Innovative Steel Casing Pipe Installation Using Mechanical Interlocking Joints

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ABSTRACT

Trenchless construction techniques eliminate the need to open-cut roadways, railroads, canals, city street intersections, and other locations where trenches for pipe and casing installations are inconvenient or can impact the general public's safety. Large diameter (24 inch and greater casing) trenchless techniques include microtunneling, pipe jacking, auger boring, and pipe ramming. Steel casing is often the product of choice for these techniques due to its strength, toughness, flexibility, resistance to high jacking forces, and butt-welded joints. Mechanical interlocking joints have steadily gained acceptance and use as a substitute for butt welded joints on steel casing pipe. The interlocking joints eliminate the need for time-intensive field butt welding and the associated higher cost. Fully machined interlocking connectors manufactured per ASTM A1097 are preinstalled in the factory and when joined in the field, are flush with the outside diameter of the pipe providing no additional drag or increased jacking force requirements. This paper will discuss the use and installation of mechanical interlocking field joints for casing installations with case histories. The paper will assist engineers and owners with casing design and specification considerations, and discuss the efficiencies gained with the various styles of innovative mechanical interlocking joints.

CASING PIPE HISTORY AND INSTALLATION METHODS

Trenchless installation techniques have been recorded in one form or another dating back to early Roman times, basically for as long as pipe has been put in the ground. There have been incredible innovations in trenchless technologies over the years, but it was in the 1980's when trenchless technology as an industry was "officially" established.

The need for improved installation methods has driven the industry to make huge leaps in trenchless capabilities and technology. Those jumps are continuing to occur as trenchless installation becomes more and more favorable vs traditional open cut in many applications.

Trenchless technology encompasses many areas including renewal and replacement of existing pipelines and utilities. This paper will focus on new installations, but the technology can be used for renewal or replacement applications as well.

There are many variations and concepts used in trenchless installations; some require manned entry of the pipe during installation, where with others the operations are completed without entering the pipe during install. All of the methods discussed here will use steel pipe in one aspect or another.

Some typical manned entry installation methods include:

Mechanical open shield pipe jacking: the pipe is jacked in the soil and the material at the face of the excavation is removed either manually or with excavation equipment.

Utility tunneling: involves installation of a temporary liner support structure. This method usually involves the use of liner plates supported with steel ribs or wood lagging (ring beam and lagging). After the tunnel is completed, the pipe is transported inside and the annular space between the carrier pipe and casing pipe is then grouted.

Tunnel boring machines: tunnel boring uses a rotating cutting face to remove the material as the pipe is advanced. This is also considered manned entry since the controls for the machine are at the face of the cut.

Some typical installation methods that do not require manned entry are:

Horizontal auger boring: the pipe is jacked to advance it as the soil from the face is removed by a rotating auger flight inside the pipe (see Figure 1).

Figure 1. Horizontal Auger Boring

Pipe ramming: utilizes a hammer unit attached to the pipe that drives the pipe through the soil (see Figure 2). This method does not require a thrust wall or other system to push against to advance the pipe.

Figure 2. Pipe Ramming

Horizontal direction drilling (HDD): a pilot bore is drilled along a route followed by a reamer, opening a hole for the carrier pipe to be pulled through. HDD allows for a steerable route to direct the pipe under obstacles, such as below a river or other body of water.

Micro tunneling: similar to tunnel boring, it removes material with a rotating cutting head, but the controls for the unit are remotely located above ground (see Figure 3).

Figure 3. Microtunneling

Pilot tube boring: an installation method that adds the step of using a precision guided tube installation prior to the boring or drilling operation.

THE INTERLOCKING JOINT

With all of the pipe installation methods previously described, steel pipe is commonly used as the tunnel casing pipe due to the strength of steel, its ability to resist high jacking forces that are commonly required, and its high strength to weight ratio. Steel pipe offers flexibility and is forgiving when dealing with underground obstacles, both known and unknown. If needed, steel pipe can be modified by plant or field cutting and welding, such as adding anchors or other attachments.

