Case Histories in Trenchless Excavation

Peter J. Tarkoy, Ph.D.

GeoConSol, Inc., Medfield, Massachusetts

ABSTRACT

Site investigations, subsurface exploration, interpretation, and presentation of anticipated conditions have not been consistent with the advance and crucial requirements of the new trenchless technology. The new technology, equipment, and methods require a greater accountability in the assessment, development, and portrayal of anticipated conditions along the construction alignment (line and grade) to minimize risks associated with ground conditions. Responsibilities must be shared by owners with respect to adequate funding and by engineers in providing innovative solutions to problems that consistently manifest on these projects. The purpose of this article is to illustrate the most common problems through actual case histories.

INTRODUCTION

The most difficult conditions in underground construction are not any particular geological condition, instead they consist of conditions that have not been anticipated, behavior that is not predictable, or conditions and behavior that could not be taken into account when selecting the method and equipment for construction. Most excavations for infrastructure in urban areas tend to be shallow and therefore in soft ground (soil materials) or mixed face (soil and rock). Encountered difficulties in small diameter trenchless excavation in soil, have been surprisingly consistent in nature. Some of the most troublesome unanticipated geological conditions in small diameter soil excavation involve unanticipated obstacles (boulders and riprap), a variation in the location of the top of rock, variable and quantitative nature of the character and properties of the soil materials, and because soil conditions are not as anticipated, thus behavior of stabilization methods required for excavation methods are not correctly predicted.

BOULDERS

Obstacles such as boulders can completely halt mechanical excavation and substantially slow even open-faced small diameter pipe-jacking. In glaciated areas, the presence of boulders along an alignment remains little more than a speculation, largely unaddressed by site investigations, interpretations, the bill of quantities, and yet can be disastrous in a small diameter operations, especially with mechanical excavation equipment. The presence of unanticipated rock or boulders has often neutralized gains offered by the use of mechanical technology.

Encountering boulders during open faced pipe-jacking may not prove fatal, yet, boulders will always slow excavation, occasionally require blasting, and require filling of voids where boulders extend outside the pipe perimeter.

Small boulders may merely disrupt the excavation progress. Larger boulders are likely to necessitate complete access to the face and removal of the mucking system to pass boulders. Large boulders, especially when extending outside the perimeter of the pipe, may also require blasting. The larger boulders are more likely to intersect the outside of the pipe perimeter and require removal of material outside the pipe excavation. These voids eventually require filling to prevent "loss of ground" and instability around the pipe. Excavation outside the pipe diameter is considered excess excavation, typically left unaddressed in the specifications.

Encountering boulders with a full-face mechanical system would completely halt excavation and may even require retrieval from the surface. Possible solutions to avoid problems unique to mechanical excavation include providing site investigation that satisfies the needs of anticipated mechanical excavation methods or limiting excavation methods and equipment to more traditional means that are less sensitive or not completely halted by unanticipated conditions. In the latter case, it would still be necessary to provide alternative unit pricing for payment of variations in ground stabilization, removal of boulders and rock, and material characteristics and quantities.

Case A

Figure 1 presents a soil boring profile of anticipated conditions. A buried valley (indicated by the sloping rock surface to the left of boring P-81F) remained largely unexplored and boulders were noted only in one instance (Boring B-4, drilled by one of the bidders) at a shallow depth (five ft). No boulders were encountered, noted, or anticipated at the pipe-jacking horizon.

The top-of-the rock was explored by a percussion drill, without the benefit of samples. Consequently, no differentiation could be made whether refusal meant boulders or the top of rock. The percussion holes were actually drilled to locate the top of rock and refusal was accepted as such.

The "refusal" or top-of-rock line was never re-evaluated by the engineer even though B-82 (drilled by one of the bidders) very notably conflicted with the rock line.

The encountered conditions are illustrated in a sketch of the pipe-jacking face in Figure 2. The pipe-jacking operation through the buried valley encountered what may be described as a "boulder pavement" or "nested boulders." The large volume of large boulders required excessive excavation outside the pipe. The encountered boulders were unusual in that they were large, continuous, and in layers.

