River-activity history evaluation critical in horizontally drilled crossing design

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Thorough evaluation of a river's activity and historical movement, especially through preconstruction surveys, will enhance chances for a successful horizontally drilled pipeline river crossing.

The first article on the subject of river crossings (OGJ, Sept. 19, p. 96) examined the installation process and how its advantages and limitations affect crossing design.

This conclusion will explore the effect of river activity on design, how preconstruction surveys should be conducted to define future river movement, and how design and installation procedures might be improved.

River-activity mechanisms. Efficient use of the advantages offered by horizontal drilling requires primary consideration be given the obstacle itself, the river.

A river is a dynamic entity which transports water and entrained soil material from its source to its mouth. In this process, a large path (valley) is established in the pre-existing earth material.

The extent of such a valley depends upon the stream's ability to scour vertically and meander horizontally into the surrounding soils. Capacity for this river "activity" is primarily a function of the current's velocity, which in turn is controlled by the stream's hydraulic gradient.

For the most part, a river's hydraulic gradient will vary over geological time but remain constant over much shorter periods. Consequently, a river's long-term ability to erode boundary soil conditions will produce a valley during periods of steep hydraulic gradients and partially fill, with alluvial sedimentation, the previously formed valley in times of shallow hydraulic gradients.

Further discussion of the mechanisms driving hydraulic-gradient change over the course of geologic time is outside the scope of crossing-design interest.

During the short-term, i.e., the crossing's economic life, the river regimen (mechanism for positioning or shaping of the channel within the valley) is driven by the stream's seeking equilibrium between current speed, i.e., entrainment capacity, and the erodibility of the previously deposited alluvium.

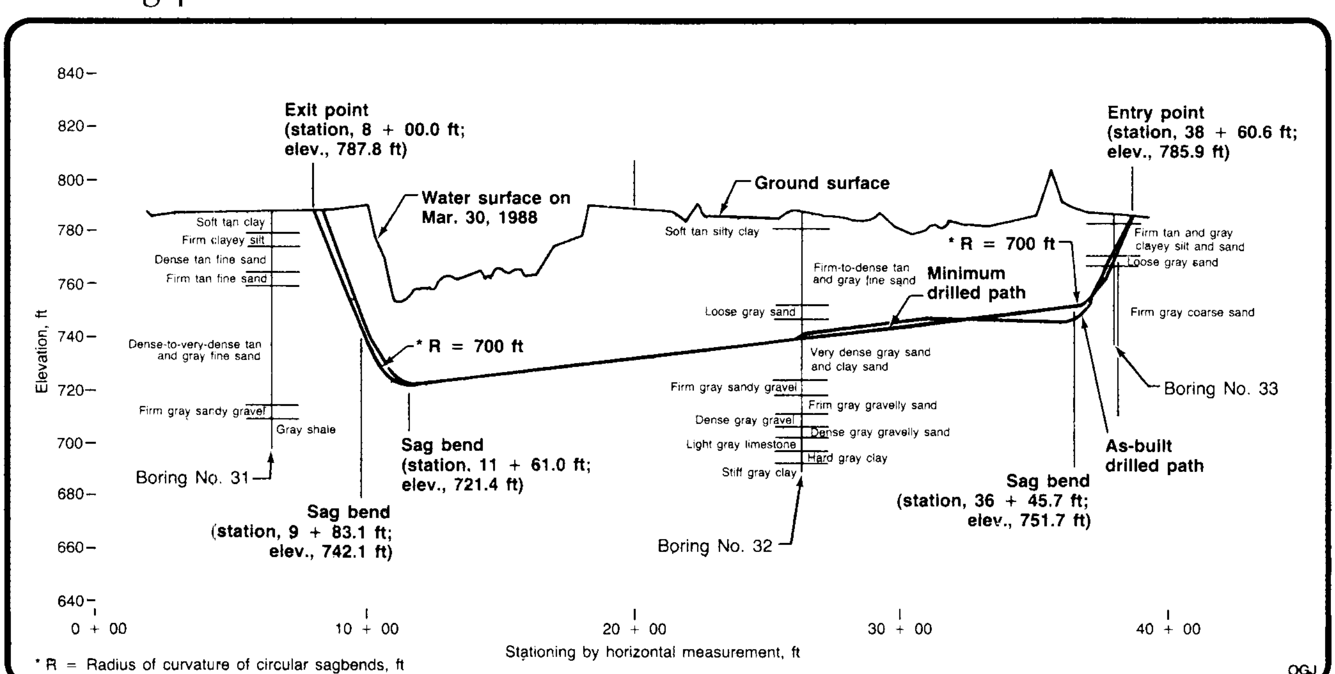
Because alluvial soil conditions are not completely uniform, the river channel location and cross-section configuration must vary in attaining such balance.