One of the issues with the use of common steel pipe for trenchless installations is the need to weld the joints. In a trenchless operation the time to weld joints can be very costly. The contractor not only has the cost of the welding, but the rest of the installation crew is typically waiting as the welding process is completed on each joint. Installing contractors were looking for a solution to speed the installation process up and reduce wait time. In the late 1980s an idea was born and developed by a trenchless technology pioneer named Mike Argent that led to a Patent being issued in 1993 for the Permalok® interlocking joint Figure 4.

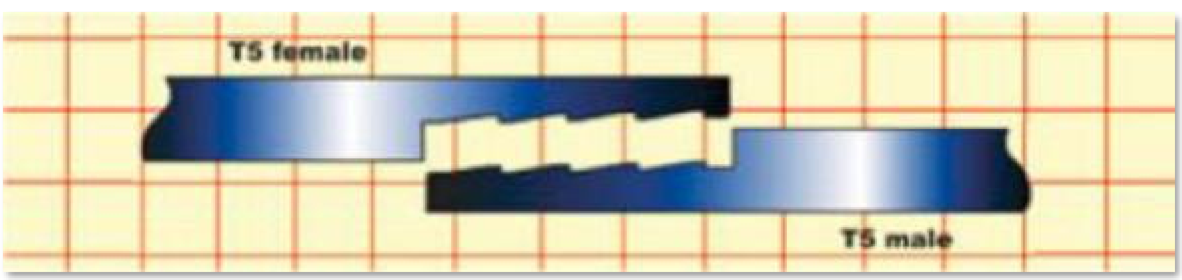

Figure 4. Interlocking Steel Joint

Since the introduction of the steel interlocking joint into the trenchless process, installers have found many advantages to using the joint over welding, something not likely envisioned when the joint was first imagined.

The most common advantage contractors site for the use of interlocking joints is the cost savings to the project. It may first appear that the additional cost to add a precision machined end to a steel pipe would make an interlocking joint non cost-competitive. To understand the full advantage, a look at the total process of installing the pipe must first be examined.

There are a number of considerations that can be easily overlooked when installing a field-welded steel pipe. If the installer wants the pipe to be installed on a straight alignment, they must first make sure the pipe ends have been cut true, since any angularity can misdirect the drive. The ends must be prepared for a properly installed butt weld. On heavy wall pipe this requires a precision bevel end; the face of the pipe must be true or large gaps in the weld will develop. With a properly faced pipe, the two mating ends must be the same diameter and of the same matching shape. Any slight out of roundness of either end can require extensive fit-up of the ends to make sure the two faces meet up properly for the entire circumference. With wall thicknesses sometimes exceeding 1 inch, fit-up can be a very difficult process.

Once the pipe ends are fit, the actual welding process can be considered. This requires a knowledgeable welder that should be certified to weld on pipe through either AWS or ASME. The welding process can take multiple hours to complete. Once complete, the welds should be inspected by a certified weld inspector.

The critical path for a trenchless installation involves anything related to getting the pipe into the ground. If the pipe is not moving into the ground, crews and equipment that install the pipe are not being productive. The potential savings of not having an entire crew and all the equipment waiting for joint fit-up and welding in the process saves both time and money, allowing earlier completion of the project. A typical drive that may take a week with conventional methods can be completed in a little more than a day. A time comparison can be found in Figure 5.

Figure 5. Interlocking Joint vs Welded Joint

Along with the time and cost savings there is the inherent safety issues that are eliminated by removing welding from the installation process. There are always safety concerns with welding; improper grounding can damage electronics and other systems in the boring equipment. If there is ground water present, welding in wet conditions offers its own set of safety concerns.

One of the advantages of using interlocking joints that may be less obvious is the reduction of some of the friction forces that can be generated in trenchless installations. When the pipe installation is stopped for the welding process, the material around the pipe can settle in over a relatively short period of time, dramatically increasing the start-up friction drag. This in turn requires substantially more force to get the pipe moving again after a down period. The longer the pipe sits, the harder it gets to overcome the friction forces that have developed.