Boulders that are largely outside the outer perimeter of the pipe have to be blasted in the hope that breakage extends far enough outside the perimeter to allow the pipe to pass without being damaged. In the case illustrated in Figure 2,

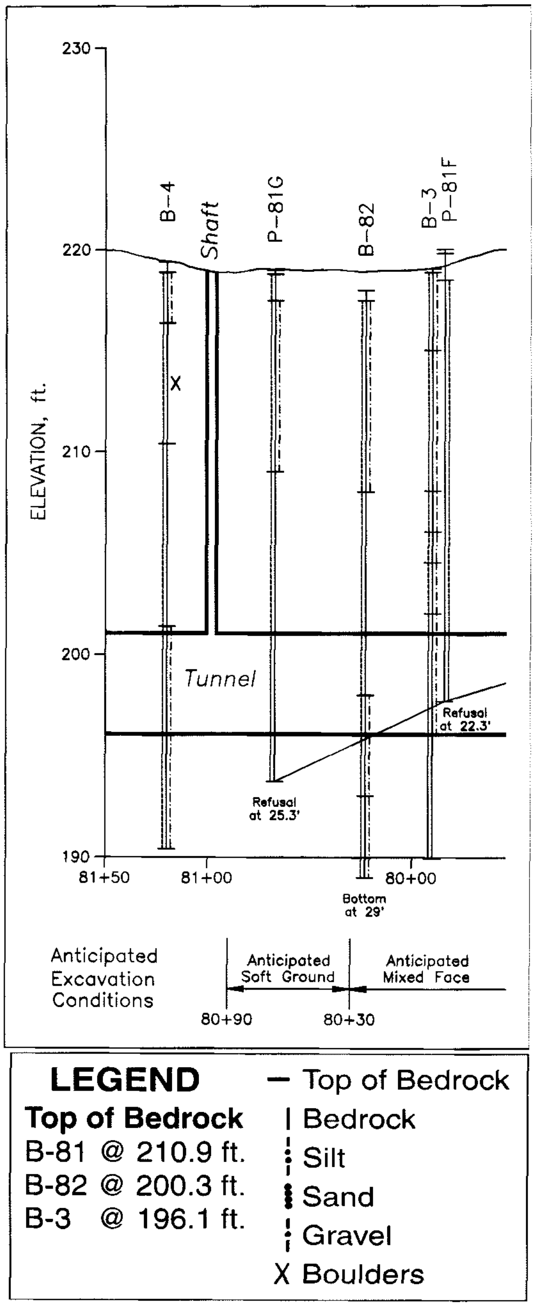

Figure 1: Soil Boring Profile of Anticipated Conditions

the situation was complicated by the presence of unstable flowing silts overlaying the boulders that could not be dewatered from the surface.

The upper part of the face had to be breasted from within the excavation while an attempt was made to remove boulders without losing the face. Most commonly, the face was consolidated by grouting on one shift and the boulders mined on the following shift, and the face advanced through the stabilized silt on the following shift.

The contractor's anticipated progress was based on similar experience and was therefore reasonable. Since the excavation encountered boulders right from the beginning, it was not possible to contrast excavation progress with and without boulders. Encountered progress was substantially less than anticipated throughout. Progress was also affected when the rising top-of-rock was encountered earlier than indicated by the geotechnical profile.

ROCK

Unanticipated rock or the top of rock at an elevation higher than anticipated generally causes major disruptions in excavation progress, extends duration, and increases costs. In geological regimes where glacial soils and boulders overlie bedrock within the construction envelope, the issue becomes even more problematic because it may be difficult to distinguish between glacial boulders, loosened slabs of bedrock, weathered rock, and competent bedrock.

The presence of rock can be disastrous in the horizon where it is entirely unanticipated and where soil excavation equipment cannot deal with rock. Unanticipated rock in trenchless technology can be fatal in a mechanized or small diameter heading. In an open heading, such as pipe jacking, it will at least slow excavation, require blasting, and blasting may disrupt otherwise stable conditions.