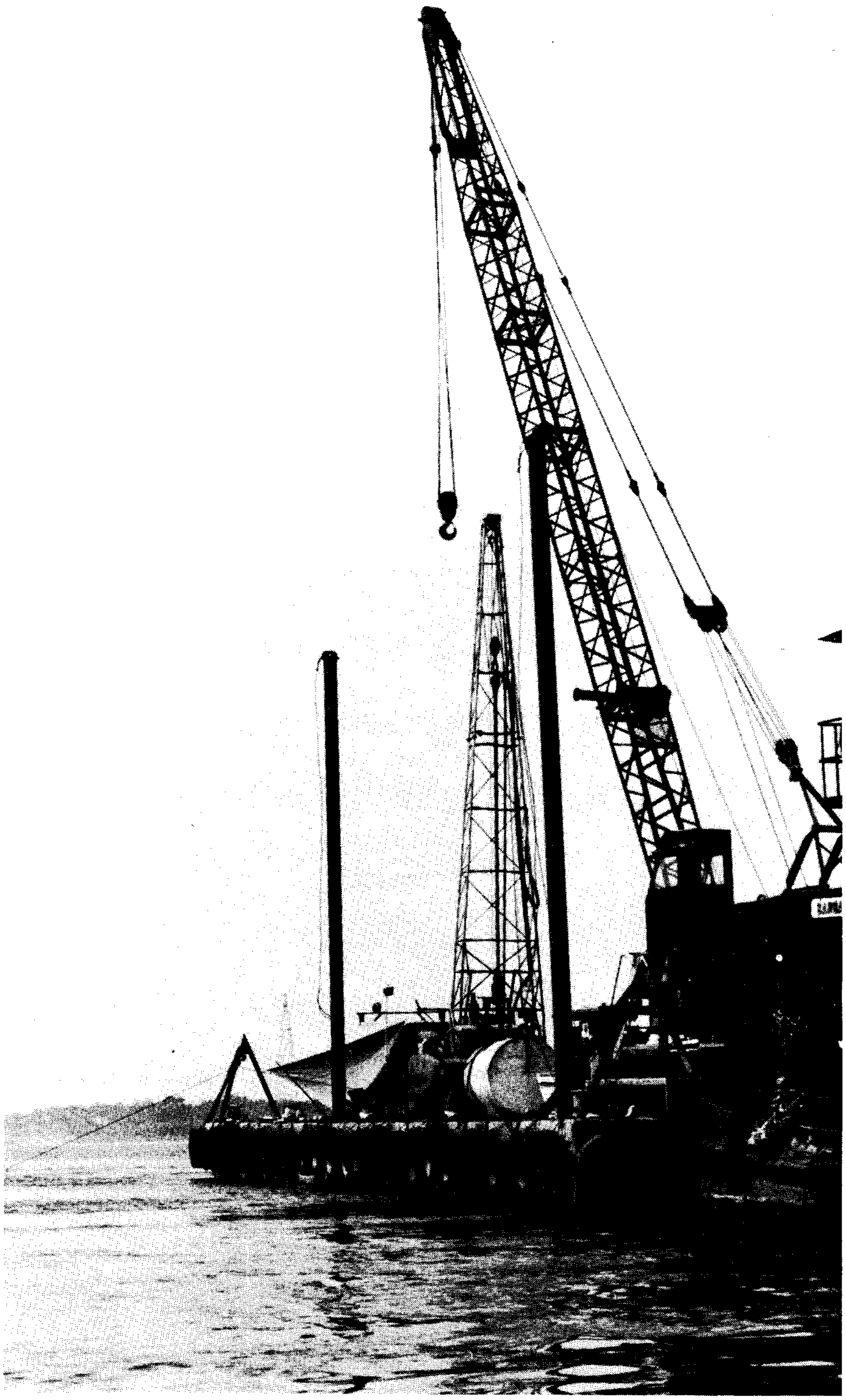
The river will meander and scour to preserve its established hydraulic gradient.