It has also been found that in longer installations, such as microtunneling, where the alignment must be adjusted during the installation to deal with varying soil conditions, the interlocking joint offers some freedom for articulation. Because of the articulation the joints will allow the tunneling machine to steer the pipe through the soil. With the beam strength of welded joint steel pipe, the pipe tends to force or steer the machine a particular direction through the soil, often not in the direction the operator needs.

The following two recent innovations in interlocking joints have been designed for specific installation methods. An auger bore (AB) joint allows the interlocking joint to be engaged straight on and with lower force of engagement. This allows for easier connection of the auger flights inside the pipe sections. A pipe ramming joint that offers an increase of energy transfer across the joint during the ramming process has also been developed.

Interlocking joints have been successfully used for casing, carrier and outfall pipe. The more common installation methods that have used interlocking joints include microtunneling, tunnel boring, auger bore, pipe ramming and horizontal direction drilling.

DESIGN CONSIDERATIONS

In regards to the pipe in a trenchless project, all pipe materials have properties that should be considered in the design to provide ease of installation and a finished installation that meets or exceeds the expectations of the project and its future operation. Regardless of the pipe material, it is prudent to build a project specification and design with a foundation of a national standard. For steel casing pipe ASTM A1097, Standard Specification for Steel Casing Pipe, provides that foundation.

Important aspects covered in the standard are pipe straightness, end preparation and tolerances, pipe roundness, thickness, diameter, steel grades and pipe weld quality. ASTM A1097 covers both field welded casing as well as interlocking joints. For the specifier, ASTM A1097 offers a simple, yet complete way to specify steel pipe for casing installations.

Pipe cylinder smoothness, both on the interior and exterior, and flush joints assist the installation, through reduced friction and subsequent jacking effort. Pipe straightness and end preparation also help with potential jacking loads, but more importantly, assist with keeping the drive heading where it is intended.

The steel interlocking joint offers designers some tools that are different from other joints and materials. When a precision machined end is mated, the eccentricity that can happen in field welded joints does not exist. The joint also offers some degree of flexibility to negotiate adjustments in alignment similar to what a gasket joint might offer, but the interlocking joint is a homogenous material; the steel provides a resistance to keep the joint aligned, and not develop eccentricity that gasket materials may allow. Allowable jacking forces for the steel interlocking joint can be developed in a similar fashion to a welded joint.

The precision machined joints do not allow soil infiltration, and typical installations include the addition of a silicone based material to both aid in the assembly of the joint, and also provide a sealing effect to prevent water infiltration.

APPLICATIONS

Steel interlocking joints are used in many trenchless applications including micro tunneling, tunnel boring, auger bore, HDD, and pipe ramming. With any trenchless application where steel pipe may be utilized, interlocking joints can provide additional benefits. The interlocking joint also offers installations that may not be possible with welded steel joints such as:

- Urban areas where the increased speed of installing interlocking joints can reduce the time needed for the open pits or trenches that cause substantial social impacts through traffic and safety concerns.
- Areas where welding is not practical or possible, either due to safety or environmental concerns.
- High water table conditions where speed of install is important and welding may be impossible.

CASE HISTORIES

Wildcat Point Generation Facility

Construction of the Wildcat Point Generation Facility (WPGF), Figure 6, was begun in late 2014 on the northern border of Maryland and completed in 2017. A primary input to the power generation process was water that would require 23,000 linear feet (7,010 m) of intake and discharge lines that would pass below an active rail road, through mixed soils consisting of separate areas of rock, fine grained alluvial soils, and river silts. Besides soil conditions, a primary concern with the project would be counteracting the buoyant forces on the pipe and conducting a wet retrieval of the Microtunnel Machine in a condensed and aggressive schedule.

