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GEOTECHNICAL DESIGN MANUAL
CHAPTER 17- CULVERTS AND TRENCHLESS TECHNOLOGY DESIGN

GEO-ENVIRONMENTAL SECTION
OREGON DEPARTMENT OF TRANSPORTATION

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SUMMARY OF CHANGES

Chapter	Summary of changes made	Date revised
17	Updated All Chapter Content	5/06/2019

17 CULVERTS AND TRENCHLESS TECHNOLOGY DESIGN

17.1 GENERAL

Culverts, stormwater piping, and other utility pipelines are installed within the highway right of way by ODOT and by other agencies and entities. This section covers the geotechnical aspects of culvert design and construction as well as a summary of trenchless utility installation techniques.

17.2 CULVERTS

Within the ODOT Hydraulics Manual, culverts are classified as large, medium, or small. Any structure with a span larger than 20 feet is considered a bridge and this chapter is not applicable. The nature of the geotechnical work undertaken will be reliant on a number of factors, including the size classification of the culvert.

Small culverts are:

- circular culverts with diameters less than 48 inches,
- arch-pipes with spans less than 48 inches, and
- box culverts with spans less than 48 inches.

Medium culverts are:

- circular culverts with diameters more than or equal to 48 inches and less than 72 inches,
- arch-pipes with spans more than or equal to 48 inches and less than 72 inches, and
- box culverts with spans more than or equal to 48 inches less than 72 inches.

Large culverts are culverts and pipes with spans (diameters) of less than 20 feet and:

- circular culverts with diameters more than or equal to 72 inches,
- arch-pipes with spans more than or equal to 72 inches,
- box culverts with spans more than or equal to 72 inches,
- multiple barrel culverts with cumulative span widths more than or equal to 72 inches, and
- culverts with complex hydraulic structures such as cast-in-place energy dissipaters; drop, side tapered, or slope-tapered inlets.

17.2.1 SMALL CULVERTS

All culvert installation projects would benefit from the completion of geotechnical explorations in order to identify potential issues associated with the design and performance of the proposed structure. The installation of small culverts (less than 48 inches in diameter) may be completed without the benefit of geotechnical explorations based on consultation with the Region Senior Geotechnical Engineer. Exceptions, include areas of anticipated difficult excavation conditions, shallow groundwater, or adjacent settlement-sensitive structures. Geotechnical explorations and recommendations should be completed for any proposed excavation that is more than 10 feet below existing grades.

17.2.2 MEDIUM CULVERTS

Generally, geotechnical exploration and analysis would be completed for medium culverts, although the Region Senior Geotechnical Engineer may decide that the nature of the project does not warrant doing so. Geotechnical explorations and recommendations should be completed for any proposed excavation that is more than 10 feet below existing grades.

17.2.3 LARGE CULVERTS

The installation or replacement of large culverts requires the completion of appropriate geotechnical explorations and development of geotechnical recommendations.

17.2.4 PLATE ARCHES AND BOX CULVERTS

Generally large plate arches with footings and box culverts with a span of 20 feet or greater are considered bridge structures and their design is completed in accordance with the ODOT Bridge Design Manual and associated chapters of the GDM.

17.2.5 GEOTECHNICAL REQUIREMENTS FOR CULVERTS

Exploration requirements for culvert projects are addressed in Section 3.5.2.5.

As a minimum, the geotechnical recommendations for culvert projects should address the following:

- Soil conditions, including pH, resistivity, gradation, and general classification anticipated below, adjacent to, and above the proposed culvert for a distance of 3 pipe diameters around the culvert and below the outfall.
- Depth and nature of bedrock or boulders, if encountered.
- An estimate of soil strength and stiffness.
- The potential for groundwater within the depth of installation, including any potential impacts on bedding. Text to address the likelihood of construction dewatering being needed and, if applicable, dewatering recommendations.
- Anticipated total and differential pipe settlement resulting from embankment fill and/or backfill.
- Recommendations to mitigate settlements where excessive settlement is predicted.
- Suitability of excavated soil for re-use as backfill.

