Curved Microtunneling

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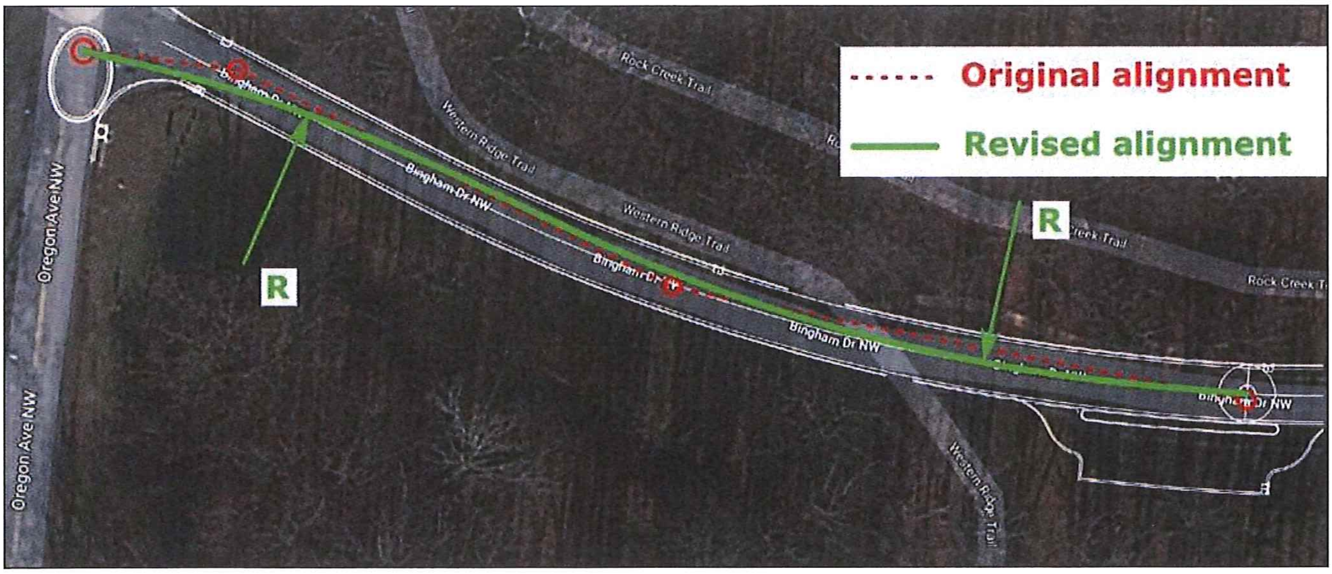
Curved microtunneling is slowly being adopted in the United States as contractors, designers, and manufacturers gain a better understanding of the requirements associated with curves. In Canada and most European countries, curved microtunneling is used as a method to reduce cost and risk on projects. As Portland and Seattle continue to expand, a number of curved drives are planned to be tunneled in the near future. The cost savings behind curved micro tunnels is primarily due to the elimination of vertical shafts and labor and schedule constraints associated with them. Five shafts can be reduced to three, or three shafts reduced to one. Elimination of shafts can also benefit the public by reducing detours, blocked trails, and the closing of public areas. Environmental considerations may also play a large role, especially in areas with contaminated soils or sensitive wildlife populations.

Reinforced concrete pipe (RCP) is the standard pipe used for curved microtunneling and pipe jacking around the globe. In Europe for example, RCP covers the vast majority of microtunnels for any purpose, including direct jacked sewer systems and railway crossings.

Reinforced concrete is the preferred material for several reasons. Apart from the competitive price, if designed correctly, the pipe is robust and ductile and can be adapted to project specific requirements. Thorough design and precise manufacturing processes may provide a design service life of 100 years or more. Inliners made of FRP, HDPE, PVC or RCP with an embedded steel cylinder (AWWA C300) pipes can provide increased corrosion resistance and reduced hydraulic friction, and some have high-pressure ratings suitable for various pressure applications. Polymer concrete pipe can also be used for curved microtunnels without the need for an inliner.

When it comes to curved microtunneling, reinforced concrete jacking pipes are typically preferred because they can be designed to allow large joint deflection angles with minimum damage potential to the joint, and still maintain the required water tightness. Large joint deflection angles require some thought on pressure distribution at the joint. Typical wooden



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packers are designed for straight runs, flat curves, and compensation of manufacturing tolerances.