Of course any nonearth anomalies in the bed also generate river activity. Conventionally placed or exposed pipelines, bridge piers, docks, mattresses, rip-rap, etc. tend to attract response by the river's current.

Fig. 1

Crossing profile





Typical geotechnical survey drill barge on station in the Mississippi River. Soil coring rig is the "A" frame mast positioned between the two barge spuds, the vertical pipes at either end of the barge. The crane sets and retrieves the spuds for borings in water less than 35 ft deep (Fig. 2).

In essence, an understanding of the river regimen is the first step in predicting in situ soil conditions as well as projecting future horizontal and vertical channel movements.

This step in turn affects design of the pipeline geometry. The line must be planned for placement in amenable soil conditions sufficiently far removed from likely channel activity to preclude disruption during the crossing's intended life.

Crossing alignment. Selection of pipeline depth below the existing thalweg (point of lowest channel-bottom elevation) should rationally be based on the river's demonstrated capacity for scour.

Scour potential, greatest during floods, is often indicated by a zone or layer of resistive soil material contained in the alluvium. Examples are substrata of gravel (whose particle size is sufficient to resist entrainment by the river during normal flows) contained within a mass of more easily scourable sand, a significantly denser sand layer underlying relatively loose sand (i.e., a conditional interface), and nonalluvially deposited material (clay or rock) beneath alluvial silt/sand (i.e., the river valley boundary conditions).

Placing the directionally drilled line beneath, or in, such scour-limit indicators provides a protective cap or encasement.

Additionally, dense nonerodible sands and nonalluvial clays generally offer optimum conditions for drilling conduct.

Avoidance of line disruption by river meander normally depends on the ability to assess the river's capability for attacking its banks. Bank attack can occur through direct erosion, washing away of soil material, or by collapse due to destabilization brought about by subaqueous slope erosion, development and propagation of landslides.

In either case, the result will be relocation of the existing channel which will hazard a crossing's overbends or sagbends.

Quantitative data as to bank material strengths and toughness are necessary for computation of erosion potential and slope-stability safety factors.

Another aspect of meander assessment is determination of the potential for gross channel relocation: re-establishment of the river in a location different from the existing position. Examples are meander cutoffs to form oxbow lakes, reactivation of inactive channels, reoccupation of former courses, and development of entirely new paths.

This type of horizontal movement is driven by channel activity elsewhere, both upstream and downstream, as the river adjusts its length to preserve the established hydraulic gradient. For example, a significant meander cutoff generates the potential for queuing up elsewhere along the channel.

Conversely, development of a large meander bend allows for channel straightening at another location. Primarily at risk from gross channel relocation are the on-land approaches to the crossing proper.

Assessment of the river's potential for meandering allows crossing entry or exit point and angle selection for avoidance of bank attack and, in some instances, gross channel relocation.

Site investigation. The four major components of a site investigation for a drilled crossing are a topographic survey, a hydrographic survey, a geological review, and a geotechnical survey.

Although each component may be performed by specialized engineering consultants, it is important that all the results be integrated onto a single plan and profile drawing (Fig. 1) which will form the basis of any contract and be used by the drilling contractor to price, plan, and execute the crossing.

Because this drawing will also be used to make the working profile which will be the basis for downhole navigation accurate measurements are essential.

- Topographic survey. The purpose of the topographic survey is accurately to describe the working areas where construction activities will take place. Both horizontal and vertical control must be established for use in referencing hydrographic and geotechnical data.

