TO KNOW OR NOT TO KNOW: THE SITE CHARACTERIZATION PROCESS AND ITS' ROLE IN HORIZONTAL DIRECTIONALLY DRILLED PIPELINE RIVER CROSSINGS

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ABSTRACT

Since the methodology's inception almost a quarter century ago, application of horizontal directional drilling (HDD) to pipelining has advanced several orders of magnitude. A major outcome of such quantum progression is that HDD is now no longer the strict purview of the technology's artesian-practitioner instigators. Rather engineering principles and procedures are coming to govern the selection, planning, permitting, execution, and followup of HDD for crossing an expanding variety of pipeline obstacles - especially rivers.

Collaterally, the investigative state-of-the-art for engineering trenchless construction of pipeline crossings has also evolved. However, the requisite site characterization process's development and employment have been constrained both by the present-day tendency for adversarial relationships on the job-site as well as the modern penchant for construction related litigation. In essence; the qualitative, decidedly non-engineering goals of avoiding responsibility for unknowns and shifting liability for changed conditions has - under the guise of risk management - often times precluded a thorough, quantitative pre-construction understanding of the site and its' possible effects on the intended installation: "Since I can't be blamed for what I don't know, I should therefore remain (blissfully) ignorant".

Based on the tri-faceted premise that:

- a pipeline crossing's objective is efficient transmission of gas or liquid products over, through, or beneath the in situ obstacle;
- the true adversaries on any such project are *humankind* and *the site* itself;
- the site's conditions, i.e. the project's unknowns, can never be completely quantified;

this paper delineates a comprehensive investigative process to support the engineering of HDD construction. As developed via performance of more than 250 pipeline river crossing site studies during the past decade and a half, the constituent categories of information as well as the type-classification of such data are defined. The manner/timing of investigation performance plus the roles/responsibilities of the various participants are discussed. Finally, an examination of the uses to which study results are/can be put are illustrated by two case histories.

INTRODUCTION

Because successful horizontal directionally drilled (HDD) installations are now commonplace, the construction technique has come to be viewed as the *method of first choice* for a wide array of pipeline crossing applications (Hair and Hair, 1988). Such perception is founded on both the demonstrated innovativeness and skill of the technology's developer-executor contractors together with the emerging design capabilities being applied to such endeavors. In line with this understanding that HDD is an engineerable, i.e. plannable, construction procedure has been the realization that its' sensitivity to site conditions was/is the major detriment to its' use. Consequently, HDD employment - increasingly dependent on before-the-fact engineering - now requires a continuously improving definition of site conditions in order to:

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- enhance/streamline design and permitting procedures,
- increase chances for construction installation success,
- augment prospects for the completed facility's long term performance/integrity.

Since HDD installation is much more sensitive to in situ conditions than is the service performance of the emplaced pipeline, the majority of the crossing's engineering effort should logically be directed toward support of the construction procedure itself. Keys to continuing the evolution of HDD planning/execution are the complimentary understandings of just **who** the project-specific participants/adversaries are and **how** each such entity affects the ultimate outcome.

In reality, the only two adversaries on any construction project are the site and humankind. The former possesses attributes of time, gravity, and a decided lack of interest in the construction's outcome (i.e. the site does not care). The latter is blessed with inate cleverness and limited resources (i.e. a finite amount of funding). Salient aspect is that - because of its' enduring attributes - the site will invariably/ultimately prevail.

As to construction participation, the site's role is largely passive: it provides the obstacle. However, an active response on the site's part is generally evoked when in situ natural conditions are artificially "destabilized" - i.e. the meandering/scouring of a river generated by installation of bed bank facilities, etc. To the contrary, humankind's largely active influences are felt through an ability to temporarily change the site via artificial construction. Such application of inate cleverness is made efficient via the practice of engineering: planning for (temporarily) overcoming the site-specific obstacle via artful application of scientifically determined, mathematically describable physical properties/natural phenomena.

Per the foregoing points, and in light of one and one-half decades' experience in geotechnically evaluating more than 250 trenchless construction projects nation wide; the following paragraphs summarize an evolving site investigative process applicable to HDD. With much of the discussion extracted from previous publications (Hair, 1993a and 1993c), initial intent is to define a framework for the site study forming the basis of HDD engineering. Afterwards, the

- timing/timeliness of process application;
- roles/responsibilities of the human players in process conduct/administration;
- usefulness of process results

are evaluated. Ultimate goal of the overall procedure is an efficiently executed, long-lived pipeline crossing.

