—his own sympathies and interest lying naturally in the direction of finance—admits that the efforts of the British financial advisers in Egypt would have been thrown away but for the work of the irrigation engineers, he says, 'We at the finance office have, so to speak, registered that improvement in our easier budgets and growing surplus, but it is the engineers who have created it.' Among the numerous bodies of engineer officers of all classes who, under the wise initiation or direction of the Government, have for so many years been engaged with

untiring industry in laying the foundations and steadily building up the material prosperity of India, many individuals of widely varying degrees of professional aptitude and capacity may no doubt be found, and there, as in every other part of the world, various degrees of success and failure will be found to have attended individual efforts; but the prodigious transformation effected in the country, and the success and economy with which, as a whole, the great railway and irrigation works of India have been created and administered, is the test to which the body of Indian engineers—whether working directly in the service of the Government, or under the supervising control of the Government officers—may confidently appeal.

To recapitulate: It has been the chief aim of this volume, however imperfectly attained, to exhibit on a single canvas an outline picture of the more important works of public utility which have been carried out in India by British or native engineers, and to emphasise their special value, meaning, and importance. The enormous aggregate of Indian public works may be regarded as the fundamental basis of that notable advance in the material prosperity, wealth, and culture of the peoples of India which has taken place mainly within the last thirty or forty years—which, alone has rendered this advance possible, and without the existence of which the best efforts of British civil administration, British finance, education, and British laws, would assuredly have been as a few grains of wheat cast into a wilderness. The judicious extension throughout India of great public works of all kinds, under the Government of Great Britain, is the true cause of the existing remarkable development of the average standard of individual wealth and comfort among all classes of the Indian people: of the great increase in population, the steady improvement in the Government revenue, and the generally improved financial condition of the country compared with what these severally were within comparatively recent memory.

The rapid internal development of the resources of India by means of public works, irrigation canals, telegraphs, and, above all, by railways, has, moreover, not only assured material prosperity, but has also rendered possible that simultaneous and marvellous moral and intellectual progress, and that steady

overturning of pernicious superstitions and caste trammels, which to-day is so profoundly affecting the whole social life of the heretofore stagnant races of the continent. To be assured that this is so, it is only necessary to try and picture in imagination what would have been the present comparative condition of a poorly irrigated, roadless, and rail-less India.

The mean level of human progress and of human wellbeing bears a direct proportion to the greater or less application of the practical sciences to the purpose of relieving the necessities and satisfying the wants and aspirations of man, and enlarging the sphere of his possible activity: to the power he possesses of favourably moulding his environment by bending the great sources of power in nature to his service and convenience. To realise this truth it is sufficient to contrast the rate of advancement of the civilised nations of the world during the present century with that of the whole antecedent historical period: to compare the India of the present day with the India of forty years ago. It is on the firm foundation of a steadily augmenting material prosperity created by the great public works of the country, that the beneficent English administration of India has its support, and it is on this foundation that it has alone been possible to erect that magnificent superstructure of moral government, which is at once its justification and the admiration of the civilised world.

APPENDICES

APPENDIX A.—PUNJAB CANALS, 1890-91

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated 1890-91.	Value of Irrigated Crops 1890-91.	Capital Outlay up to end of 1890-91.	For Year 1890-91.				Results, including Interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.		
MAJOR WORKS. Canals in operation only.	Swat River Canal,	Miles. 22	Miles. ...	Miles. 140	Acres. 88,875	£ 247,518	£ 360,349	£ 14,139	£ 3.92	£ 297	£ -88,907	
	Western Jumna,	280	243	911	388,505	2,111,943	1,119,283	103,366	9.23	+60,984	+2,995,919	
	Bari Doab, .	362	...	1048	535,045	1,624,008	1,643,356	134,777	8.07	+69,618	+128,668	
	Sirhind, { British,	319	143	2445	} 600,162	1,712,936	2,328,739	106,351	4.05	+17,285	-854,540	
	Chenab, { Native,	223	46	1940		182,007	570,315	482	0.08	-17,934	-77,127	
	Lower Sohg and Para, .	91	...	283	52,390	107,164	69,156	-1,621	*	-4,245	-13,442	
	Sidhnai, . .	58	...	146	122,525	252,949	93,575	10,181	10.88	+6,742	+25,496	
Total Major Works, . .		1450	432	6954	1,826,106	6,238,525	6,184,773	365,675	5.91	+132,747	+2,116,067	
MINOR WORKS AND NAVIGATION.	Five Works and Madhopur Workshops, .	} 2608	...	591	1,016,552	2,577,252	187,669	35,638	19.0	+35,638	+812,657	
Grand Total for Province, .		4058	432	7545	2,842,658	8,815,777	6,372,442	401,313	6.33	+168,385	+2,928,724	

APPENDIX B.—NORTH-WEST PROVINCES CANALS. 1889-90.