A typical survey should include overbank profiles on the centerline range extending from approximately 150 ft landward of the entry point to the length of the prefabricated pull section(s) landward of the exit point. Survey ties should also be made to topographic features in the vicinity of the crossing.

- Hydrographic survey. The purpose of the hydrographic survey is accurately to describe the waterway bottom contours. A typical survey should consist of fathometer readings along the centerline range and approximately 100 ft upstream and downstream.

This scope can be expanded to include more upstream or downstream ranges if these data are required to analyze future river activity.

- Geological review. An essential step in engineering a horizontally drilled crossing is to gain an overall understanding of the earth materials—types and origins—constituting the site's vicinity.

Objective of the geological review, and component potamological assessment, is establishment of the river valley's boundary/internal conditions and development mechanism(s). This information will assist in determining the river's past and future capacity for activity, help tailor the follow-on site-specific geotechnical survey (borings, etc.), and indicate the potential for such anomalies contained in the alluvium as gravel or boulder zones of glacial deposition, cemented marine sediments from ancient coastal regions, etc.

Geological data can generally be obtained from published sources. Unless a specific study is available (as is the case for a large river), potamological information must be derived from site records or review of "obsolete" (archival) topographic maps.

In any case, geological/potamological findings must be tempered by an on-site reconnaissance.

Outcome of the geological review is development of an initial crossing geometry.

Based on this, the follow-on site-specific exploration and engineering can be effectively planned and efficiently conducted.

- Geotechnical survey. An accurate description of site-specific subsurface conditions affecting river activity and crossing instability must be obtained. It will normally consist of borings, laboratory testing of recovered samples, and engineering analyses of the resulting data.

Spacing, depth of borings. Derived from pre-exploration engineering, borehole spacing and depth will depend on the crossing configuration (probable length and penetration depth) plus expected soil conditions. As a prerequisite, all borehole locations and surface elevations must be surveyed.

Borings spaced 300-500 ft on centers for relatively short crossings and 500-800 ft on centers for longer crossings are adequate unless significant soil anomalies are expected. Then, a closer spacing, depending on the probable anomaly extent, should be employed.

Marine (in river) borings will be necessary for longer crossings (Fig. 2). Shorter crossings will not require such expensive exploration components unless subchannel conditions critical to crossing design and placement cannot be determined from land boreholes.

Alternately, should access to the crossing site by land be untenable, borings from a barge in the channel may be the only means for subsurface exploration.

Alignment of the borings should be within 100 ft of the crossing's intended course; exact correspondence is necessary if small, drilling-restrictive anomalies (boulders, etc.) are likely.

For the most part, all nonmarine subsurface penetrations should be grout sealed upon completion to restore site integrity and prevent crossing installation interference such as leakage of drilling mud.

Depths of the borings should be sufficient to define pertinent soil conditions and explore the material which the pipe installation must negotiate.

Usually, sampling to 30 ft below the crossing's expected penetration depth will be adequate.

In some instances, however, deeper penetration into the underlying nonalluvial soils constituting the valley-based conditions will be necessary adequately to evaluate the site.

For large jobs, two field explorations may be warranted. A few widely spaced, though deep, borings may be conducted initially. Once the line is actually designed, a more closely spaced, depth-restrictive set of borings can then be made to define anomalies at potentially critical points such as pipe sagbends.

Sampling techniques. Sampling of the borings should involve obtaining undisturbed cores as well as standard penetration test (SPT) specimens. Undisturbed Shelby-tube samples, generally of cohesive (clay) soil, i.e., open-hole structure soil, will allow detailed strength testing as well as deformability and permeability evaluations.

Such information is important for conducting bank stability or erodibility analyses and drilling-performance assessments.

SPT sampling (blow counts for N values) usually of granular (gravel, sand, and silt) soil, such as fluid-behavior structure soil, will provide empirical in situ densities as well as classification samples.

Testing of these samples is critical for assessing granular soil drillability when gravel is present.

Also of importance is the conduct of rock coring when Shelby tube or SPT-impenetrable strata are encountered. This will define possible anomalies as well as the makeup of river-valley base materials.