Two unfortunate practices still prevalent in site exploration are the use of drillers without supervision or professional borehole logging and the use of auger borings. Boring logs have often been inadequate, even when soil samples have been re-classified in the laboratory. Soil samples taken by drillers are often of poor quality, from poorly selected locations, and are not representative of in-situ conditions.

Decisions by drillers to end borings at refusal rather than drilling through obstructions have been the subject of countless construction problems and claims. Similarly, use of auger borings have produced similar uncertainties re-

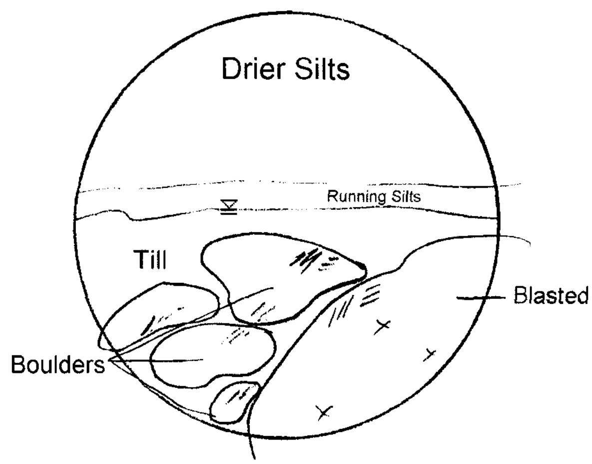

Figure 2: Unforeseen Boulder Pavement in Pipe-Jacked Excavation.

garding the material encountered. Much too often, augers are fitted with tungsten carbide fingers that can disintegrate even competent rock into soil materials that are then reported in the logs. Augers have been known to by-pass occasional boulders even when refusal is recorded for the soil sampler.