Head of Account.	Names of Canals, etc.	Main Canal and Branches	Of which are Navigable	Distributing Channels	Area Irrigated, 1889-90.	Value of Irrigated Crops, 1889-90.	Capital Outlay up to end of 1889-90.	For Year 1889-90.			Results, including Interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	
MAJOR WORKS.	Betwa Canal, .	Miles. 168	Miles. *	Miles. 321	Acres. 24,282	£ 72,138	£ 416,417	£ -41,711	£ -1	£ -19,927	£ -123,556
	Upper Ganges, .	456	213	2523	807,574	2,999,200	2,839,360	191,012	6.73	+84,380	-260,670
	Lower Ganges, .	557	199	2078	499,894	1,548,747	3,309,602	58,411	1.76	-63,620	-184,877
	Agra Canal, .	134	123	565	178,254	499,133	912,710	43,633	4.78	+9,873	-236,295
	Eastern Jumna, .	130	*	640	243,817	932,421	333,705	72,657	21.77	+60,313	+1,357,699
Total Major Works, . .		1445	535	6127	1,753,821	6,051,639	7,811,794	361,543	4.63	+71,021	+552,301
MINOR WORKS AND NAVIGATION.	Three Systems and Jhansi and Hamirpur Lakes	20	*	519	125,582	475,595	247,506	9020	3.27	9,020	+137,316
Grand Total for Province, .		1465	535	6646	1,879,403	6,527,234	8,059,300	370,563	4.60	80,041	+689,617

APPENDIX C.—BENGAL CANALS. 1890-91.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated 1890-91.	Value of Irrigated Crops 1890-91.	Capital Outlay up to end of 1890-91.	For Year 1890-91.			Results, including Interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	
MAJOR WORKS. Canals in operation only.	Orissa Canals, .	Miles. 252	Miles. 177	Miles. 765	Acres. 180,299	£ 391,059	£ 2,476,411	£ -6,316	£ -0.25	£ -108,475	£ - 4,029,596
	Midnapore Canal,	72	72	339	82,002	188,605	842,837	+ 3,576	- 0.42	- 30,236	
	Hidgellee Tidal Canal, .	29	29	...	...	...	204,739	- 2,553	- 0.21	- 10,238	
	Sone Canals, .	367½	218½	1211	281,014	1,080,820	2,643,336	- 2,480	- 0.09	- 99,062	
Total Major Works, .		720½	496½	2315	543,315	1,660,484	6,107,323	- 7,774	- 0.12	- 248,011	- 4,029,596
MINOR WORKS AND NAVIGATION.	Six Systems, Two being Navigation Canals only, .	163½	144½	...	2,226	4,997	1,032,873	+ 26,363	2.55	+ 23,562	+ 1,275,343
	Grand Total for Province, .	884	641	2315	545,541	1,665,481	7,200,196	+ 18,589	0.025	- 224,449	- 2,754,253

APPENDIX D.—MADRAS CANALS. 1890-91.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	of which are Navigable.	Distributing Channels.	Area Irrigated 1890-91.	Value of Irrigated crops 1890-91.	Capital Outlay up to end of 1890-91.	For year 1890-91.			Results, including interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	
		Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
MAJOR WORKS.	Godavery Delta,	506	496	1732	680,495	1,574,579	1,273,203	157,419	12'36	+ 114,067	Not Given.
	Kistna Delta,	325	284	1614	463,071	1,123,705	1,001,052	131,663	13'15	+ 95,370	
	Pennair Anicut,	22	...	120	65,080	130,679	187,540	10,641	5'67	+ 4,129	
	Sangam Do.	9	...	250	68,224	165,996	364,001	7620	2'09	- 4,262	
	Kurnool Cuddapah Canal,	190	190	313	24,848	70,050	2,164,131	- 3768	- 0'17	- 90,334	
Canals in operation only.	Barur Tank,	7	...	22	2,774	8,002	41,133	59	0'14	- 1,479	Not Given.
	Kaveri Delta,	844	...	1250	1,013,344	2,530,345	177,945	66,154	37'18	+ 59,530	
	Srivaikantham Anicut,	28	...	62	28,896	33,929	145,154	2652	1'83	- 2,752	
Total Major Works,		1931	970	5363	2,346,732	5,637,385	5,354,159	372,440	6'95	+ 174,269	Not Given.
MINOR WORKS for which Capital and Revenue Accounts are kept—22 Works,		1158	304½	1264	421,043	833,961	1,405,532	28,902	2'05	+ 28,902	
MINOR WORKS for which no Capital or Revenue Accounts are kept,		not given	...	not given	2,746,409	not given	not given	406,485	...	+ 406,485	
Agricultural Works,		...	...	...	...	...	...	- 56,949	...	- 56,949	
Grand Total for Presidency,		3089	1274½	6627	5,514,184	6,471,346	6,759,691	750,878	...	+ 552,707	