Curved microtunneling is not new. Most tunnel boring machines (TBM) are fit to mine curved alignments. Besides, even a straight microtunnel will be executed as a curved one as various aspects, like geology, groundwater, overcut or simply the weight of the TBM require steering operations to keep the tunnel aligned.

As the pipes are pushed behind the TBM they experience similar joint deflections (with reduced amplitude) as the TBM is steered. It is important to remember the pipes are passively following the TBM as it is actively steered. Therefore there are two important considerations, both concentrated in the pipe joints: The joint needs to stay water tight, and it has to distribute the jacking force around the circumference of the pipe as the tunnel advances.

DIFFERENT REQUIREMENTS FOR PIPE JOINT

The primary purpose of a pipeline is to transfer different media between two points. The pipe itself as a bearing structure in the shape of a circular ring that withstands external loads like earth load, traffic load, and groundwater pressure. It maintains its shape and profile in the ground and is typically fabricated as a circumferentially endless, closed ring. The dimensions and reinforcement of the pipe wall can be designed according to different codes worldwide. In North America ASCE 27-17 provides a direct design approach. A combination of ASTM C76 and ASCE 27 specifications are sometimes used to simplify design. This can have some drawbacks since C76 leaves out some checks that would be performed if designing the pipe with a direct design method.

The pipe joint is a discontinuity in the pipeline and has to fulfill several requirements for a project to be completed successfully. The most obvious is the sealing effect. It has to prevent bentonite, grout, water, earth, and any other foreign materials from infiltrating the pipe during construction and prevent the transmitted fluid from leaving the pipe during pipeline operation. In a typical open-cut application, this requirement is fulfilled when no external material enters or leaves the pipeline during its service life. This can be achieved with a joint design that produces a seal anywhere in the joint.

In pipe jacking, the pipe must also serve as a bearing and load transferring structure in the longitudinal direction. Large jacking forces have to be transferred from the main jacks in the drive pit to the tunnel face through the pipe's wall and through the pipe joints. Since no external debris should enter the load bearing surface of the joint during jacking operations, the seal preventing infiltration is best suited to be on the outer circumference of the pipe.

COMMON JOINT DETAIL

A widely used joint detail that illustrates an external joint seal is the Type C joint in ASCE 27-17. This joint prevents debris entering the pipe joint bearing area and provides maximum surface area for jacking operations. The joint consists of a steel bell band that is cast into the concrete pipe around the outer circumference, forming the female end of the jacking pipe. The spigot end is shaped by a reduced outer diameter with a groove that keeps the gasket in place. Essential to this detail are the tight fabrication tolerances that keep the gasket within its design compression rate suitable to the project specific requirements. These tolerances can be achieved using steel molds and a well-controlled wet-cast manufacturing process.

The steel bell is cast into the concrete to provide resistance against lateral forces acting on it due to joint articulation. It is anchored into the concrete with shear studs or steel anchors. The water tightness between steel bell and concrete is achieved either by a cast-in steel profile, fully welded around the circumference of the steel bell band, or by applying a hydrophilic seal.

This design can be adjusted to project specific curve radii or joint deflection angles. The length of the steel bell can be increased when tighter curves have to be driven to ensure that the gasket never slips out of the steel bell. The outer diameter of the spigot may be reduced or beveled to provide enough space between the steel bell and concrete to facilitate the articulation.

The gasket groove is an essential part of the design as well. Opening and closing joints during a (curved) drive could otherwise pull the gasket off the spigot end into the pipe and lead to leakage. The gasket itself can be of circular or wedge shaped cross-section, where the wedge-shaped gasket has the advantage of easier joining of the pipes and a well-defined contact area between gasket and concrete grove.

CONVENTIONAL PRESSURE TRANSFER

Another important consideration is the pressure transfer ring. It is an import part of pipe jacking with RCP. It helps distribute eccentric and point loads by distributing the forces from the jacking operation. Eccentric loads can occur from out of square end sections and steering operations, and point loads can occur from rough or uneven joints, or when a joint deflects enough to loose full contact around the joint. Since the concrete pipe itself is very stiff compared to the joint assembly, any deflection resulting from a curve or steering operation is concentrated in the joints. Changing directions due to steering movements cause the packer to experience multiple cycles of loading and unloading during construction. These conditions define the properties that a pressure transfer medium has to fulfill: It should be rather soft compared to the pipe material and it should have reversible behavior, without inducing unfavorable tensile splitting stress into the pipe's face.