PROCESS DEFINITION

Objective. Any crossing site investigation involves determination and portrayal - i.e. **characterization** - of the in situ aspects relevant to selecting, designing, and executing the construction methodology. Attaining this objective entails producing three types - or classes - of information:

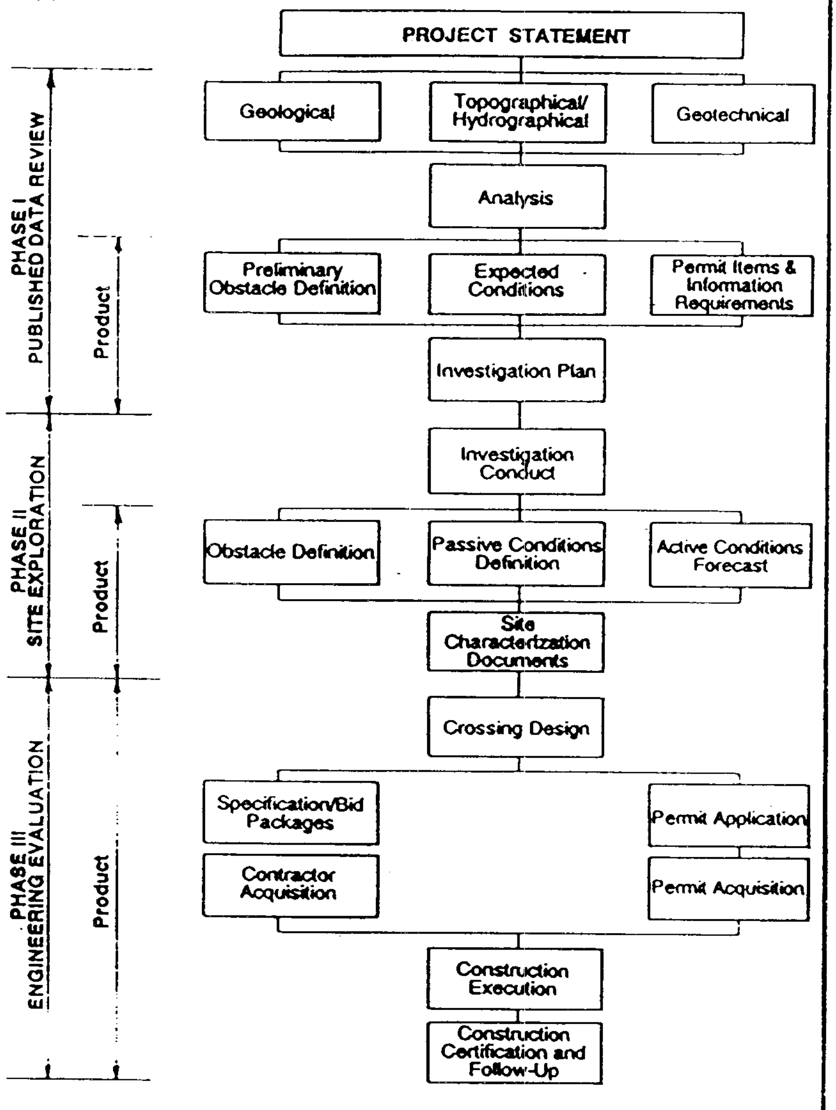
- **Class 1.** Raw data, i.e. *direct measurements.*
- **Class 2.** Processed data, i.e. *analytical results* stemming from experimental testing and computational procedures performed on Class 1 and (often times) other Class 2 data.
- **Class 3.** Evaluated data, i.e. *rationalized opinions* - based on analysis of Class 1, 2, and 3 data - consisting of and/or for input to construction designs, drawings, specifications, bid documents, permit applications, etc.

Results of this sequentially developed body of information are: definition of **what** must be overcome as well as delineation of **how** best to effect the desired outcome.

Structure. Based on the above mentioned points, Figure 1 schematically portrays the site characterization process generally applicable to any HDD crossing. Three phases are featured:

- **Phase I.** Review of available published information.
- **Phase II.** Site exploration.
- **Phase III.** Engineering evaluation for project design, permitting, execution, and certification.

Since details of the individual phases have been completely defined elsewhere (Hair, 1995), only highlights are presented in the paragraphs below. Outstanding feature is that each phase progressively generates an increased size product: approximately half of the Phase I effort is intended for internal consumption by the characterization's latter phases while virtually all of Phase III is destined for external use outside the characterization process.



