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Engineering Geologic Conditions for Trenchless Application in the Denver Metro Area

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1. ABSTRACT

This paper provides insight into the challenges posed by the local geologic conditions as they affect trenchless projects. On the surface, the geology of the Denver area appears pretty straightforward; young outwash deposits overlying weak Tertiary rock. The crystalline rocks, so prominent to the west of town, are buried thousands of feet deep due to faulting. However, as with most things geological, once you look closely, at the individual project level, all sorts of challenging variables begin to complicate things. Trenchless installations deal with small diameter borings and excavations, which means that micro-variations in the geologic conditions can significantly affect the success and complexity of each installation. Alluvial deposits along the major drainage ways regularly contain cobbles and boulders. The frequency and size of the clasts typically increases closer to the range front. We also often see a cobble layer near the bottom of the alluvial units. Additionally, due to paleo-meanders of the local drainage systems, the alluvium varies from fine clay to coarse sand and gravel with abrupt transitions both vertically and horizontally, which makes creation of accurate geologic profiles for trenchless projects challenging. Local bedrock in the area is really an over-consolidated clay and sand deposit. Typically, the material is quite weak with zones of "sandstone" even being totally uncemented. However, the opposite also occurs in places with sandstone and limestone lenses up to 4,000 psi in localized areas.

2. INTRODUCTION

Unlike most construction, building tunnels is intimately tied to geology from start to finish. This is evident in the numerous types of machines and technology that have been developed to effectively excavate holes through the ground. Tunneling is a risky business anywhere and the geologic conditions in the Denver area provide no exception. In this paper, the author relies on experience from the past eight years designing tunnels and evaluating ground conditions and behavior for tunnels in and around Denver. The purpose of this paper is to highlight the various types of challenges trenchless construction encounters as related to the local ground conditions in an attempt to educate prospective designers and contractors when working in the Denver area.

On the surface, the local geology appears to be pretty straightforward. There are some quaternary sediments concentrated around the river channels, windblown silt and sand spread around, all overlying generally soft over-consolidated claystone and sandstone. The crystalline rocks, so prominent to the west of town, are faulted several thousand feet below the metro area. Why then do so many trenchless projects encounter differing site conditions and complications with installation?

The reason is that trenchless technologies are susceptible to micro-variations in geology due to the typically small diameter of the installations. What appears benign in the macro view is actually fraught with all kinds of small-scale variations that are difficult to characterize on geologic maps and in geotechnical explorations. These variations can
include unforeseen cobbles and boulders, collapsible soils, horizontally and vertically varying deposits that vary radically in grain size distribution, and hidden concretions as well as limestone and sandstone lenses that are orders of magnitude stronger than the surrounding rock. While these conditions can complicate any construction project, they are especially troubling to trenchless work where the linear nature of the construction is so susceptible to unanticipated conditions.

3. COMPLICATIONS TO TRENCHLESS INSTALLATIONS

Figure 1 shows a generalized geologic map of the Denver area. Yellow and orange colors represent alluvial deposits, green is sandstone and claystone rock, and pink/tan are eolian sediments. Superimposed on the map are locations of projects the author has been involved in, most of them trenchless, and the major geologic condition that complicated the design and construction of the tunnel.

Before embarking on any construction project, it is always important to review the available geologic information. Also of importance is to study any nearby projects of similar construction that may reveal insights into the ground conditions and behavior. The author and Brierley Associates keeps a records of past project locations. Figure 1 above is limited primarily to trenchless projects and many other non-tunnel projects could also be shown on the map. The geologic hazards associated with a trenchless project, as discussed below, vary across the Denver Metro area. From Figure 1 above, it can be seen that trenchless projects generally are focused near the rivers and tributaries. This is due to the fact that many pipelines must cross under these drainage ways and because storm and large interceptor sewers tend to be located near the valley bottoms. For this reason, knowledge about the hazards imposed by the South Platte River and tributary alluvial deposits is paramount to successful work in the local area and will be discussed first.

4. ALLUVIAL DEPOSITS
Alluvial deposits are centered in the drainage valleys of the South Platte River and its major tributaries: Clear Creek, Cherry Creek, Bear Creek, and Sand Creek. Trenchless construction in these alluvial channels will typically encounter the following conditions:

- Shallow groundwater
- High permeability
- Interbedded sand, gravel, and clay layers that are discontinuous both vertically and horizontally
- Cobbles near the base of the deposit near the contact with the bedrock
- Boulders on the west side of town near the mountain front

These conditions challenge trenchless construction in several ways. Shallow groundwater and high permeability means that water must be controlled either through the trenchless method or external to the excavation. External dewatering operations can be complicated by the presence of clay layers interbedded with the sand and gravel that effectively split the localized unconfined aquifer. However, these lenses are typically not continuous enough to create a pressurized aquifer below the clay layers.

The variability, both vertically and horizontally, of the alluvial deposits can make it quite difficult to prevent overexcavation and lost ground, especially when microtunneling. The author has seen tunnels develop numerous sinkholes, as shown in Figure 2, because the microtunnel operator has increased the slurry pressure to handle a full face of clay one moment and the next moment encounter a full face of sand and gravel that is rapidly eroded by the slurry jets. These lenses also create variable mixed-face conditions that complicate steering and efforts to avoid overexcavation regardless of the trenchless method, especially if the coarse-grained soil is above the clay.

