# UNDERSTANDING GEOLOGICAL HISTORY WHEN SELECTING TRENCHLESS INSTALLATION METHODS

## PART 2: EFFECTS OF GLACIAL AND PRE-GLACIAL COASTAL DRAINAGES ON HDD CROSSINGS

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### INTRODUCTION

On many large, engineered trenchless installations, it is imperative for the engineer to understand the geological history of the subsurface, and determine the possible consequences and controlling effects the geology has on the proposed crossing. Deciphering the underlying geologic history (and its local anomalies) drives selection of the most appropriate trenchless method.

Part 2 of this three-part series looks closely at the complications associated with an HDD crossing in an over-deepened, coastal New England pre-glacial bedrock valley, and how it was affected both by glacial advance and catastrophic meltwater releases from an upstream glacial lake that filled the valley with large cobbles and boulders, at thicknesses approaching 100 feet. A more favorable 15-foot thick layer of sands and gravel below the cobble/boulder layer was targeted for part of the HDD crossing to install the 12-inch natural gas pipeline. This paper will review the regional bedrock and local glacial geology, and its effect on the engineering complications encountered during HDD drilling and pipe installation.

### SELECTION OF TRENCHLESS METHODS

When undertaking new trenchless installation work, it is crucial that engineers and contractors understand how the ground may behave in response to a given trenchless method. Much of the expected behavior is based on real-world experience and also a fundamental understanding of ground response when a specific soil matrix is removed from the ground, whether the ground has sufficient strength to support equipment and also to provide a stable borehole to prevent inadvertent drill fluid returns (aka, "frac-out"). Ground behavior from the Tunnel-Man's Ground Classification Guide like "raveling" (slow and fast), "squeezing," and "running" (or similar terms) are used to describe the anticipated unstable ground and emphasize areas of concern.

The major concerns for trenchless projects are: weak overburden soils, weight-of-hammer (WOH) material, nested cobbles, gravel with little fines, running ground, and squeezing or swelling ground all that suggest unfavorable ground conditions. Where bedrock is shallow, the contrast in drilling behavior between overburden (soil) and bedrock drilling is a further complicating factor to consider.

For expensive and large-dollar trenchless projects, extensive ground characterization is typically performed, but for small-dollar trenchless projects, adequate ground characterization is often overlooked, either due to lack of budget, a perception of low value for the upfront project cost, or in the case of limited engineering/designer experience with trenchless installations, a misjudgment of the possible risks.

For many owners, a new installation project is just a line on a piece of paper - but there is much more to it than that. It is understanding construction risk and how to manage that risk and how the ground will behave based on a specific trenchless method. Thus, understanding the sequence of geologic events of a specific area provides clues that can inform the designer of the anticipated ground behavior.

## TAUNTON RIVER CROSSING

This crossing in southeastern Massachusetts is an excellent example of how geological history can affect both the planning, execution and success of a trenchless project.  A deep, pre-glacial bedrock valley exhibiting different bedrock types on either side of the river, combined with thick cobble and boulder gravels from a rapid draining of an upstream glacial lake, required modifications to the HDD crossing by the contractor due to the difficult ground conditions.


*Figure 1 – Plan of 12-inch gas pipeline installed in 2016/2017 by HDD below the Taunton River. Base image from Google Earth Pro, dated 26 Feb 2018.*

## IT'S THE BEDROCK

Geologic maps [Reference 1] and subsurface data from highway bridge studies [2] indicated the Taunton River is aligned with a major northeast-trending bedrock fault zone separating Pennsylvanian-age Rhode Island Formation rocks to the west from the older Fall River Granites to the east. Yet, even though bedrock is exposed on both sides of the Taunton River upstream, bridge borings indicate the bedrock surface drops to at least 200-foot depths below the river in the vicinity of the HDD crossing, and further deepens to over 450 feet in depth below the Sakonnet River downstream, between Portsmouth and Tiverton, RI.

Both the bedrock surface and fault between these two rock types remain poorly understood. The Taunton River valley was scoured by glacial ice advance, but recent research suggests [3] that wholescale removal of all pre-glacial material down to rock by ice was not as complete as often portrayed, a concept attributed to the "thin ice" model near the terminal limit.