The Site Characterization Process
Figure 1

Published Data Review - Phase I. Overall effort amounts to assessment of what should be expected from the site in terms of HDD design and permitting. Such understandings allow preliminary definition of the obstacle plus rational configuration of the detailed site investigation plan.

Obstacle Definition. Basically, two obstacle types are negotiated via HDD:

- *Time Dependent.* Obstacles such as rivers (alluvial), zones of migrating subsurface contamination, etc. possessing the capability of expanding and/or relocating with the passage of time.
- *Feature Dependent.* Obstacles such as highway and/or railroad embankments, flood protection levees, environmentally sensitive surface areas, etc. having positionally fixed boundaries.

Primary concerns in evaluating either type are the obstacle's make-up plus its' spatial extent. For the former obstacle category, determination of these aspects must be for at least the design life of the HDD installation. Potamology - the study of rivers - yields a time dependent alluvial obstacle's potential for horizontal displacement and vertical penetration; i.e. a stream's meandering and scouring characteristics during a selected period (Hair, 1991). By the same token, some feature dependent obstacles will also exhibit transitory (time dependent) characteristics - i.e. uncompleted consolidation settlement of a massive highway embankment, integrity maintenance of a flood protection levee, etc. - which must be evaluated. Therefore, a thorough definition of the obstacle to be crossed will not only dictate HDD's geometry/performance characteristics, but also provide data necessary to permit the work plus restore site integrity following crossing completion.

Site Conditions. A thorough understanding of the site's constituency is predicated on the dual-faceted premise that:

- in situ features, both natural as well as artificial, control the manner in which HDD construction is accomplished;
- application of the HDD process elicits responses from the site's features during both the short and long terms.

Consequently, site conditions can be divided into two major groups - **passive** and **active**. The pre-construction investigation for a HDD project usually involves defining, in detail, the former and forecasting the latter.

Passive Conditions. Phase I efforts center on outlining the site's constituency - i.e. its' "makeup"/inplace characteristics. Major considerations are:

- geological factors.
- topographic/hydrographic details.
- geotechnical aspects.

In context, such data forms the basis for adequately characterizing the site.

Geological Factors. Chief informational item is an understanding of the site's origin, i.e. how it came into being. This is important not only in projecting the site's effects on HDD, but also in planning an effective site investigation. An appreciation of the mechanism by which the site evolved - whether through inplace weathering or by aeolian (airborne), colluvial (gravity), alluvial (river), laucustrine (lake), glacial, marine (saltwater sea), etc. depositional processes - forecasts the types of materials to be expected as well as the potential for anomalous impediments (boulders, cobble fields, buried logs, stumps, etc.) affecting HDD construction. In this context, geological evaluation also provides the background for assessing the obstacle.

Topographical/Hydrographical Details. Essential characteristics stemming from these considerations are the site's geometrical configuration and surface condition. Not only do such data initiate definition of the obstacle to be crossed, they also allow rational planning for conduct of the construction. Information products include statements of both the dry land and underwater contours of the site/obstacle as well as extent/positioning of the relevant in situ artificial features/works of humankind. Basically, results constitute the first step in forecasting the efficacy of a HDD installation.

Geotechnical Aspects. Traditionally regarded as the geophysical, or "subsurface conditions", dimension of a site; geotechnical characteristics can be divided into two types: earth material parameters and subsurface stratification.

In terms of *earth material parameters*, four principal categories are:

- material classifications.
- strength properties.
- deformation properties.
- groundwater table/permeability behavior.

Standards manuals - from AASHTO, ASTM, the US Army Corps of Engineers, etc. - plus published texts (Lamb, 1951) present details and test methodologies of/for the first three items. Normally, the phreatic surface is measured in situ. However, the potential for variation must be derived from review of longer term site-specific records. Permeability can be determined through laboratory testing via either direct measurement (falling head, constant head, or triaxial evaluation) or indirect extraction from consolidation test time-rate parameters.