![Figure 2 – Sinkholes from microtunneling caused by abrupt transitions from clay to sand and gravel in the subsurface.](image)

In addition to the factors above, cobbles and boulders can often be found in the alluvium. The frequency and size of the clasts increases toward the west. The cobbles and boulders are remnants of the Rocky Mountain granitic rocks and are resistant to decomposition. Unconfined compressive strength tests on specimens have shown results as high at 30,000 psi. although most fall between 10,000 and 20,000 psi. The quartz-rich mineralogy of the cobbles and boulders also means they are highly abrasive to equipment. The cobbles and boulders are rarely nested and techniques like pipe ramming, microtunneling, and hand mining are usually successful. Note though, that nested cobbles have been observed in the Clear Creek drainage basin. See Figure 3 for a photograph of cobbles and boulders along Clear Creek.
5. BEDROCK

Discussion on bedrock will be confined to the marine claystone, shale, and sandstone that dominate the Denver metro area. Trenchless construction in these units will typically encounter the following conditions:

- Excellent stand-up time and stability
- Claystone is weak and behaves more like a stiff clay soil than rock
- Claystone is highly plastic and muck can become very sticky when wet
- Sandstone varies from uncedented to strengths up to 3,500 psi
- Top of bedrock elevation is often near the level of deep sanitary sewers and interceptors
- Claystone is very low permeability, but sandstone can hold water pockets

In general, most trenchless contractors report that the local bedrock is good ground for tunnel excavations. Claystone is the predominate material type in the area and if the trenchless project encounters only claystone, the project is likely to be relatively painless. The biggest issue with the claystone is its plasticity, which creates problems across the Denver area with its susceptibility to swell and shrink with changes in moisture content. While swell pressures of the claystone can reach upwards of 200 psi, it is not a problem during construction. The low permeability of the stone and the relatively rapid timeframe of most projects means the work is usually done before the claystone has a chance to swell enough to create problems with jacking forces. However, if the muck from excavated claystone becomes wet, it gets very sticky and can clog augers and other metallic equipment, slowing production as the sticky material must be removed by hand or high-pressure washing over and over. The best option is usually to try and keep the tunnel well-drained and the muck as dry as possible.

To call the claystone a “stone” is almost a misnomer in terms of the engineering properties of the material. The material is a compaction stone with little to no cementitious binder. As such, the strength of the material is quite low as shown in Figure 4. According to Jubenville and Hepworth (1981), the range of unconfined compressive strength for the Denver Formation is from about 40 to 400 psi. This range is also referenced in the Colorado Department of Transportation document on drilled shafts for Denver area (Abu-Hejleh, et al, 2003). The author’s experience with the material agrees well with this range of strengths.

Interbedded with the claystone are sandstone layers and lenses. The sandstone is tricky for both designers and contractors. The majority of it is weak and often has little if any cementation. The material is very dense and will stand when excavated until it dries out, then slow raveling will occur. However, there are lenses of sandstone that have been highly cemented as well, see Figure 4. These highly cemented areas are random and not widespread. Because of this, they are often missed in the geotechnical exploration and the source of differing site conditions claims.
The strength of the cemented sandstone lenses have been seen to reach 3,500 psi, which is an order of magnitude stronger than the surrounding claystone. The author has been involved in two local tunnel projects that encountered strong sandstone and in both instances the material was not found in the geotechnical exploration. The engineer is then faced with including a provision in all GBRs for hidden lenses of hard sandstone even when not seen during design. The contractor must decide if it will bid to cover the higher strength rock or roll the dice. The author has also been involved with a similar condition occurring with limestone beds. One such project resulted in a stuck auger bore under a park when a one foot thick limestone bed was encountered and the auger could not cut the rock. Additionally, although not common in the claystone, the shale bedrock can contain concretions that are almost impossible to find through borings or other typical exploration methods. The concretions are typically 2 to 4 feet in diameter and can have strengths of 2,500 psi or more, which is significantly stronger than the surrounding bedrock.

Figure 4 – two samples after unconfined compressive strength tests, one of claystone (left), one of cemented sandstone (right). Samples were approximately 200 feet apart. The claystone UCS was 54 psi and the sandstone UCS was 830 psi.

The top of the bedrock elevation varies across the Denver area, but is often found between 15 and 30 feet deep. Inconveniently, this depth seems to be right about the elevation of many gravity interceptors, which have little or no freedom to adjust grades. This can result in a difficult mixed-face condition or the situation where the bedrock is just under the invert of the tunnel making dewatering challenging.

6. EOLIAN SOILS

Wind-blown deposits exist around much of the Denver area as seen in Figure 1. These soils are composed of clay, silt and sand and have low density, which means they are susceptible to collapse. Collapsible soils are typically bad actors when subjected to increased load or changes in groundwater elevation. Some have such weak cementation that the vibrations or slurry of a microtunnel boring machine or pipe ram can induce settlement of the ground surface. While this condition can be discovered during the subsurface exploration and the contractor alerted it, it is still very difficult to prevent. The best option appears to be using a dry method that does not induce heavy vibrations. Auger boring or use of an open face tunnel boring machine can help minimize vibrations and do not induce fluids in the ground.

7. CONCLUSION

This paper has shown some of the challenges to trenchless design and construction in the Denver area. The author recommends to anyone, regardless of their area of practice to keep a geographic database of their projects and the difficulties encountered so that future work can be better planned for and mitigated. The geologic conditions in and
around Denver make for challenging trenchless installations including variable alluvial deposits, bedrock that can rapidly change from very soft, even soil-like, to moderately hard, and collapsible soils that appear stable but can easily end up resulting in significant settlement.

As is commonly the case, being educated about the possible difficulties that may be encountered prior to starting a project offers the best defense against potential problems. Numerous obstacles are hidden in the ground that can stop a trenchless installation in its tracks. Knowing the local tunneling engineering geology and planning accordingly can mean all the difference between a successful project and being embroiled in an unpleasant situation.

8. REFERENCES