## IT'S THE GLACIERS

Late Wisconsinan glacial ice reached its limit along the Rhode Island and Massachusetts southern coasts around 28,000 to 23,700 years before present (YBP)[4] creating an intermittent string of morainal islands along the ice terminus: Long Island, Block Island, the Elizabeth Islands, and portions of Martha's Vineyard and Nantucket (5) (see Figure 2).

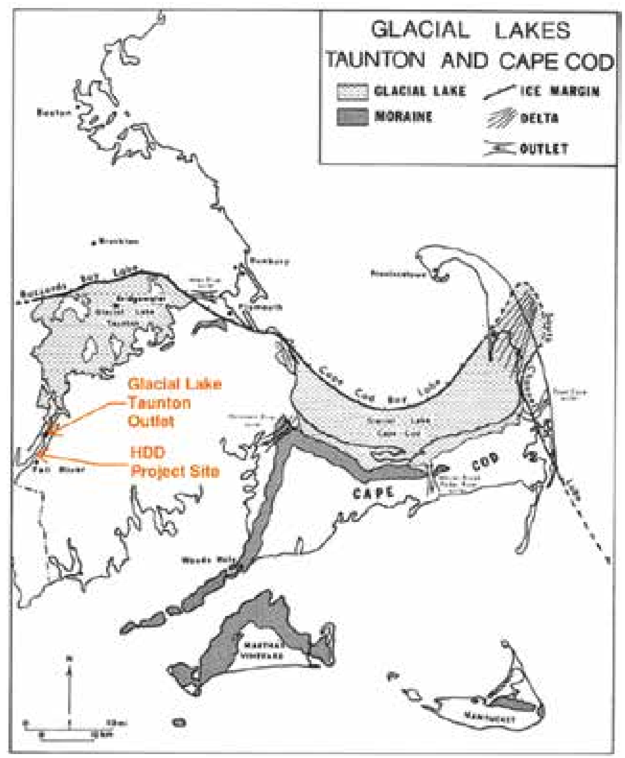


*Figure 2 - Glacial Lake Taunton impounded against ice front or moraine formed by Buzzards Bay ice lobe. Outlet channel and HDD project shown (Modified from Larson, 1982, Fig. 3).*

The melting and retreat of the ice sheet across southeastern New England discharged streams with significant volumes of sand and gravel into the proto-Narragansett Bay, to a paleo-shoreline was about 360 ft below present sea level, forming a shoreline at the southern end[6]. The Narragansett Bay "valleys" (such as the Taunton and Sakonnet Rivers) were exposed and filled with sediments [7, 6].

Deglaciation was rapid during warming trends, and intermittent cold events caused ice retreat to halt and locally re-advance, building moraine ridges during the cold periods [4, 8]. This retreat pattern is seen in several irregular topographic "belts" of sandy moraine till, formed at the ice lobe margins, that cross parts of southeastern Massachusetts [8], including the Sandwich Moraine near Wareham. An impoundment termed "Glacial Lake Taunton" was formed in a lowland against the ice margin on the north and blocked by a debris dam across the Taunton River to the southwest [9, 8]. The shallow water body spread over much of southeastern Massachusetts, exacerbated by crustal depression due to weight of overlying ice [3].

At its maximum extent, Glacial Lake Taunton was estimated to cover an area of approximately 54 square miles [5], extending roughly from Norton, MA (to the west) to Kingston, MA (to the east), and beyond Bridgewater to the north [10], and estimated to be over 130 feet deep in places [11] with an overall lifespan slightly longer than 300 years [12]. The lake plane surface was about 55 to 65 ft above mean sea level [5].

Eventually, the contribution of glacial meltwater and sediments caused the lake to overflow its basin and catastrophically breach, erode, and drain down the outlet channel near Fall River, flowing into the upper reaches of Narragansett Bay [11]. Engineering investigations in the Fall River area provide us with direct subsurface evidence of the Glacial Lake Taunton catastrophic event.