Case B

An interesting example of unanticipated top of rock is

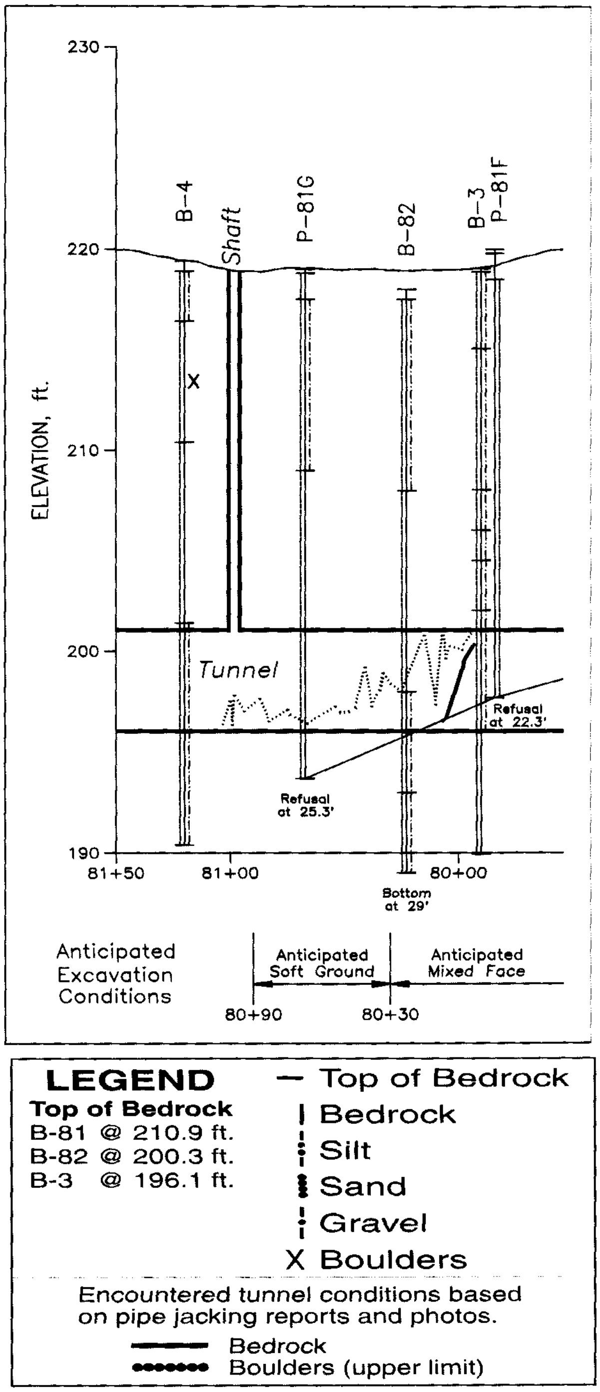

Figure 3: Anticipated and Encountered Rock Profile

illustrated in Figure 3. The engineer selected top of rock based on sampling in the borings (B-80 series) and refusal of auger probes (P series). Anticipated conditions in the geotechnical report and summarized at the bottom of the profile (Figure 3) were inconsistent with boring B-82. The inconsistency manifests in P-81F&G and B-82 and suggests that refusal in P-81G may be a boulder since B-82 extends four ft beyond refusal in P-81G.

One of the bidders had drilled a series of boreholes (B-1 through B-4) and provided them to the engineer and other bidders. The contractor's borings were not utilized by the engineer to revise the profile even though the inconsistency became even more pronounced with B-3 encountering rock at the invert of the proposed excavation and above the rock line in Figure 3.

The low bidder elected to excavate from two headings, one as a conventional rock excavation, the other by pipe-jacking through anticipated gravel, sands, and silt. The respective methods were selected based on anticipated conditions indicated in the geotechnical report. The encountered conditions were quite different.

The crown of the rock tunnel excavation continually penetrated into the soil horizon that was lower than anticipated and resulted in a more extensive mixed-face mining than anticipated. The pipe-jacking operation encountered the top of rock earlier and higher than indicated by the geotechnical report (Figure 3). The progress rate in both headings suffered.

The pipe-jacking heading anticipated a small amount of rock in the lower portion of the excavation as indicated in Figure 3. However, the encountered rock rose higher and more steeply to a full face, necessitating abandoning the pipe-jacking method much earlier than anticipated. The encountered boulders and top of rock are illustrated in Figure 4.

Case C

In another case involving unanticipated rock, the consequences were much more serious. A closed face, small diameter microtunneling machine encountered what was originally thought to be a boulder; however, upon excavation, it turned out to be a rock slab (Figure 4) that may have slid off an adjacent slope of the buried valley.

Specifications originally called for excavation without surface disruption. When the tunneling machine was halted by the slab of rock, it became necessary to dig up the street to rescue the halted machine after an eight-month delay.