Structural design of culverts shall be based on AASHTO LRFD methods with soil loads and design procedures as specified in Sections 3 and 12 of the AASHTO LRFD Bridge Design Specifications.

17.2.6 WING WALLS

The design of wing walls is a frequently overlooked aspect of culvert installation and repair projects. In general, any wing wall not directly connected to, and structurally supported by, the culvert pipe is considered a retaining wall and should be investigated and designed in accordance with Chapter 15 of the GDM.

17.3 TRENCHLESS UTILITY INSTALLATION

Trenchless installation methods allow for the installation of utility conduits without breaking the ground surface above the pipe. Such methods are frequently more technically difficult and, on first examination, may appear to be more expensive than open cut, trenched, methods. However, they represent the most viable and cost effective approach for crossings under many existing roads, railroads, and rivers. Other reasons for trenchless methods to be considered include work adjacent to settlement sensitive structures or avoidance of hazardous materials.

The cost of trenchless can seem higher with respect to conventional open cut methods unless all costs of open cut work are considered. One such cost would be the potential for future maintenance associated with cutting and patching the pavement. Other costs include pavement and trench spoil transportation and disposal, backfill, and traffic control. (labor, detours relocation of utilities., social \ economic costs and environmental costs)

The principal techniques utilized in transportation projects include the following:

- Pipe Jacking
- Horizontal Auger Boring
- Pipe Ramming
- Microtunneling
- Horizontal Directional Drilling
- Pipe Bursting
- Utility Tunneling

Each method listed above is described in more detail below.

17.3.1 PIPE JACKING

Aside from open cut installation, pipe jacking is the most common technique used to replace failed, failing, or undersized culverts. In general, pipe jacking consists of using hydraulic jacks to push pipes through the ground. The forward element of the pipe typically consists of a slightly oversized tunnel shield that minimizes pipe damage and side friction. For culvert replacement, the technique involves jacking a new pipe into place around the existing culvert and then subsequently removing the original culvert and residual soil.

The pipe jacking procedure uses the thrust power of the hydraulic jacks to force the pipe forward through the ground as the pipe jacking face is excavated. The spoils are transported through the inside of the pipe to the drive shaft, where it is removed. After each pipe segment has been installed, the rams of the jacks are retracted so that another pipe segment can be placed in position for the jacking cycle to begin again. Excavation is accomplished by hand mining or mechanical excavation within a shield or by a microtunnel boring machine (MTBM).

The selection of excavation method is based on a careful assessment of subsurface conditions in the installation zone for the presence of bedrock, boulders, cobbles, and fill obstructions such as stumps or logs as well as instability. Many methods are difficult to infeasible in areas where bedrock, cemented soils, or large particles (boulders and cobbles) are present. If there is any possibility of excavation face collapse, soil stabilization techniques must be considered. Common soil stabilization techniques are dewatering and grouting. Important optional equipment available for the pipe jacking method includes a pipe lubrication system and intermediate jacking stations. The pipe lubrication system consists of mixing and pumping equipment necessary for applying bentonite or polymer slurry to the external surface of the pipe. An adequate lubrication system can decrease jacking forces by 20 to 30 percent.

Backstop Design. The backstop is a rigid plate placed between the jack and the back wall of the jacking pit that is used to distribute the jacking load into the ground. The load required to push the pipe through the ground depends on the method and lubricants used and equipment capacity. The backstop is typically constructed normal (square) to the proposed pipe casing alignment. The sizing of the backstop can be based upon a passive soil pressure of 400 pounds per square foot (psf). The backstop or jacking wall should be Contractor-designed and should support the maximum obtainable jacking pressure with a safety factor of at least 2.0.