APPENDIX E.—SCINDE CANALS. 1889-90.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated 1889-90.	Value of Irrigated Crops 1889-90.	Capital Outlay up to end of 1889-90.	For Year 1889-90.			Results, including Interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	
All Works by Districts.	Bigari Canals, .	Miles. 443	Miles. .	Miles. .	Acres. 350,261	£ . . .	£ . . .	£ . . .	£ . . .	£ . . .	£ . . .
	Shikapur Canals, .	338	. . .	. . .	135,574	. . .	. . .	. . .	. . .	. . .	. . .
	Ghar Canals, .	784	. . .	. . .	404,828	. . .	. . .	. . .	. . .	. . .	. . .
	Eastern Nara, .	293	. . .	. . .	174,936	. . .	. . .	. . .	. . .	. . .	. . .
	Hyderabad Canals, .	1670	. . .	. . .	364,297	. . .	. . .	. . .	. . .	. . .	. . .
Major Works, Minor Works, Minor Works for which only Revenue accounts are kept, Agricultural Works, .	Fuleli Canals, .	1141	. . .	. . .	290,657	. . .	. . .	. . .	. . .	. . .	. . .
	Karachi Canals, .	1265	. . .	. . .	256,710	. . .	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	. . .	. . .	. . .	. . .	850,730	72,701	8.54	+39,951	+153,238
	. . .	. . .	. . .	. . .	. . .	. . .	332,907	73,047	22.0	+60,409	+1,127,675
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	104,711	. . .	+104,711	not given.
Grand Total for Province, .	. . .	5944	. . .	. . .	2,349,819	not given.	1,183,637	232,365	. . .	+186,977	+1,280,913
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

APPENDIX F.—BOMBAY CANALS. 1890-91.

Head of Account.	Names of Canals, etc.	Main Canal and Branches.	Of which are Navigable.	Distributing Channels.	Area Irrigated, 1890-91.	Value of Irrigated Crops, 1890-91.	Capital outlay up to end of 1890-91.	For Year 1890-91.			Results, including interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	
MAJOR WORKS.	Nira Canal, . .	Miles. 95½	Miles. 109	Acres. 16,913	£ 34,731	£ 500,244	£ 560	£ 5	...	£ 18,396	Not given.
	Mhasvad Tank, .	27	66½	7,106	18,815	203,477	670	...	...	7,214	
	Hathmati Canal, .	21	30	3,766	11,166	51,829	71	...	...	1,893	
	Lower Panghra, .	...	45	2,390	3781	45,607	626	...	...	1,107	
	Kadva River Works	21½	15	2,227	6,553	71,895	310	...	...	2,443	
Canals in operation only.	Pravara (Lakh Canal),	23	11	433	2,621	37,196	-235	...	...	1,640	Not given.
	Mutha Canal and Reservoir,	88	67	11,201	158,646	630,713	13,776	...	...	10,449	
	Ekrak Tank, .	48	...	2,598	15,131	133,341	1,099	...	...	3,813	
	Krishna Canal, .	61½	...	3,950	45,750	84,031	1,749	...	...	1,431	
Total Major Works, . .		385½	...	50,584	297,194	1,758,333	18,626	1'06		- 48,386	
MINOR WORKS AND NAVIGATION	Sundry—27 Works.	220½	...	25,317	102,575	704,132	3,494	0'5		- 22,357	
	MINOR WORKS. Only Revenue Accounts kept.	not given	...	145,563	not given	...	33,111	...		+ 33,111	
	AGRICULTURAL WORKS.	...	...	...	...	2,559	802	...		+ 802	
Grand Total for Presidency, without Scinde.		606	...	221,464	399,769	2,465,024	56,033	2'2		- 36,830	

**APPENDIX G.—GENERAL ABSTRACT FOR ALL INDIA, 1890-91,
Except Scinde, and North-west Provinces, which are for 1889-90.***

Head of Account.	Names of Provinces.	Main Canal and Branches.	Of which are Navigable.	Distri- buting Chan- nels.	Area Irrigated 1890-91.*	Value of Irrigated Crops 1890-91.*	Capital Outlay up to end of 1890-91.*	For Year 1890-91*.			Results, including Interest, from commencement.
								Net Revenue earned.	Per ct. on Cap.	Results, including Interest.	
MAJOR WORKS. Canals in operation only.	Punjab.	Miles.	Miles.	Miles.	Acres.	£	£	£	£	£	£
	N.-W. Provinces.	1,450	432	6,954	1,826,106	6,238,595	6,184,773	365,675	5.91	+ 132,747	+ 2,116,067
	Bengal.	1,445	535	6,127	1,753,821	6,051,639	7,811,794	361,543	4.63	+ 71,021	+ 552,301
	Madras.	720½	496½	2,315	543,315	1,660,484	6,167,323	- 7,774	- 12	- 248,011	- 4,029,596
	Scinde.	1,931	970	5,363	2,346,732	5,637,385	5,354,159	372,440	6.95	+ 174,269	Not given.
Total Major Works,	Bombay.	5,924	...	...	2,349,819	Not given	850,730	72,701	8.54	+ 39,951	+ 153,238
	Bombay.	385½	...	343½	50,584	297,194	1,758,333	18,626	1.06	- 48,386	Not given.
		11,855½	2433½	21,102½	8,870,377	19,885,227	28,127,112	1,183,211	4.26	+ 121,591	No total available.
MINOR WORKS AND NAVIGATION. Do. with lesser works and Agricultural.	Punjab.	2,608	...	591	1,016,552	2,577,252	197,669	35,638	19.0	+ 35,638	+ 812,657
	N.-W. Provinces.	20	...	519	125,582	475,595	247,506	9,020	3.27	+ 9,020	+ 137,316
	Bengal.	163½	144½	...	2,226	4,997	1,032,873	26,363	2.55	+ 23,562	+ 1,275,343
	Madras.	1,158	304½	1,264	3,167,452	833,961†	1,405,532	28,902	2.05	+ 28,902	Not given.
	Scinde.	...	...	...	{ Included above	Not given	...	349,536	...	+ 349,536	+ 1,127,675
		220½	...	220½	170,880	102,575	{ 704,132 2,559	73,047	22.0	+ 60,409	Not given.
		...	...	...	...	...	...	86,617	0.5	- 22,357	Not given.
		...	...	...	...	...	...	33,913	...	+ 33,913	Not given.
Total, all Minor Works,		4,170½	449	2,594½	4,482,692	3,994,380	3,913,178	646,530	16.5	+ 605,240	No total available.
Grand Total, all India,		16,026	2882½	23,696½	13,353,069 or 20,864 square miles	23,879,607	32,040,200	1,829,741	5.74	+ 726,831	No Grand Total available.