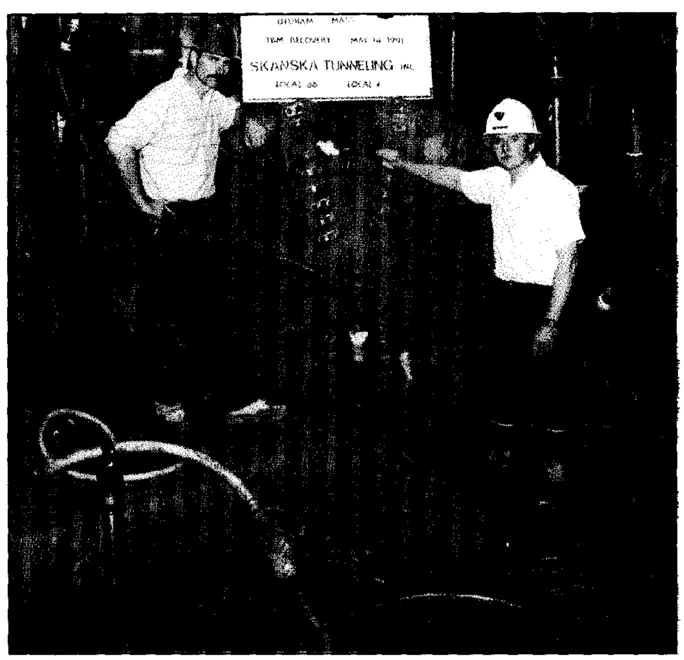

Figure 4: Rock Slab Encountered by Microtunneler

SOIL CHARACTERISTICS AND STABILIZATION

Many pipe-jacking operations require some sort of soil stabilization. The method of choice for stabilizing a soil excavation is invariably based on borings that suffer from very poor descriptions, inaccuracies with respect to grain size distribution of the material, and qualitative descriptions rather than quantitative values for evaluating behavior under typical construction conditions.

Often, boring logs prepared by the driller instead of an experienced geologist or soils engineer are unreliable, inaccurate, and often suspect even in general terms. A common shortcoming of many boring logs is the lack of quantitative description of the soil character. In most cases, boring logs provide description that can only be crudely related to a wide range of grain size distribution. A reliable grain size distribution is necessary for the assessment of stability, behavior, and selection of appropriate stabilization methods.

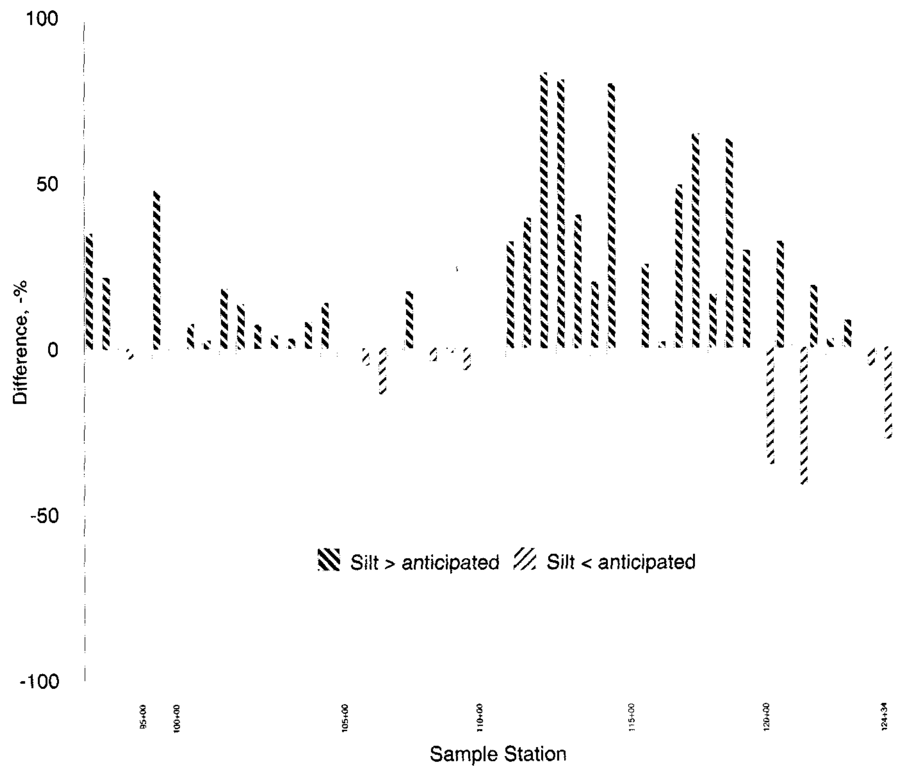

Figure 5: Anticipated and Encountered Silt Content.

Case D

Poor quality logs were provided on a project that consisted of several thousand feet of sewer pipe installation. The logs were prepared by the drillers who estimated relative quantities of various soil components using terminology as summarized in Table 1.

Naturally, the driller's estimates left a great deal to be desired in terms of accurately portraying the nature of the soil materials anticipated. Even though the logs were corrected by a geotechnical engineer based on the soil samples, the boring logs were never adjusted with the corrections. In effect, the borings indicated that a (silty) sand was to be encountered along the tunnel alignment.