17.3.2 HORIZONTAL AUGER BORING

Auger boring is similar to pipe jacking except that a rotary cutting head is used to form the bore hole as the pipe is jacked, significantly reducing the necessary jacking forces. Spoils are removed from the pipe by a rotating auger. In general, auger boring allows for little to no steering. The stress and impact associated with an auger working within the casing generally limits the material choice to steel. Frequently a steel exterior casing is lined with a smaller carrier pipe of different materials.

Auger boring should generally not be used when the presence of cobbles and boulders larger than one third of the casing diameter is possible. This method can also be difficult in loose granular soils below the groundwater table. Bores in rock are feasible but are generally limited to weaker rock.

17.3.3 PIPE RAMMING

Pipe ramming uses a pneumatic hammer to drive a steel casing. The casing itself generally constitutes the drilling tool. Cuttings are removed using an auger or with compressed air or water. In some situations, small-diameter pipes can be driven with a closed end, negating the need for cuttings removal. Pipe ramming is most successful in stable, cohesive soils. With unstable soil conditions, the potential for voids and settlements are large. The method is generally not feasible within gravels and cobbles unless the casing diameter is large relative to the largest anticipated soil particle size.

17.3.4 MICROTUNNELING

Microtunneling is a trenchless construction method for installing conduits in a wide range of soil conditions, while maintaining close tolerances to line and grade from the drive shaft to the reception shaft. The microtunneling process is a cyclic pipe jacking process. For the soil types present (generally silts and clays with shallow groundwater), microtunneling methods can include slurry tunneling or earth pressure balance (EPB).

In the slurry type method, slurry is pumped to the face of the MTBM. Excavated materials mixed with slurry are transported to the driving shaft and discharged at the soil separation unit above the ground. EPB is a mechanized tunneling method in which spoil is admitted into the tunnel boring machine (TBM) via a screw conveyor (cochlea) arrangement which allows the pressure at the face of the TBM to remain balanced without the use of slurry.

Microtunneling can be applied to a wide range of soil types. The most favorable ground condition for slurry microtunneling is wet sand.

17.3.5 HORIZONTAL DIRECTIONAL DRILLING

HDD is a trenchless method of installing underground pipes using a specialized drill rig. Typically, a pilot hole is drilled and then subsequently enlarged using a tool known as a back-reamer. Finally, the pipe or casing is pulled into the enlarged shaft. The drilling is typically accomplished using a drilling slurry of water and bentonite or polymer. HDD can be applied to a wide range of soil types.

The primary geotechnical issue that complicates HDD installation is the leaking of drilling fluids to the ground surface (referred to as hydro fracture or frac out). Significant differences in density and stiffness between two formations will result in a tendency for the drill string to wander.

If encountered, cobbles and boulders present issues with respect to steering, borehole advancement, and borehole stability. Perhaps more challenging in such soils is the inability to maintain drilling fluids within the borehole. The loss (and necessary replacement) of drilling fluids directly results in expense and delay. Additionally, failure to maintain pressures can result in borehole collapse.

A known difficulty in drilling in formations containing cobbles is to avoid freeing up cobbles that then drop into the bore path. Cobbly formations are easily disturbed. Aggressive pressure on the drill string can result in damaging the soil structure that is present. This typically results in freeing up cobbles and gravels that might otherwise stay in place. In addition to moderating drill string forces, borehole support through increased gel strength of the drilling fluid is crucial. Enhanced gel strength would involve a higher concentration of bentonite and likely a polymer additive designed for gel strength enhancement.

Another significant issue with gravels and cobbles is that of removing the cuttings from the bore path. Removing whole cobbles and smaller pieces created through mechanically breaking-up the cobbles with the bit or reamer can be difficult.

All projects that involve HDD should include the development of a geotechnical report based on project-specific subsurface explorations and laboratory testing. The geotechnical report should include a description of the geotechnical feasibility of completing the proposed project using HDD techniques. The report should summarize the explorations and laboratory data as well as present an overall conceptual model of the materials anticipated to be encountered during drilling. Specific items to be addressed include:

- A cross section of the soils anticipated to be present across the proposed bore;
- Anticipated groundwater conditions, including the potential for confined or artesian conditions;
- The presence of coarse granular soils; and
- Bedrock strengths.