† Without the lesser Minor Works, value not given.

APPENDIX H.

Irrigation and Navigation Works for which Capital and Revenue Accounts are kept.

Class of Work.	No. of Works.	Direct Capital Outlay to end of 1890-91.	Gross Revenue.	Working Expenses.	Net Revenue.	Irrigated Area.	Percentage Net Revenue on Capital Outlay.	Remarks.
<i>Irrigation.</i>		£*	£	£	£	Acres.		
1. MAJOR WORKS—								
(a) Productive, . . .	35	25,465,011	1,985,041	760,493	1,224,548	7,025,621	4.81	
Add on account of old Irrigation in Madras, . . .	..	..	289,700	34,882	254,818	..	..	
<i>Navigation.</i>								
(a) Productive, . . .	1	199,779	2,804	5,197	- 2,393	..	..	
(b) Protective, . . .	8	1,660,527	38,046	24,893	13,153	146,847	0.79	
2. MINOR WORKS—								
<i>Irrigation.</i>								
(a) Works for which Capital and Revenue Accounts only are kept, . . .	69	2,607,739	425,063	222,919	202,144	2,102,634	7.75	
<i>Navigation, . . .</i>	7	1,687,254	68,060	50,194	17,866	..	1.06	
Totals, . . .	120	31,620,310	2,808,714	1,098,578	1,710,136	9,275,102	5.40	

* These figures should be read as tens of Rupees or Rs.

APPENDIX J

COLOUR-BLINDNESS

THE inner lining of the human eyeball is the retina. It is chiefly composed of nerve-matter whose function is to receive impressions of external objects focussed upon it, and convey them through the optic nerve to the brain. The retina is able to perceive not only the form of objects but also their colour. In mechanical arrangement the eye is very similar to a photographic camera, and the retina corresponds to the ground-glass focussing screen, on which a coloured image of the view is thrown.

The nerve fibres of the retina are really the direct prolongation of those of the optic nerve itself, and the rays of light which are focussed upon them form the stimulus which excites the sensorium at the other, or cerebral, extremity of the optic nerve.

There have been many theories expounded to account for the manner in which the retina performs its functions; but none of these hypotheses are quite satisfactory, inasmuch as they all leave some of the phenomena of vision unexplained. That which is usually accepted as being nearest to the truth, and which accounts for the majority of the facts, is known as the 'Young-Helmholtz' theory. It supposes the existence of three separate and distinct sets of nerve-fibres in close proximity to one another, and so disposed that the whole surface of the retina is well supplied by each set. Each of these three kinds of nerve-fibres is specially sensitive to one of the three primary colours—one set to violet light, one to red light, and the other to green light. But in addition to exciting its own special nerve-fibres *vividly*, each primary colour has also the power to excite each of the other sets of fibres, but *to a much less extent*. When white light (a blend of the three primary colours) enters the eye, all three sets of fibres are, of course, strongly stimulated. Suppose that one of the three sets of nerve-fibres is absent from the retina, the primary colour corresponding to that particular set cannot, *de facto*, be seen; but that primary colour will nevertheless slightly stimulate each of the

other two sets of fibres. In such a case colour-blindness for the said colour is said to exist.

Let us take as an example of this condition, a person in whose retina the fibres for *red* are wanting. This person is incapable of perceiving red in the sense that a normal eye understands it. But the fibres for violet, and those for green, will be slightly stimulated by a red ray, and so he will receive an impression resulting from the stimulation of these two sets only, and consequently a sensation of faint bluish green (a mixture of faint violet and faint green) will result.

So we see that a person who is colour-blind for any particular colour, really sees the *complement* of that colour; and moreover that the said complementary colour thus produced is much less brilliant, *cæteris paribus*, than other colours for which he is not blind.