QUANTITATIVE RANGES OF QUALITATIVE TERMINOLOGY

Description	Range	Average of the Range
Trace	00-10%	05.0%
Some	10-20%	15.0%
Little	20-35%	27.5%
And	35-50%	42.5%

Table 1

The first sign of difficulties manifested when it was discovered that the installed dewatering system could not lower the water level as required. Sieve analyses of samples taken from the trenches, the pipe-jacked face, and dewatering wells indicated a much higher than anticipated silt content (Figure 5),

The sieve analyses and field experience confirmed that the encountered material consisted of (sandy) silt which was cohesive and hard when dry and flowed when wet, could not be dewatered by the installed system, could only be stabilized by chemical grouting, required daily breasting of the face, and made the excavation of boulders and higher than anticipated top-of-rock more difficult.

When dry the silt was hard and required blasting. When wet, or allowed to stand overnight, the silt flowed like thick soup and it posed a stability problem at the pipe-jacked heading.

This silt was well known to local experienced drillers who called it "cemented till." Perhaps a more rigorous investigation of regional geology and local experience would have provided a more practical basis for further investigation. As a consequence, the contractor sustained additional and excessive costs that remained unacknowledged by the engineer. It was necessary for the contractor to stop the job and seek just compensation through the courts. In the end, everyone suffered, but the owner and the underground space industry suffered the most.

CASE E

Several cases of pre-cast concrete jacked pipe failure prompted an investigation that shed light on common phenomena in pipe jacking. The investigation examined the properties of the pipe itself and the construction process. Even though the maximum axial load on the pipe was less than one third of the ultimate strength of the concrete, consistent with industry experience without pipe failure, and consistent with the recommendations of the Concrete Pipe Handbook, sections of pipe failed on several occasions. Investigation of the construction process uncovered several notable facts, such as highest stresses were naturally on the last section of pipe installed in the jacking pit where no failures occurred. Failures occurred after weekends and holidays, were coincidental with noted pipe misalignments, and where boulders and/or rock had been encountered, Stresses on the pipe at failure were less than the uniaxial strength of the concrete, and the pipe strength was within required tolerances.

It becomes obvious that the failure of the pipe could be related to less than ideal bentonite lubrication; failure to clear out obstruction (boulders and rock) around the pipe; failure to observe and respond to high jacking pressures; failure to correct misalignment of the pipe; and inadequate care during startup after a long hiatus of jacking.

In one instance, fuilure to adequately clear obstacles around the pipe resulted in a boulder puncturing the wall of the pipe.

Unfortunately, the matter was resolved only after a costly finger pointing exercise between the prime contractor, pipe supplier, and the pipe-jacking subcontractor.

CONCLUSIONS

A variety of difficult ground conditions are commonly encountered in pipe-jacking and microtunneling, especially in glaciated and coastal urban environments. Typical difficulties in glaciated terrain, such as dealing with boulders and blasting the top of rock in a mixed face excavation have been successfully negotiated. Similarly, common obstacles such as piles, granite piers, muck, and various types of debris typical of urban coastal environments have also been traversed successfully. The greatest difficulties have always been associated with unanticipated conditions rather than the type of condition.

Unanticipated conditions that are associated with difficulties commonly consist of unanticipated boulders, variations in the top-of-rock, lack of grain size distribution data to determine soil behavior and stabilization requirements, behavior of soil materials under construction conditions, and unanticipated soil stabilization requirements.

Each of these potential problems has a number of possibilities for prevention as well as solution. The time has come for preventative measures to be incorporated into the contract documents that deal with small projects. Pipe-jacking and micro-tunneling subcontractors, exploration, interpretation, and presentation of geotechnical data must be brought up to available state-of-the-art methods, and contract provisions must reflect the nature of ground conditions rather than non-responsive, non-responsible disclaimer philosophy much too common in the industry.

These recommendations will be summarized in Tarkoy (1994).