Geotechnical data presented for HDD projects includes the nature and distribution of material anticipated to be encountered during installation. For each formation, the Professional of Record (POR) should provide the Friction Angle, Cohesion Intercept, Unit Weight, and Shear Modulus.

17.3.6 PIPE BURSTING

Pipe bursting consists of breaking up the existing pipe, pushing aside the fractured pipe pieces, and pulling or jacking a new pipe in place. Subject to site conditions, the method can be used to maintain the existing pipe size or to install a new pipe size up to 100 percent larger than the original pipe diameter.

The soil conditions most conducive to pipe bursting are those that allow for the deflection of the burst pipe segments through compaction or consolidation of the soils. Stiff soils can result in significant surface heave or impacts to adjacent utilities. Cohesive soils can be preferable in that they will maintain the open hole formed by the pipe-bursting while the new pipe is being pulled into place; this limits the friction on the new pipe and reduces tensile stresses. As such, the most favorable soils would be soft clays, preferably above the groundwater table.

Pipe bursting below the groundwater table can be quite difficult. The pipe-bursting process can increase pore water pressures, reducing effective stresses; this can result in a “quick” condition where soil strengths are seriously reduced and the soil behaves as a fluid. The result is that pipe buoyancy forces are increased and soils in the pipe zone can flow into the pipe and into the receiving pit. It may be necessary to dewater for pipe-bursting processes.

The International Pipe Bursting Association (IPBA) classifies pipe bursting installations into three categories based on the depth of the existing pipe, existing and new pipe diameters, and burst length (IPBA, 2004). The IPBA Pipe Bursting Classification System is presented in the table below.

Table 17.1 IPBA Pipe Bursting Classification System

IPBA Classification of Difficulty	Depth of Pipe (feet)	Existing Pipe ID (inches)	New Pipe Diameter Compared to Existing Pipe	Burst Length (feet)
A - Minimal	<12	2-12	Size on Size	0-350
B - Moderate	>12 to <18	12-18	Single Upsize	350-500
C - Comprehensive	>18	20-36	Double/Triple Upsize	200-1,000

Pipe-Bursting Equipment. The contractor's choice of pipe replacement method and equipment should be compatible with the project requirements and subsurface conditions. It is particularly crucial that the Contractor select equipment that is capable of completing the proposed burst lengths given the subsurface conditions, depth, and upsize. Although specialty techniques exist to burst nearly any type of pipe, conventional pipe bursting is generally only applicable to existing vitrified clay, asbestos cement, unreinforced concrete, and PVC pipes. More complex methods exist for bursting some reinforced concrete pipes. Corrugated metal pipe is typically difficult to burst.

Lubricant. A primary component of the installation load applied to pipelines installed using pipe bursting methods is the friction generated between the new pipe and the burst pipe/soil matrix as the new pipe is pulled into place. In many cases, friction (and, therefore, the installation load) on the installed pipe can be reduced through the use of pipe lubricants. According to the IPBA (2004), the use of lubricants should be considered when:

- The new pipe diameter is equal to or greater than 2 times the existing pipe diameter;
- The burst length exceeds 300 feet;
- The new pipe diameter exceeds 12 inches;
- The host pipe is below groundwater;
- The ground conditions are unstable (i.e., flowing ground); and
- Recommended by the bursting equipment manufacturer.

Resistance Forces. Passive pressures against native or embankment soils are likely to be used to develop forces necessary to accomplish the pipe bursting. Allowable resistance forces with estimated deflections would typically be included in the geotechnical recommendations prepared for the project.