Defined as the manner in which earth materials are distributed throughout the site, *subsurface stratification* - i.e. the profile - is composed of two interface types: *material* and *conditional*. A material interface is the demarcation between two dissimilar classifications - clay/sand, rock/gravel, etc. - while a conditional interface is the differentiation, based on inplace state, within a particular earth material type - loose/dense sand, soft/hard clay, etc. Also a part of stratification determination is assessment of the possibilities for natural as well as manmade anomalous "impediments" to HDD conduct. Buried logs, stumps, small areal extent gravel pockets/cobble fields, boulders, etc. exemplify natural anomalies. Manmade determinants consist of existing pipelines, sunken barges, bulkhead/bridge pier piling, etc. Strictly speaking, the *subsurface profile* - graphically incorporating geological/potamological and geotechnical findings in the context of topographic/hydrographic measurements - should be the primary means of reporting the site's passive conditions relative to HDD.

Active Conditions. Essentially the "products" - whether intended or not - of HDD; this category of subsurface conditions includes (Hair and Schultz, 1994):

- shape/condition of the bored hole (the directional drilling's actual "geometry");
- the various efforts/procedures necessary to complete the HDD installation (pull force/torque requirements; carrier pipe buoyancy adjustment; downhole equipment alterations, etc.);
- response of the site's passive conditions to the directional boring process (drilling mud surface seeps, deformation and/or destabilization of surface embankments, potential for free flow of groundwater along the soil-pipe annulus, development of underground voids, groundwater quality alterations, etc.);
- short/long term effects on the installed pipe (placement stresses, corrosion potential, loadings/deformations due to future construction at the site surface, etc.).

Simply stated, active conditions are the *construction dependent phenomena* at a given location: the site's responses - i.e. behavior - when subjected to drilling plus HDD's in situ performance peculiarities. Because a lengthened construction time and greater physical effort are involved, active conditions are more manifest during large diameter HDD installations. In fact, the diversity and severity of a site's active responses constitute two of the major differences between large and small diameter HDD projects. In any case, knowledge of *active conditions* is necessary to adequately configure the site-specific *investigation* inherent to a HDD project.

Site Exploration - Phase II. Constituting physical determination of the surface and subsurface conditions outlined during study initiation, execution produces/finalizes the Class 1, 2, and 3 information needed to fully define both the site as well as the obstacle. Project-specific data/recommendations relative to design, permit acquisition, and construction ensue.

Field/Laboratory Work: Classes 1 and 2 Data Production. At the present time, topographic/hydrographic particulars stem from *traditional land/water-bottom surveying* as well as *emerging technologies*: global positioning systems (GPS), satellite mapping, side-scan sonar imaging, etc. Results can/should also be used to configure the characterization study's subsequent conduct.

The *below ground investigation* primarily rationalizes subsurface stratification: material interfaces, conditional interfaces, and inplace anomalies. Definition of such items provides the basis for assessing the obstacle's time dependent/feature dependent bounds in addition to HDD's site-specific efficacy. Basically, two techniques are available: *intrusive* - i.e. sample borings, penetometer soundings, etc. - and *non-intrusive* - i.e. reflective-refractive surveying, ground penetrating radar, etc. Since the constitutive methodologies are fairly well known, discussion of particulars is not germane. The important understanding is that intrusive sample borings generate "point-specific" profile details plus specimens for followon testing while intrusive soundings and the non-intrusive techniques quantitatively measure the various "inter-boring" interfaces and subsurface anomalies. Complimentary performance of both investigative techniques is therefore necessary to completely evaluate a given site.

Followon *laboratory testing* of samples resulting from borings experimentally defines the earth material parameters - especially those factors varying with time and/or imposed loading - needed for conducting job-specific analytical procedures.

Key points regarding Class 1 and Class 2 data are: all field exploration/laboratory testing efforts must be accomplished as part of a coordinated effort and then resolved - via engineering evaluation - into Class 3 information. Raw and processed data are not ends in themselves but rather the foundation for developing analyzed data/rationalized opinions.

Analytical Work: Class 3 Data Production. Per the field/laboratory efforts' body of Class 1 and Class 2 data, various engineering processes/procedures culminate in Class 3 opinions regarding the site. Considering location-specific natural/artificial features, these assessments of the project's/site's mutually interactive effects could entail: riverbank/flood protection levee slope stability analyses, embankment under-seepage evaluations, subsoil elastic/plastic and consolidation (time-dependent) deformation determinations, etc. While discussion of details is beyond this present paper's scope, it is imperative that all findings be graphically portrayed - in concert with the in situ obstacle's time dependent/feature dependent bounds - on the *subsurface profile* presenting the site's passive conditions. Since such an integrated depiction of site characterization findings is the *Class 3 data basis* for HDD design and execution; it must be as inclusive as possible, easily understandable, and pervasively distributed.