It has been independently observed by Professor Grossman of Liverpool, by Dr. Edridge Green, and by Mr. St. Clair Buxton of London, as well as by a well-known Swiss ophthalmologist, that there are persons who may be blind for a certain colour when looking at a luminous object (as for instance a signal-lamp) who are quite able to see and recognise the same colour reflected from the surface of an opaque, non-luminous substance (such as a flag). This is an extremely rare form of colour-blindness, but its existence has been proved. Its importance is obvious in considering the proper tests to be employed in weeding out men unfit for railway service.

The usual test recommended for ascertaining if any deficiency of colour-perception is present, is that known as Holmgren's Wool Test. It consists of placing before the candidate a heap of forty or fifty skeins of Berlin wool, of various colours and shades of colour. The examiner picks out one of the skeins, and directs the candidate to match it in colour—*irrespective of shade*, with all the other skeins which at all resemble it. Should a mistake be made, the candidate is at once rejected, but should he accomplish the task satisfactorily another skein differing entirely in colour from the first is presented to him, with instructions to proceed as before. A mistake will here again reject the man. A third skein is used if the second ordeal is passed, on the same terms as the other two.

Many railway companies have hitherto been singularly lax in their methods of examining men for colour-defect. They have often satisfied themselves with directing a foreman to test the man with a so-called 'test-card.' This is merely a stout piece of

paper divided into a few squares, each of a different colour, and any man able to *name* each of the squares is considered fit for duty. It is quite easy to procure these cards, and the candidates can readily be instructed beforehand so as to give correct replies. Obviously the system is useless. Another plan much in vogue, is to take the men out on the line at night and require them to name the colour of certain signal-lights indicated. This is quite as easy a matter as the other, inasmuch as the lamps are fairly *equally illuminated*, and a man who is blind for green knows that a green lamp looks just like a red one, only much *fainter*. Even if he did not know this and simply made guesses, the chances would be equal each time that he named the right colour. Such tests as these are worse than useless, for not only do they not detect colour-blindness, but they foster a false feeling of security which by no means exists.

There is no doubt that the *principle* of the Holmgren Wool Test is the best, and this method of examining candidates should always be used, with, however, the addition of a luminous test to ferret out any cases of deficiency which may have escaped detection by means of the wools. No lantern test is of any use *unless the brilliancy of the illumination can be greatly and quickly varied*, however many pieces of coloured glass it may contain. With lanterns deficient in this feature, the examiner is placed in very similar conditions to those of the men tested by real signal-lights; a man who is conscious of his defect may often pass such tests to the complete satisfaction of the examiner. But place this man on a locomotive, let the weather be misty, the distance from the signal uncertain, and that man will be absolutely unable—perhaps in a moment of imminent peril—to decide whether the dim light before him is red or green. It has been computed that about four per cent. of the male population is colour-blind from birth, and not a few more cases are traceable to tobacco-smoking. It is therefore obvious that not only should all railway servants whose duties necessitate the recognition of signals be thoroughly tested, but also that they should be tested *frequently*.

An instrument named the 'Telechrome' has been for some time in constant use at the Admiralty, which has been found by the naval medical authorities to work admirably. This instrument, devised by Mr. St. Clair Buxton, one of the surgeons to the Western Ophthalmic Hospital, consists essentially of two parts; a lantern, in which the brilliancy of the illumination can be rapidly varied

by moving the arm of a lever, and a metal disc placed vertically in front of the lantern. The disc turns upon its axis at the pleasure of the examiner, and it carries a number of coloured glasses set in small apertures near its periphery. Light from the lantern can only pass through one of the coloured glasses at any given time, and the candidate (who has previously been tested with Holmgren's wools) is required to match a skein of Berlin wool with any similar colours he may be shown in the Telechrome, irrespective of their brilliancy. A colour-blind man who has managed to pass the Holmgren wool portion of the examination, thus finds himself confronted by a far more severe test, and one which he cannot be 'coached up' in. A faint-coloured ray from the Telechrome is more likely to be confused with its complementary colour in Berlin wool, than would two skeins of Berlin wool each complementary to the other. In using the Telechrome, therefore, the examiner shows each of the coloured rays (not in regular succession, but in irregular order) several times, and each time with different degrees of luminosity. If the candidate shows no hesitation in matching or rejecting colours when given first a red skein, then a pale green one, and finally a buff one, it may be safely taken for granted that his vision is normal.

It was stated in evidence given before the committee recently appointed by the Royal Society to inquire into the subject of colour-blindness and colour tests, that no candidate who had once failed to pass the Admiralty colour-tests, had ever succeeded in satisfying the examiners on subsequent occasions.

No test, however good in itself, can be relied on unless the skill and knowledge of the examiner are beyond question. The time and care necessary to employ any test adequately is necessarily long and great; but is of small moment compared with the serious risks to life and property which must be incurred, when men are intrusted with the charge of trains, without having been subjected to the most searching examination.