17.3.7 UTILITY TUNNELING

Utility tunneling is a method of soil excavation similar to pipe jacking. The difference is in the lining used. In Pipe Jacking, the pipe is the lining. In utility tunneling, the tunnel liner is installed as the tunnel excavation progresses. Liner systems include steel or concrete liner plates and steel ribs with wood lagging. The liners are used to provide temporary ground support.

The process involves removing soil from the front cutting face and installing a liner to form a continuous support structure. The tunnel is normally constructed between two access shafts. The procedure consists of four major steps:

- Soil excavation.
- Soil removal.
- Segmental liner installation.
- Line and grade control

The work normally includes workers within the pipe excavating and removing spoils as well as setting the liner sections. Since workers are inside the pipes, the normal minimum inside diameter of the tunnel is 42 in.

17.3.8 GEOTECHNICAL EXPLORATIONS FOR TRENCHLESS METHODS

For trenchless installations within State rights of way, a minimum of two borings per 150 feet of trenchless pipe should be completed. The borings should be completed to a minimum of 5 feet or twice the pipe diameter below the invert elevation, whichever is deeper. In general, sampling should be continuous, and certainly within two pipe diameters above and below the proposed pipe centerline. Groundwater depth should be monitored through the use of piezometers or wells where necessary.

One issue somewhat unique to HDD installation is the potential for exploratory boreholes to serve as pathways for drilling fluids to escape. For most other geotechnical explorations, the boreholes are located as close as possible to the proposed construction. However, geotechnical borings for HDD installation should be located a minimum of 25 feet from the proposed alignment.

Selection of Trenchless Method

The selection of a particular trenchless technology for use in a project will be guided by a number of non-geotechnical issues including budget, site access, and pipe diameter. Geotechnical conditions will also limit the number of options available and may rule out trenchless methods entirely.

Characterization of subsurface conditions within the proposed pipeline alignment has a significant impact on the overall project success. The most critical conditions to address are gradation (fine grained cohesive, fine grained non-cohesive, coarse grained, etc.), the presence of cobbles or boulders, the presence of rock, the soil density or stiffness, and the depth to groundwater. Guidance prepared by NCHRP indicates the potential for success for a variety of trenchless methods versus the anticipated soil conditions. The table below is derived from that guidance.

Table 17.2 NCHRP, Synthesis of Highway Practice 242, Trenchless Installation of conduits Beneath Roadways

N Blowcount (Standard Penetration Test)	Cohesive Soils (Clay)			Cohesionless Soils (Sand/Silt)			High Ground Water	Boulders	Full Face Rock
	N<5 (Soft)	5<N<155 (Firm)	N>15 (Stiff)	N<10 (Loose)	10<N<30 (Medium)	N>30 (Dense)			
Auger Boring (AB)	○	●	●	○	●	●	X	≤ 33% φ ¹	≤ 12 ksi
Microtunneling (MT)	●	●	●	●	●	●	●	≤ 33% φ ¹	≤ 30 ksi
Maxi/Midi-HDD	○	●	●	○	●	●	○	○	≤ 15 ksi
Mini-HDD	○	●	●	○	●	●	○	X	X
Impact Molding/Soil Displacement	○	●	●	X	●	○	X	X	X
Pipe Ramming	●	●	●	●	○	○	○	≤ 90% φ	X
Pipe Jacking (PJ) with TBM	○	●	●	○	●	●	○		≤ 30 ksi
Pipe Jacking with Hand Mining (HM)	X	●	●	○	●	●	X	≤ 95% φ	○
Utility Tunneling (UT) with TBM ²	○	●	●	○	●	●	○		≤ 30 ksi
Utility Tunneling with Hand Mining (HM)	○	●	●	○	●	●	○	≤ 95% φ	●

●: Recommended ○: Possible X: Unsuitable (based on the assumption that work is performed by experienced operators using proper equipment)

¹ Size of largest boulder versus minimum casing diameter (φ).

² Ground conditions may require either a closed face, earth pressure balance, or slurry shield.

APPENDIX

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