## EFFECTS OF MELTWATER RUNOFF FROM RETREATING GLACIERS

The draining of Glacial Lake Taunton rapidly discharged several square miles of meltwater, entrained with sediment, down the Taunton River rock valley leading into Narragansett Bay. The high-velocity glacial meltwater carried very coarse debris of gravel, cobbles and boulders in torrents, filling in the upper portions of the rock valleys and deposited them on finer-grained sands beneath. As depicted in Figure 3, the very coarse deposits are primarily found on the Fall River side of the Taunton River and approach 100 feet in thickness.

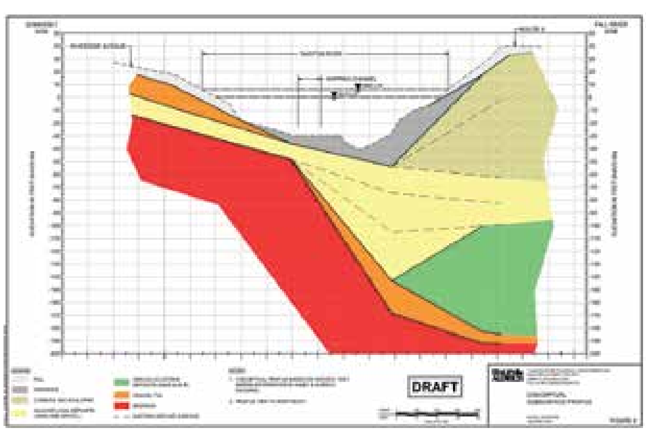


*Figure 3 – Conceptual subsurface profile from test borings taken near the Taunton River HDD crossing. Profile is oriented west to east, with view towards north. Explanation of color representations are provided in text.*

Geotechnical data assembled from the nearby Grand Army of the Republic (GAR) Highway-Veterans Memorial Bridge (Route 6) bridge, from borings for the old Brightman Street Bridge, and other proprietary sources indicated varying thicknesses of cobbles and boulders, granular outwash sands, and deeper glaciolacustrine deposits filled the Taunton River valley. The variation in thicknesses can be attributed to variable warming periods during the retreat of the glaciers in combination with rising land and rising sea level when glacial run off was slower or flow impeded by the rising ocean.

The presence of these coarse boulder-cobble-gravel deposits were confirmed during the construction of the GAR Highway-Route 6 bridge by the Massachusetts Department of Transportation between 2007 and 2011 (see Figure 1). The bridge was designed to be founded on deep caisson (shaft) foundations. Difficult drilling conditions in the cobble and boulder-containing glacial soils hindered the drilled shaft advance. A photograph of the well-rounded material air-lifted from the drilled shafts is shown on Figure 4, with a hardhat placed in the photograph for scale.

*Figure 4: Gravel, cobbles and boulders from deep glacial meltwater deposits below the Taunton River. Note hard hat for scale*

## NEW TRENCHLESS CROSSING

Just south of the new Route 6 Bridge, Liberty Utilities recently replaced two old distribution gas mains with a new 12-inch diameter steel grade X-52, FBE & Powercrete-coated, natural gas pipeline using horizontal directional drilling.

The route of the HDD crossing is shown on Figure 1, which was about 1,950 feet in length. The cross-section profile of the Taunton River in the area of the HDD crossing is provided as Figure 3.

On the profile, bedrock is indicated by the red coloration; glacial till deposits are colored in orange; granular glaciofluvial sand and gravels are colored in yellow; coarse glacial meltwater deposits of boulders/cobbles and gravel are in yellow with an open symbol overprint; green reflects glaciolacustrine sands and silts; and organic river bottom muds are depicted in dark gray.

The subsurface profile also depicts shallow bedrock that extends below the west side of the Taunton River in the vicinity of the HDD alignment. However, the top of bedrock drops off to over 200 feet below the Fall River shoreline.

## KEY CONSIDERATIONS FOR HDD DESIGN

The glacial deposits on the Fall River side are granular and contain numerous hard cobbles and boulders, which would be

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a critical factor to consider in the HDD drill-path design. In contrast, the Somerset, MA (western side) of the alignment is underlain by glacial till deposits overlying shallow bedrock, which is classified as gray/black, fine-grained weathered shale of variable strengths and fracture density. Glacial till typically contains cobbles and boulders; nevertheless, the western side poses a slight advantage for HDD because glacial till and "soft" bedrock tends to remain open during pilot boring advance.