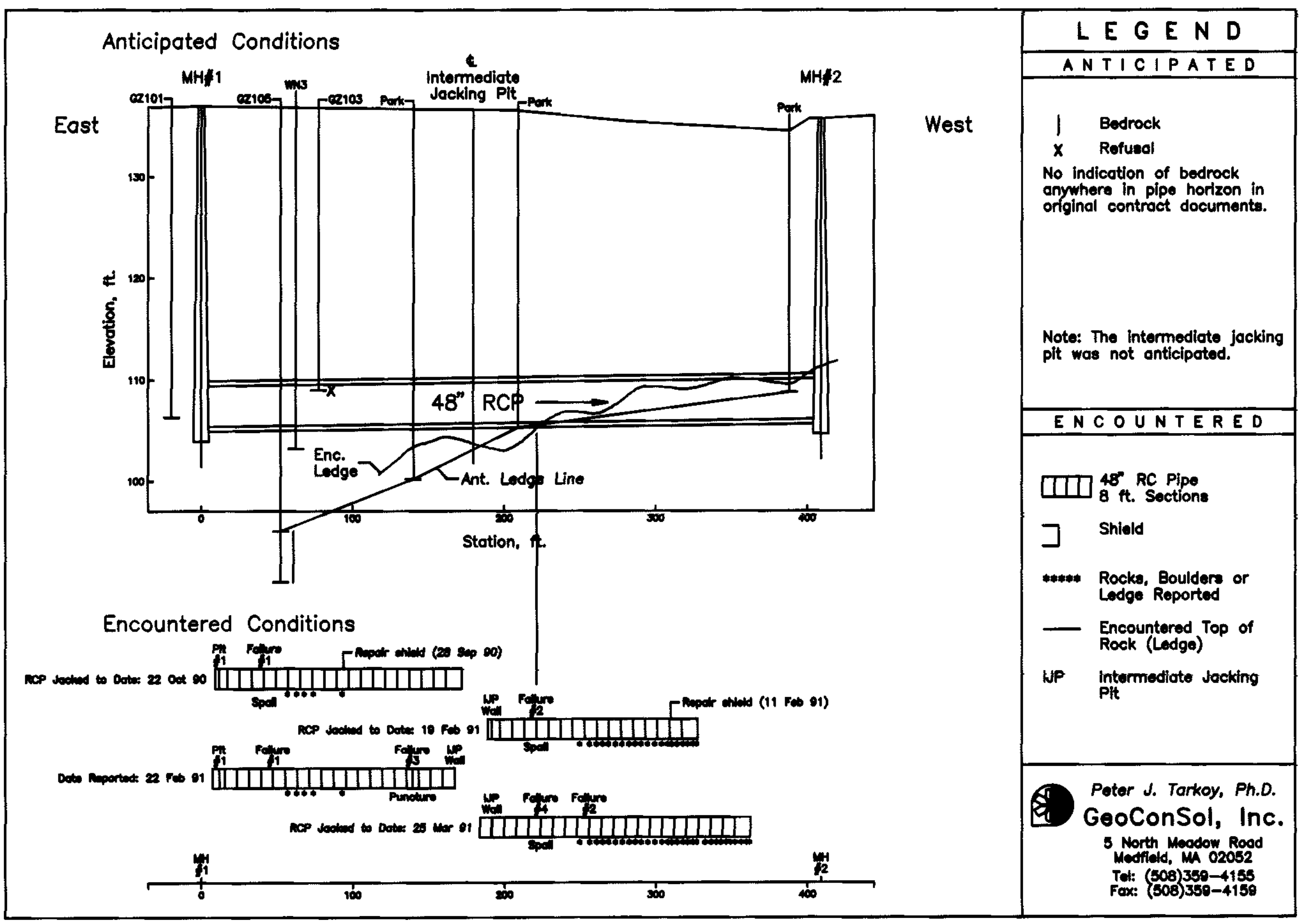

Figure 6: Profile of Jacked Pipe Failures