APPENDIX K.—PARTICULARS OF SOME OF THE LARGE RAILWAY BRIDGES IN INDIA.

APPENDIX K.

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Standard Gauge Railways. 5 ft. 6 in.	Name of Bridge.	No. of Spans.	Span in clear.	Max. depth of founds be- low low- water.	Height low water to under side of Girders.	Total length of Bridge.	Total cost, including Protective Works.	Remarks.
EAST INDIAN RAILWAY.	Sone,	28	Feet. 150	Feet. 32	Feet. 35½	Feet. 4726	Ra. 43,33,324	{ For double line, railway above and roadway below. Single line. Do. Do. For double line. * Includes plant and supervision. Brick arches. Single line. Piers for double line. For double line. Single line. Piers for double line. Do. Do. Does not include cost of old bridges renewed. * Approximate only.
	Jumna—Allahabad, {	14	200	42	60	3235	44,46,300	
	Jumna—Delhi,	12	30	39	23½	2640	16,60,355	
	Jubilee—Hooghly, {	2	524	98½	55	1213½	32,51,514*	
	Approach viaducts. {	1	106½	...	...	3719	5,44,874	
GREAT INDIAN PENINSULA RAILWAY.	Kistna,	36	100	9	48½	3855	12,73,066	Single line. Piers for double line. For double line. Single line. Piers for double line.
	Tapti,	28	59	16	60½	2556	16,27,248	
	Nerbudda,	5	138	4½	81½	1052	6,60,096	
BOMBAY, BARODA, AND CENTRAL INDIA RAILWAY.	Nerbudda,	25	183½	76	48½	4687½	37,75,759	Do. Do. Does not include cost of old bridges renewed. * Approximate only.
	Tapti,	30	60	20	50½	1875	9,02,082	
	Cheyar,	50	64	100	14	3500	12,45,464	
MADRAS RAILWAY.	Tungbhadra,	58	64	14	34	4060	7,55,756	{ Does not include cost of old bridges renewed. * Approximate only.
	Fenner,	13	131	54	22	1830	11,32,077	
	Chitravati,	19	131	78	18	2670	13,58,194	
	Papaghni, { Old,	20	64	...	...	1410	1,62,354	
	Papaghni, { New,	15	131	62	15	2110	9,29,598*	
EASTERN BENGAL.	Gorai,	7	185	96	51	1744	14,83,750	Do. Do. Does not include cost of old bridges renewed. * Approximate only.
		9	46½	25	46½	46,882½	295,45,811	
			Carry forward,					

LARGE BRIDGES—Continued.

Standard Gauge Railways, 5 ft. 6 in.	Name of Bridge.	No. of Spans.	Span in clear Feet.	Max. depth of founds be- low low- water. Feet.	Height low-water to under side of Girders. Feet.	Total length of Bridge. Feet.	Total cost, including Protective Works. Rs.	Remarks.
BHOPAL RAILWAY.	Brought forward, Nerbudda, . . .	14	150	4	65	46,882½ 2240	295,45,811 9,44,171	Railway and roadway on same level.
	Gumti, Jaunpore, . . .	16	82	50	44	1472	7,54,678	Railway and roadway on same level.
	Raneegunge, . . .	34	56	85	26	2260	14,92,400	Heavy protective works.
	Ganges, Raighat, . . .	33	80	55	24½	3040	7,98,199	Do.
OUDH AND ROHILKUND RAILWAY.	Ganges, Cawnpore, . . .	25 2	100 40	65	32	2830	17,46,957	Railway above and roadway below.
	Ganges, Balawali, . . .	11	248	100	40	2904	27,72,709	Do.
	Ganges, Dufferin Bridge, Benares, . . .	7 9	331 104	141	75½	3523	48,91,151	Roadway on same level as railway.
	Solani, . . .	11	148½	60	16	1760	10,12,473	Do.
BENGAL NAGPUR RAILWAY.	Kanhan, . . .	6 2	170 60	26	50	1237	6,72,915	Do.
	Weingunga, . . .	9	150	21	54	1450	10,03,733	Converted from metre gauge.
	Sheonath II., . . .	14	150	12	57	2250	8,83,593	Do.
	Eeb, . . .	9	150	55	38	1401	6,30,425	Approximate only.
INDIAN MIDLAND RAILWAY.	Damuda, . . .	2 10	100 200	75	40½	2364	10,25,549	Do.
	Chambal, . . .	12 2	186 136	75	112½	2714	32,71,035	Abutments and piers for a double line.
	Jumna, Kalpi, . . .	10	250	90	76½	2640	25,27,545	
	Betwa, Manikpur, . . .	13 1	150 60	13	77½	2166	13,95,181	
	Ken, . . .	12 1	100 250	4	65½	1558	7,36,008	
	Betwa, Lalitpur, . . .	9	150	12	56	1446	7,64,672	
Carry forward,							86,197½	568,69,205

LARGE BRIDGES—Continued.