In contrast, highly granular deposits without silts or clays as binding agents are subject to HDD drill fluid loss and unstable behaviors (collapsing/raveling/enlarging of the borehole), as drill fluids used in stabilizing the HDD drill hole may penetrate and disperse into the permeable deposits if the fluid pressures are not carefully controlled. High fluid pressures exiting the bore and hydraulically fracturing the overlying soils may lead to inadvertent drill fluid returns. As such, during the HDD drilling, drill fluids were subject to seep out through the deposits into the Taunton River itself on the Fall River side of the crossing.

With this faulted and highly variable bedrock geometry, a challenging "mixed-face" condition for the HDD drill in this situation could also be anticipated, where the drill advances from bedrock-into-soil, or from soil-into-bedrock. Drills of this nature have been successfully built, but the variation in ground conditions must be carefully defined, clearly communicated, and understood by the HDD contractor.

*Figure 5: Historical photograph of the old Brightman Street Bridge looking west across the Taunton River towards Somerset, MA. The bridge has since been closed for demolition. Note the quantity of man-made debris on the Fall River shoreline. The new natural gas line was installed below the river to the right of the image. (Photograph courtesy of Liberty Utilities.)*

An additional point of consideration in trenchless design is the history of man-made impacts, and how they can also have a significant effect on a trenchless alignment, as shown on Figure 5 (above). Industrial cities and modified commercial coastlines can jeopardize a trenchless crossing, as a deep debris field, in combination with the steep river bank sides, can present obstructions and the potential for some very significant impediments to HDD drilling and pipe installation. Challenging geology only adds to the complications.

## PROJECT SUCCESS

Based on the as-drilled HDD records, Liberty Utilities reported that the contractor drilled the HDD crossing from the west side to the east side, and also used an intercept method (drilling down from the HDD exit end to meet up with the initial pilot drill from the HDD entry side).

The contractor reported difficulty with the HDD pilot drill and borehole collapse once it reached the east (Fall River) side of the alignment and needed to open up the borehole to 36-inch diameter for around 100 feet. (In comparison, typical bore hole sizes for a 12-inch diameter steel pipe would be 18 inches). The additional enlargement was required to stabilize the borehole and prevent cobbles and boulders from rotating or dropping out of the borehole wall. Liberty also reported that the contractor had two inadvertent fluid returns on the Fall River side of the alignment, which is likely attributed to the highly permeable coarse cobble and boulders shown on the Figure 3 profile. Nonetheless, the contractor was successful in building the HDD crossing and installing the new pipeline.

## CONCLUSIONS

Clearly, the complex geological history in the Taunton River area was a major factor that had to be accommodated in constructing a successful trenchless crossing. In this case, the geologic models of the region drive the constructability of the HDD crossing.

New trenchless installation work is not without risk. Small, low-dollar/low risk on new installation projects may not necessarily warrant a detailed understanding of ground conditions, especially in areas of homogenous ground conditions not impacted by irregular bedrock or glacial/coastal deposits. However, for high-dollar value projects, long alignments, or in complex geologic settings, more than just a few geotechnical borings are required to sufficiently characterize the ground conditions.

**FOR HIGH-DOLLAR VALUE PROJECTS, LONG ALIGNMENTS, OR IN COMPLEX GEOLOGIC SETTINGS, MORE THAN JUST A FEW GEOTECHNICAL BORINGS ARE REQUIRED TO SUFFICIENTLY CHARACTERIZE THE GROUND CONDITIONS.**

Having a sound understanding of the local geologic history provides a valuable understanding of how the ground may behave when pipe jacking, microtunneling, or selecting between a small-bore HDD versus large bore HDD. It is not just a line on a piece of paper - understanding ground behavior when selecting a trenchless method typically leads to lower risk with an associated decrease in cost of that risk.

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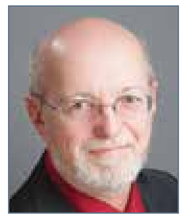

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