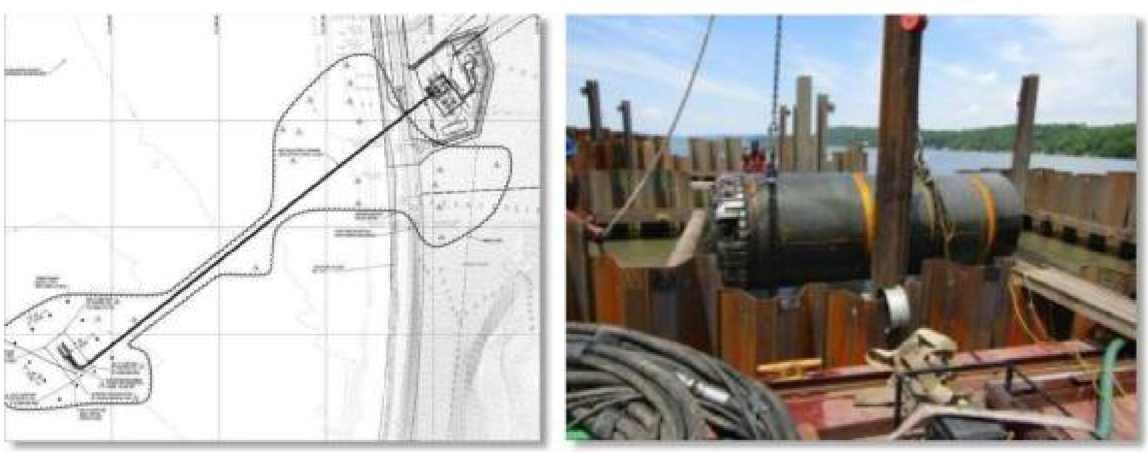

Figure 6. Wildcat Point Generation Facility

Interlocking steel pipe was the preferred pipe material for this project to allow for rapid installation addressing any potential of settling during the microtunnel installation. The final project would consist of a single drive with 160 linear feet (48 m) of 60-inch (1,524 mm) diameter by 0.844-inch (21.4 mm) wall and 900 linear feet (274 m) of 60-inch (1,524 mm) diameter by 1.625-inch (41.2 mm) wall thickness pipe. To address the concern of buoyancy it was determine that increasing the wall thickness would not be sufficient to overcome the current and buoyant forces. It was determined to add cast iron counter weights encased in 0.625-inch (15.875 mm) plate to increase the pipe weight to over 2,000 pounds per foot (2,976 kg/m) while still providing sufficient internal space for the operation of the intake structure (see Figure 7). The final project was completed in 2016 utilizing 24 hour-a-day, seven day-a-week shifts to complete the project nearly six months faster than operating on traditional shifts and welding of pipe.

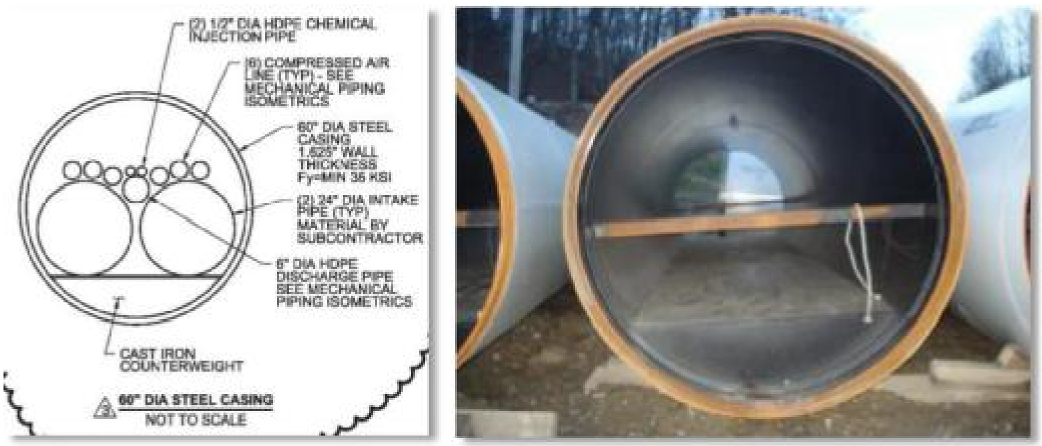

Figure 7. Cast Iron Ingots for Buoyancy

OHSU Center for Health and Hearing-South

The OHSU-CHH South project, Figure 8, was driven by the need for expanded and updated healthcare facilities in support of the OHSU Mission. The project included a 15-story hospital and research building and adjacent 11-story Family Pavilion and parking garage. As the city of Portland has a moratorium on elevated pedestrian bridges connecting buildings, construction plans called for the design and installation of approximately 70 linear feet (21 m) of 12 ft. (3,657 mm) diameter pedestrian tunnel to be installed with a depth of cover in excess of 30 ft. (9.1 m). With the pipe connecting buildings within a critical healthcare network and the volatile seismic nature of the area, the soils, primarily consisting of glacial till and boulders, presented some unique challenges to this project.