The typical timber material for conventional packers fulfills some of these conditions and provides enough admissible jacking force for straight drives and flat curves. However, the material properties of timber are highly irreversible; upon unloading a timber packer, a certain plastic deformation remains but the stiffness of the material is increased compared to the unloaded state before. The more loading and unloading cycles a wooden packer experiences, the stiffer it gets and its capacity to equalize unevenness or joint deflection is reduced. The stresses induced to the concrete pipe by the wooden packer may increase during the construction period. Consequently, the damage potential increases as well.

Along with the imposed stress on the concrete, the resulting jacking force at an articulated joint is acting eccentrically on the pipe regarding its axis: The joint opens up on the outside of the curve and the jacking force is transferred by a "point load" on the inside of the curve. This eccentric forces may also impose a turning moment onto the pipe if the resulting force on the front end of a pipe is acting at a different location than on the back end of it. This is the case as soon as the joint articulation angles differ from the front to the back of the pipe. This is commonly observed due to the variability of steering operations and manufacturing tolerances.

This moment pushes the pipe against the ground, which means that ground reactions are acting laterally on the pipe. These reactions can be of the same amplitude as the jacking forces, especially if the pipe's length is similar to its outer diameter. Such high lateral forces are normally not considered in the dimensioning of the pipe and can lead to severe pipe damage.

A straightforward solution to reduce the joint deflection angles in curves is to shorten the pipes. However, short pipes have various disadvantages. Short pipes have a direct influence on the cost gener-

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ated by the manufacturing of the pipe as well as the installation cost on site. Furthermore, a joint is always a weak spot in a pipeline, therefore the number of joints is preferred to be as small as possible.

HYDRAULIC JOINT FOR PRESSURE TRANSFER

For longer drives, and especially curved drives, the hydraulic joint can provide an easy solution to the challenges mentioned before. It replaces the wooden packer as a pressure transmission ring.

The hydraulic joint is based on two principles: First, the principle of communicating vessels stating that the pressure level inside a vessel is constant, and second, the perfectly reversible mechanical behavior of non-compressible fluids independent from the deformation/load history. The hydraulic joint consists of a hermetically sealed hydraulic conduit, filled with a specific amount of fluid, which is mounted on the pipe's face instead of the conventional wooden packer.

As the jacking force is applied, the hydraulic joint gets squeezed and because of the constant volume enclosed in the hermetically sealed conduit, the fluid is set under pressure as a reaction to the applied force. This pressurized fluid cushion transfers the jacking force to the next pipe. Due to the hydraulic communication, no stress concentrations are acting on the pipe's face.

When driving through a curved alignment, whether planned or unplanned, the hydraulic joint gets squeezed more on the inside of the curve than on the outside, but no open gap will occur as would be the case using wooden pressure transmission rings. Therefore, the jacking force is distributed more uniformly around the pipe's circumference and the unfavorable eccentricity mentioned before is reduced by dimensions.

As a result of the reduced eccentricity, the lateral forces acting on the pipe are reduced by dimensions, which generates a series of advantages compared to the conventional joint design. Reduced lateral forces mean that the maximum jacking force can be maintained in a curve even with regular pipe lengths, without risking

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any damage of the pipe. The possible radii of curvature for a pipe line is drastically reduced by the application of the hydraulic joint. This allows the design of new curved alignments that with wooden packers would be too risky or uneconomic, if not even impossible. Also, reduced lateral forces mean that the friction between soil and pipe is reduced by the same dimension. This reduces the possibility that an intermediate jacking station installed in the microtunnel will need to be activated, further increasing efficiency.

CHANGES IN APPLICATION FOR CONTRACTOR

The application of the hydraulic joint only requires insignificant changes for the tunneling contractor compared to the conventional joint design. The pipe manufacturer and hydraulic joint designer can work together on an acceptable design. Since the hydraulic joint's ends are tightened by steel fittings, cavities are required in the pipe's rear face for the fittings to be protected during jacking operations. Next, the hydraulic joint has to be mounted on the cured pipe using specially designed equipment, however this process is quick and easy. Besides, for these changes the jacking process can continue as it would be using conventional wooden packers.

Properly designed reinforced concrete jacking pipes are the first choice for micotunneling operations worldwide, especially for curved alignments. Various characteristics and technologies allow for easy to implement project specific designs that can cover a wide range of applications.