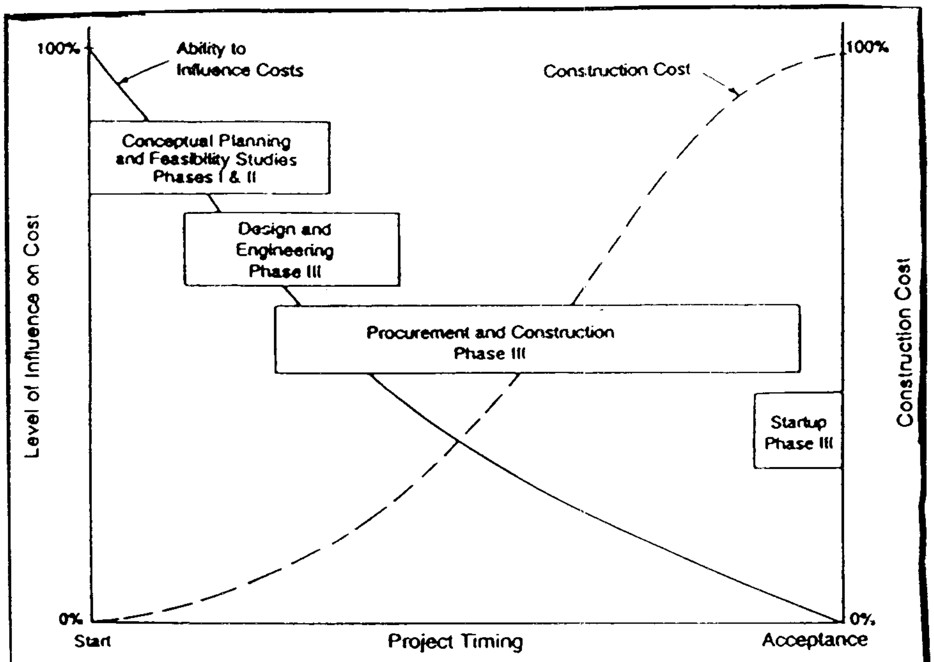
In sum, Phase II is the nominal heart of the site characterization process. By *documenting* the in situ obstacle and the site's passive conditions - plus *forecasting* the location's active responses to HDD; phase "products" are useful to all of the project's participants. Comprehensive presentation/widespread dissemination of the resultant Class 3 information - plus the progenitor Class 1/Class 2 "backup" details - not only foster efficient HDD planning and performance; but also enable expeditious pre-construction permitting, timely during-construction problem solving; and straight forward post-construction certification.

<u>**Engineering Evaluation - Phase III.**</u> Encompassing the overall project's design and installation efforts, Phase III is not usually regarded as a site characterization item. However, because such pragmatic activities are the culmination of the site study; their efficient execution may require adjustment of Phase II recommendations and/or development of additional information. Furthermore, evolution of the site characterization process itself is directly dependent on feedback from project-specific design, permitting, and construction experiences. Consequently, Phase III is, in actuality, a site characterization component.

Performance of Phase III begins with resolution of Phase II's product documents into: HDD design drawings, construction specifications, permit applications, and contractor bid packages. Construction contracts plus construction completion certifications ultimately emerge. To facilitate all these tasks - whose accomplishment is increasingly in conformance with mainstream engineering practice; organizations such as the American Gas Association's Pipeline Research Committee (AGA-PRC), the Directional Crossing Contractors Association (DCCA), and ASCE are now publishing design/procedural conduct manuals (PRC, 1995). While space limitations of this paper preclude detailed treatment of these items and the other Phase III topics, significance is that the stated procedures represent rational application of engineering to HDD pipeline crossings. Such engineering is based on the understanding that before-, during-, and after-construction matters must all be addressed to maximize the chances for a successful, economical trenchless pipeline placement.

PROCESS TIMING/TIMELINESS

As with the other aspects of engineered construction; site characterization results must be expeditiously generated in order to beneficially influence the overall project. Figure 2 (Hendrickson and Au, 1988) illustrates the relative effect of site study timing on a typical HDD project. Salient point is that development and dissemination early-on of accurate, site-specific Class 3 data promotes harmony among the project's participants plus engenders efficient stewardship of their limited monetary resource.