Standard Gauge Railways, 5 ft. 6 in.	Name of Bridge.	No. of Spans.	Span in Clear.	Max. depth of founda- tions be- low low- water.	Height low-water to under side of Girders.	Total length of Bridge.	Total Cost, including Protective Works.	Remarks.
	Brought forward,							
	Beas,	33	99	70	20	86,197½	Rs. 568,69,205	Abutments and piers for a double line.
	Junna, Saharanpur,	26	99	42	19	3820	25,90,166	
	Kaiser-i-Hind, Fero- zepore, Sutlej,	27	144½	78	26	2663½	15,34,600	Railway below and roadway above.
	Ravi,	33	90	75	20	3217	16,02,315	Railway above and footway below.
	Alexandra, Chenab,	64	133½	75	20	9088	56,50,433	
	Jhelum,	50	90	30	20½	4875	17,11,872	
	Attock, Indus,	5	{ 2-368-4 3-257 }	10-12	111	1655	32,20,516	Railway above and military road- way below.
	Empress, Sutlej,	16	250	103	28½	4210	71,02,689	Railway and roadway on same level.
	Adamwahan,	17	150	82	19	2720	19,48,811	Do.
	Victoria, Jhelum,	1	790	...	51	900	27,89,340	Do.
	Lansdowne,	1	270	6	46	620	5,57,380	Do.
	Sukkur Indus,	1	230	90	29	3650	28,34,101	Do.
	Rohri Channel,	1	200	75				
	Sher Shah, Chenab,	17						
	Total,		Standard Gauge			127,909½	925,25,694	

24½
Miles
£9,252,500 at par of exchange.

LARGE BRIDGES—continued.

Metre Gauge Railways. 3 ft. 3½ in.	Name of Bridge.	No. of Spans.	Span in clear.	Max. depth of low- founds below water.	Height of low- water under side of Girders.	Total length of Bridge.	Total cost including Protective Works.	Remarks.
RAJPUTANA MALWA STATE RAILWAY.	Jumna-Agra, . .	16	133	70	31½	Feet. 2272	Rs. 18,33,877	Railway below and roadway above.
	Nerbudda, . .	14	183	14	80	2836	18,73,925	Railway above and roadway below.
	Jumna-Mutra, . .	7	150	71	27	1146	8,49,000	Railway and roadway on same level.
SOUTHERN MAHARATTA RAILWAY.	Bhima, . .	14	150	18½	59	2342	8,30,383	Do.
	Kistna-Byapur, . .	21	150	13	43	3392	11,39,327	Do.
	Kistna-Poona, . .	14	150	4	75½	2339½	8,29,643	Do.
	Hagari, . .	34	64	68½	16½	2396	7,63,905	Do.
BENGAL AND NORTH- WESTERN RAILWAY.	Dorabavi, . .	1	250	...	179½	670	7,088,67	Do.
	Rapti, . .	2	150	86	41	1445	14,29,172	Do.
TIRHOOT RAILWAY.	Gundak, . .	1	66½	90	37½	2176	13,84,883	Footway on each side.
Total Metre Gauge Railways,							21,014½	= 554 Rs. per foot-average.
Total Standard Gauge Railways,							127,911½	= 723½ Rs. per foot-average.
Grand Total all Railways,							148,925½	= 699½ Rs. per foot-average.

28½ Miles
£10,416,867 at par of exchange.

APPENDIX L.—PARTICULARS OF IMPORTANT TUNNELS ON INDIAN RAILWAYS.

Railway.	Name of Tunnel.	Single or double line.	Gauge.	Proportion lined.	Total length.	Cost, including Tools and Plant.	Material.
GREAT INDIAN PENINSULA RAILWAY.	Thul Ghât No. 2, . . .	Double	5' 6"	Feet. 1625—all	Feet. 1625	Rs. 3,90,394	Loose rock.
	Do. No. 7, . . .	Do.	Do.	...	1461	1,77,255	Rock.
	Do. No. 8, . . .	Do.	Do.	...	1247	1,52,325	Rock.
	Bhore Ghât No. 13, . . .	Do.	Do.	...	1395	1,73,649	Hard Trap Rock.
SOUTHERN MAHRATTA RAILWAY.	Do. No. 24, . . .	Do.	Do.	...	1023	1,50,352	Do.
	{ Castle rock, . . .	Do.	5' 6"	1242—all	1242	9,08,615	Loam.
BENGAL NAGPUR RAILWAY.	{ Nandicanama, . . .	Single	Do.	1527—all	1527	4,41,418	Limestone rock.
	{ Bhortonk, . . .	Do.	5' 6"	1000—all	1000	2,09,715	Hard rock, no water.
NORTH WESTERN RAILWAY.	{ Saranda, . . .	Do.	Do.	1253— $\frac{2}{3}$ 388 unlined	1641	7,53,943	Hard Rock. *Still unfinished.
	Karez, . . .	Do.	5' 6"	...	2034	4,41,963	Hard Limestone.
	Iron Gates, . . .	Do.	Do.	...	1233	3,12,679	Do.
	Mud Gorge, . . .	Do.	Do.	1092— $\frac{2}{3}$	1092	4,12,344	Do.
Combined length and cost of 23 Minor Tunnels on various lines, 300' to 900' long,	Khojak, . . .	Double	Do.	5000— $\frac{1}{2}$ 7870— $\frac{1}{2}$	12,870	65,24,872	Shale, clay, and shingle, with much water, nearly all requiring timbering.
	Grand Total, . . .	.	.	.	16,131	39,96,467	Various.
					45,431	150,45,991	
					8 $\frac{1}{2}$ Miles	£1,50,460 at par of exchange.	