Throughout the course of borings, records should be kept of drilling performance such as type of bit used or ease of penetration. Such information should be transmitted to the directional-drilling contractor for use in tailoring equipment and conducting the pipe bore.

All undisturbed core samples should be subjected to strength testing, generally unconfined compression checks.

Particular attention should be paid to the existence of prefractures ("slickensides"), organics, roots, and other such anomalous features in these specimens.

These conditions will bear on directional-drilling performance as well as a river's activity potential.

If required, more sophisticated strength testing as well as permeability and deformability analysis can be run. Clay-soil classification testing should consist of Atterberg-limit determinations.

When necessary, mineralogical evaluation of rock specimens can be made.

SPT-sampled material should be subjected to sieve analyses for grain-size distribution determination, especially if gravel is present.

Data for assessment of drillability, as well as resistance to river activity, will result.

Improvements. In site investigations, primary focus should be on developing a more detailed picture of the crossing site's subsurface conditions.

Although sampled boreholes will continue as the major source of such information, their cost and execution timing limit the "volume" of subsoils which can be explored.

This limitation is especially critical when such directional-drilling restrictive anomalies as boulders are possible.

Supplementation or extension of sampled borehole data is possible through piezo-electric cone penetrometer (PCPT) soundings (an intrusive exploration technique) and nonintrusive, near-surface geophysical surveys: vibrosonic procedures, ground-penetrating radar studies, etc.

Intrusive PCPT soundings allow a more closely spaced exploration at a reduced cost and timing than sample borings.

However, because no samples are obtained for actual observation or testing, necessary calibration of the penetrometer readings precludes exclusive PCPT use.

Also, the sounding holes, like sample boreholes, must be grout sealed on completion.

Nonintrusive surveys permit evaluation of virtually the entire site. Relative stratification, conditional interfaces. anomalies, etc. can be observed.

However, as with PCPT soundings, no actual material specimens are produced.

To improve future geotechnical surveys, a nonintrusive study should first be made of the crossing alignment. This will allow more efficient location of the intrusive exploration components such as sampled boreholes and PCPT soundings.

In concert, the resulting data will more fully define pertinent in situ conditions.

Pilot-hole logging. Experience gained during drilling of a pilot hole is important in preparation for pullback. At present, however, this information is limited to drilling performance and thus restricted to the area directly in the path of the pilot string.

Development of an instrument, akin to an electric log, which could be drawn through the wash pipe after completion of the pilot hole and sense the surrounding soil characteristics would significantly reduce the risk of encountering an obstruction during reaming and pullback operations.

This is especially critical in areas where random boulders are present. Also of interest would be quantification of drilling-fluid pressure downhole at the drill bit.

This information and the ability to monitor mud pressure during actual pilot-hole drilling may prove crucial in instances where mud is likely to intrude into, or even fracture, the surrounding soils.

Pulling-load analysis. At present, the pulling force required during installation is predicated on experience for a given pipe diameter and soil type.

The two principal components considered are the force necessary to cut the hole in advance of the pipe and the friction forces which must be overcome to pull the pipe along the open hole.

It is also realized that for larger diameters the stiffness of the pipe is an important factor, although calculations are generally not made to assess this impact.

A sound analytical method which takes into account all factors is needed for calculating installation pulling loads.

The method should be time dependent so that variations of load as the pull section proceeds through bends can be determined.

This information can then be utilized by contractors to take steps to reduce the loads or ensure that equipment is on hand or can be modified to overcome them.

An example of how this advance knowledge can be used to reduce pull load is in pull-section buoyancy adjustment.

For a straight section of pipe being pulled into a reamed hole, the optimum buoyancy is neutral. This allows the pipe to be suspended in the hole without a force either up or down against the hole wall.

Sliding friction forces are thus reduced.

For a section of pipe being pulled around a sagbend, however, neutral may not be the optimum buoyancy. Without either negative or positive buoyancy, the only force available to overcome the section's stiffness and deflect it around the end must be transmitted from the rig through the reaming assembly.

If buoyancy is adjusted, it can induce a bending moment and assist in deflecting the pipe.

Buoyancy can be altered by internal weighting of the pull section during pullback. ▪