Ability to Influence Construction Costs/Project Efficiency
After *Hendrickson & Au*.
Figure 2

Somewhat counter to the foregoing notion is a trend in standard tunnelling - a technological "cousin" of HDD - toward performance of detailed, post-design site characterization reviews (Gould, 1995). Intent of these is to pre-determine "differing subsurface conditions" should site-related problems arise during construction. Even though such studies' results are extremely useful in tunnelling to enhance down-hole worker safety plus reduce/resolve disputes among the project's participants, their ability to elevate HDD success chances and/or foster economy are restricted by a lack of timeliness. In fact, discovery of site conditions potentially differing from those assumed by the HDD design should - at the least -

call for a "tie-breaker" re-evaluation analysis. At most, such revelation could mandate redesignof the project and/or renegotiation of the construction contract. Overriding consideration is that - for maximum benefit - the HDD site characterization study must be developed as precisely and as extensively as possible for employment as early in the design process as practical.

PROCESS PARTICIPANTS/ROLES

Originally, site characterization responsibility rested almost entirely with the artesian-practioners: as part of the crossing's price, a HDD contractor would commission alignment surveying plus core borings. The resulting information - developed shortly before construction start-up - was generally closely held and mainly geared to supporting drilling execution. Mostly Class 1 data relative to passive site conditions was generated with little regard given to defining the obstacle or forecasting the site's active responses. Of greater import, though, was that - while some study of HDD execution and problems/failures was accomplished - virtually no Class 2 or Class 3 data was produced to explain implementation successes. HDD technological advancement therefore required/relied on: the considerable cleverness and skill of the individual constructors, a certain degree of luck, plus an occasional failure.

As HDD matured, site study impetus shifted to the project owners. Partly driven by the requirement for environmental permits, owners increasingly began to employ specialized consultants for configuring and conducting site/obstacle focused investigations well in advance of drilling execution. Development of formalized characterizations was also encouraged by professional/industrial technical groups and trade associations: the ASCE, AGA-PRC, and DCCA plus the International and North American Societies for Trenchless Technology, the Trenchless Technology Center at Louisiana Tech University, etc. In turn, this tendency for early production of project-particular Class 3 data by formally schooled investigators has resulted in site characterization products gaining wider acceptance from crossing design engineers as well as regulators/permitters and HDD contractors. Additional outcomes have been: a rational basis for planning such installations, a "level playing field" for the construction bidders, a studied means for assessing/solving HDD performance and site-related problems, plus a quantitative foundation for transferring/applying job-particular experience to other project locations. Although contractor competency still remains the cornerstone of HDD utility, such site characterization outgrowths have largely removed luck and infrequent installation failures as drivers of technology advancement.

At the present time, project owners are continuing to engage independent specialists for performing the sequentially staged generation of raw, processed, and evaluated data. This assignment of "engineering responsibility" is logical since the owner - involved in the project from conception to termination - is best able to orchestrate timing and efficient use of the talents/atributes of knowledgeable consultants, designers, and contractors. Ultimately, because the owner will derive the greatest benefit from the completed crossing, he cannot avoid overall responsibility for its' planning and efficient execution.

While a holdover opinion exists that qualifying and/or compartmentalizing - i.e.. "risk-managing"- liability can be achieved through saddling other project team members (generally the contractor) with site characterization responsibility; such thinking is not in the best interests of a comprehensive study nor a well managed crossing. Besides providing the basis for adversarial conflicts among the project's participants - and thereby fostering expenditure of resources on intra-team squabbles rather than against the site; this thought process invariably precludes timely development/effective use of site characterization data.

PROCESS USEFULNESS

Undoubtedly, the single most important aspect of a site characterization study is that its' results be used. To illustrate this point, the following paragraphs briefly describe two relatively recent HDD installations accomplished with widely varying degrees of efficiency.

Gulf Coast Shore Landing: Southwestern Alabama. Performed in mid 1990; this nearly 915 meter (3,000 foot) long, roughly 24 meter (80 foot) deep, 200 millimeter (8 inch) nominal diameter pipeline was placed to carry offshore-gathered crude oil beneath the ship channel and adjacent beach constituting lower Mobile Bay's western edge. Project site characterization was, at best, sketchy: an alignment trace topographic/hydrographic survey plus a single soil exploration boring laterally off-set about 610 meters (2,000 feet) from the HDD rig's onland set-up point. Such Class 1 data was augmented by a small amount of like information from a nearby HDD shore landing for/by others.