**APPENDIX M.—MAIN RESULTS OF WORKING ALL INDIAN RAILWAYS FOR THE
YEAR ENDING 31st DECEMBER 1891.**

Details.	Standard Gauge.	Metre Gauge.	Special Gauge.	Total of all Gauges.
Open Mileage on 31st December, . . . Miles,	10,047.73	6,946.68	288.31	17,282.72
Mean Mileage worked during year,	10,055.82	6,695.22	286.59	17,037.63
Capital Outlay on open line, including steamboat services and suspense—Rs.	1,6869,18,826	5,149,13,408	88,09,682	2,210,641,916
No. of Passengers booked, No.	80,335,272	41,596,189	923,876	122,855,337
No. of Passengers booked per mean mile worked, . . .	7.989	6.213	3.224	7.211
No. of tons of Goods moved, Tons,	19,343,709	6,652,013	163,231	26,158,953
No. of tons of Goods moved per mean mile worked, . . .	1.924	994	570	1,535
Passenger unit miles, Unit miles,	3,561,612,772	1,641,930,653	22,564,548	5,226,107,973
Ton mileage of Goods, Ton miles,	3,589,116,058	845,567,526	4,308,847	4,438,992,431
Train Miles, Miles,	42,047.302	18,257.923	494.940	60,800.165

APPENDIX M.—MAIN RESULTS OF WORKING ALL INDIAN RAILWAYS FOR THE YEAR ENDING
31ST DECEMBER 1891.

APPENDIX M.

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Details.	Standard Gauge.	Metre Gauge.	Special Gauge.	Total of all Gauges.
<i>Gross Earnings</i> —Coaching, Rs.	552,25,243	216,93,010	6,19,367	775,37,620
" Goods, "	1,240,28,024	313,59,858	6,93,304	1,560,81,166
" Steamboat, Telegraph, and Miscellaneous, "	48,08,465	19,58,026	1,7,513	67,84,004
Total, "	1,840,61,732	550,10,874	13,30,184	2,404,02,790
Gross Earnings per mean mile worked, "	18,304.00	8,216.44	464.42	14,110.11
<i>Working Expenses</i> —Maintenance, "	232,65,868	75,30,981	1,98,783	309,95,632
" Locomotive, "	277,72,861	97,83,966	2,71,849	378,28,676
" Carriage and Wagon, "	80,18,041	23,11,739	80,889	104,10,669
" Traffic, "	126,59,477	44,34,979	1,47,406	172,41,862
" General, "	74,49,011	38,13,184	1,29,387	113,90,224
" Steamboat—Special and Miscellaneous, "	39,38,543	12,07,401	24,106	51,71,408
Total, "	831,03,801	290,82,250	8,52,420	1,130,38,471
<i>Working Expenses</i> per mean mile worked, "	8,264.25	4,343.73	2,974.35	6,634.64
Percentage of Working Expenses to gross earnings, "	45.15	52.87	64.08	47.02
Net Earnings, "	1,009,57,931	259,28,624	4,77,764	1,273,64,319
Percentage of net earnings on total Capital on open line, including suspense, "	5.98	5.04	5.42	5.76

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APPENDIX N.

Statement showing the Quantity in Tons of Coal produced in India during the last twelve years.

Years.	Bengal.	Punjab.	Central Provinces.	Assam.	Central India.	Nizam's Territory.	Madras.	Baluchistan.	Total.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1880	988,565	...	31,228	...	...	...	...	...	1,019,793
1881	930,203	...	67,527	...	...	...	...	...	997,730
1882	1,038,872	...	91,370	...	...	...	...	...	1,130,242
1883	1,200,957	...	115,019	...	...	...	...	...	1,315,976
1884	1,257,392	...	121,833	16,493	2,100	...	...	...	1,397,818
1885	1,123,700	...	119,116	43,707	7,698	...	...	...	1,294,221
1886	1,186,802	...	117,287	70,859	13,539	...	...	...	1,388,487
1887	1,319,090	7,523	128,981	89,302	15,497	3,259	...	411	1,564,063
1888	1,380,594	11,249	157,768	101,528	41,580	13,382	...	2,802	1,708,903
1889	1,541,356	22,835	144,465	116,676	52,956	59,646	...	7,420	1,945,354
1890	1,626,245	40,677	137,022	145,708	77,842	125,486	...	15,541	2,168,521
1891	1,537,175*	60,714	141,736	154,208	69,741	144,668	70	10,368	2,118,680
Totals,	15,130,951	142,998	1,373,352	738,481	280,953	346,341	70	36,542	18,049,688

* All returns not received.

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