The final design consisted of 72 linear feet (22 m) of 144 in. (3,675 mm) diameter pipe with a 1.25 in. (31.75 mm) wall thickness to be installed via Pipe Ram. Steel pipe with interlocking joints was selected by the contractor as the preferred pipe for the project. The selection was based on two primary factors: the mechanical press fit connection, removing the necessity to weld the pipe therefore reducing project completion time, and the seismic performance of the pipe itself. The job was completed ahead of schedule achieving all of the parameters of the project resulting in one of the largest diameter pipe ram installations ever completed.

Figure 8. OHSU-CHH South project

Campbell River Water Supply

The Campbell River Water Supply project, Figure 9, connected a new source of potable water to the residents for Campbell River, Vancouver Island, BC. John Hart Lake originally served as the water supply reservoir to BC Hydro's power generation facility, the $28-million-dollar upgrade project eliminated a transmission line through Elk Falls Provincial Park. Site mobilization would prove challenging moving all equipment and materials to the site via barge and concerns to lessen the ecological impact of the project on the salmon population and drinking water source. The soil conditions provided shallow depth of cover and flowable material at the lake also presented concerns to the project.

The final project would consist of 370 linear feet (113 m) of 60 inch (1,524 mm) diameter by 0.750 in. (19 mm) wall thickness steel pipe with interlocking joints that were installed via microtunnel, a 62-inch (1,600 mm) fused joint HDPE pipe was then be floated and pulled back into the casing pipe with both pipes ultimately being attached to an intake screen at a depth of approximately 45 feet (14 m).

Figure 9. Campbell River Water Supply Project

Ala Moana Force Main Projects

At the time of its installation, the Ala Moana Force Main Projects in Honolulu Hawaii, Figure 10, was the largest single Microtunneling Project in North America. The project was part of the Emergency Beachwalk Force Main Construction project and included 14,700 linear feet (4,480 m) of pipe. Over 3,000 linear feet of 81-inch (2,057 mm) by 1-inch (25 mm) thick steel pipe with interlocking joints was selected for the project which would also include two 1,700 linear foot canal crossings. The soil conditions consisted primary of basalt and coral.

A portion of the project consisted of five 72-inch (1,830 mm) microtunnel drives totaling 5,800 feet (1,770 m) and constructed five shafts at 45-foot (14 m) deep. One of the five drives was the first multiple curved drive in North America at 1,241 feet (378 m). The installing contractor utilized multiple crews operating simultaneously at different jobsites across the project to get a successful completion within the EPA mandated and project required timeline.

Figure 10. Ala Moana Force Main Project

CONCLUSIONS

With greater population expansion and the ever changing demands on aging infrastructure, minimizing the impact to consumers while replacing and improving systems is an omnipresent concern for owners and designers alike. While improvements in trenchless construction have drastically reduced the impact to consumers, innovations in pipe design has traditionally lagged behind all industries as a proven commodity that has endured for hundreds of years. However, improvements in equipment and design methods that provide increased efficiencies and lower cost should not be hampered by a stagnant technology. Steel interlocking joints offer the strength and ductility of steel with the benefit of a flexible joint, providing an alternate product with similar performance characteristics and specifications that provides increases in speed and throughput. Interlocking joints offer many proven innovative options that the designer and installer can take advantage of for their trenchless installations, lending support to new technologies and improved efficiencies. This results in faster project completions, lower overall trenchless construction costs for the owner, lessened impact to the consumer, and little to no design change for the designer.