The HDD contract - executed between the owner and general contractor prior to engagement of the drilling subcontractor - assigned responsibility for the design, plus most of the execution risk, to the constructor. However, based on the characterization study's "findings", contract language limited contractor liability for site-related HDD problems solely to those difficulties caused by naturally occurring clay, silt, and sand subsoils.

Crossing installation ultimately required four pilot hole attempts. The first three of these failed due to an "impenetrable" subsurface obstruction horizontally located approximately 760 meters (2,500 feet) from the HDD bore's onshore entry. Loss of drilling/tracking equipment down-hole, standby of pipe-lay barges, plus overall delay of the project ensued. As would be expected, these rather expensive consequences evoked a series of claims/counter-claims culminating in an owner versus general contractor lawsuit.

Based on litigation-driven forensic engineering - in this case amounting to the "post-event" conduct of a comprehensive site characterization's Phase I together with an evaluation of pilot hole conduct and geometry (Hair, 1993b); the obstruction was determined to be a cheniere, i.e. a buried shell reef. Partly because such a profile anomalie did not constitute an earth material for which the constructor was contractually responsible, the owner eventually paid job extras/damage awards approaching two million dollars.

The extra cost was entirely unnecessary. Application of a thorough, pre-construction site characterization would - as a minimum - have generated the Phase I information stemming from the forensic evaluation. Each member of the team could have been made better aware of - and taken appropriate steps to address - the site's conditions crucial to HDD. Since reliance was placed more on contractual posturing than quantitative site definition; a relatively straight forward HDD installation was unduly complicated, unnecessarily delayed, and made inordinately expensive.

Mississippi River Crossing: Southeastern Louisiana. Installed underneath the river's lower reaches just upstream of New Orleans, this project entailed placement of an 825 meter (2,700 foot) long by 36 meter (120 foot) deep, horizontally curving, 510 millimeter (20 inch) nominal diameter natural gas pipeline. Construction - in a rather congested utilities corridor - occurred in early 1992. Although not strictly a part of the directional bore, the overall project also included surface-laid crossings of the channel bounding flood protection levees and jack-bored pipe installations beneath the adjacent state highways. Consequently, a thorough site characterization (Eustis and Hair, 1992) - involving Phases I, II, and III - plus a detailed design were performed by specialists acting on behalf of the owner.

Using the site characterization's products, the requisite state and federal highway-levee-river crossing permits were expeditiously acquired and an HDD contractor engaged. Actual installation went smoothly: less than three weeks elapsed between the HDD equipment's onsite arrival and its' final departure.

A potentially significant installation roadblock developed just prior to construction start-up when a state agency - in a letter-permit offering no objection to the HDD construction - stipulated that the bored crossing's entire annulus (space between the pipe and surrounding soil) be sealed with pressure injected grout. Because doing this would have made the project either overly expensive (via development/purchase of delayed-set grout) or technically unfeasible (standard grout would likely have set-up prior to carrier pipe pullback completion);

several urgent conferences were held with the responsible state officials. Such discussions revealed Louisiana's concerns for the "open annulus" were based on beliefs that groundwater quality degradation plus levee slope instability (landsliding) would result. In both instances, however, the site characterization's quantitatively generated Class 1, 2, and 3 data rationally demonstrated that an HDD installation's presence would not generate these problems: the subsurface profile's hydraulic connection to the Mississippi River obviated HDD's water quality effects while size and offset positioning of the bore's surface penetrations could not mechanically impinge the levee embankments. The requirement for a complete annular seal was therefore lifted and replaced with the much less stringent mandate for surficial grout plugs. Extending along the annulus for only a short distance below both riverbanks, such site restoration measure was easily accomplished at minimal expense following carrier pipe pullback.

Final result - the HDD crossing's economically efficient performance - demonstrates the value of a detailed characterization study in overcoming the site's physical aspects as well as in meeting regulatory/statutory requirements.

CONCLUSION

The site characterization process presented by this paper - progressively developed during the past 15 years - offers a logical foundation for achieving cost effective, efficiently constructible HDD pipeline placements beneath a host of obstacles: rivers as well as other natural and artificial features. Outstanding point is that the products of such investigative effort are of greatest value when widely disseminated and employed early in a project's planning. In this manner, process utilization injects the benefits of quantitative engineering into the installation of HDD pipeline crossings.

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