Sustainable Construction for Large Diameter Steel Pipeline on the Integrated Pipeline Project

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ABSTRACT

After nearly four years of construction on several sections of the integrated pipeline (IPL) project in north Texas consisting of approximately 60 mi of 108-in steel pipeline using imported granular embedment, the existing soil conditions in IPL Sections 10 and 11 provided the contractor the opportunity to use native excavated material for a sustainable construction solution to importing embedment material. Most of the these completed sections of the IPL project were constructed in soils that were not conducive for use as pipe embedment without extensive screening and processing in the form of controlled low strength material (CLSM) for fat clay soils or crushing and screening of limestone. IPL Sections 10 and 11 which consists of approximately 12.5 mi of 84-in raw water steel pipeline in Ellis, Johnson, and Tarrant Counties partly runs through sandy soils that can be processed and mixed with cement to make cement stabilized sand (CSS). IPL Sections 10 and 11 begins in fat clay soils in the south and ends in the north and west in sandy soils. There are several sand borrow sites in the area including one that the pipeline runs through. This sand borrow site was active prior to construction of the pipeline. The contractor proposed using the native sandy soil excavated along the pipe alignment for CSS in lieu of gravel embedment. This paper highlights the steps taken to evaluate the use of the native sand for making CSS for pipe embedment: triaxial testing to determine Young's modulus properties of various CSS sand mixes ranging from 1% to 5% cement content; determine modulus of soil reaction, E', values for each CSS mix design to confirm it's suitability for a standard trench width; and require contractor to demonstrate that CSS could be produced from a pug mill with consistent quality that had optimum moisture determined as part of the triaxial testing process. By using native sandy soils excavated along the pipeline for producing CSS for the pipe embedment, the contractor was able to greatly reduce the number of embedment deliveries to the project site and reduce the amount of spoil material that had to be hauled off. This directly reduced the impact to existing roads and the environment.

INTRODUCTION

The Integrated Pipeline (IPL) Project is a raw water delivery system consisting of approximately 150 miles of pipe made possible through a partnership of the Tarrant Regional Water District and the City of Dallas (IPL Team). Together they currently supply water to over four million people in the Dallas Fort Worth metropolitan area. The IPL Project begins at Lake Palestine, which is approximately 80 miles southeast of Dallas, Texas and terminates at Benbrook Lake in southwest Fort Worth, Texas.

Black & Veatch (B&V) was responsible for design and construction administration of IPL Sections 12, 13, and 14 consisting of approximately 30 miles of 108-inch water transmission pipeline. At the end of 2016, IPL Sections 10 and 11 was advertised and awarded for construction. B&V was contracted to provide construction administration services for IPL Sections 10 and 11 which consists of approximately 12.5 miles of 84-inch steel raw water

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pipeline located in Ellis, Johnson, and Tarrant Counties. Figure 1 below shows the location of the overall IPL Project with IPL Sections 10 and 11 shown in red.

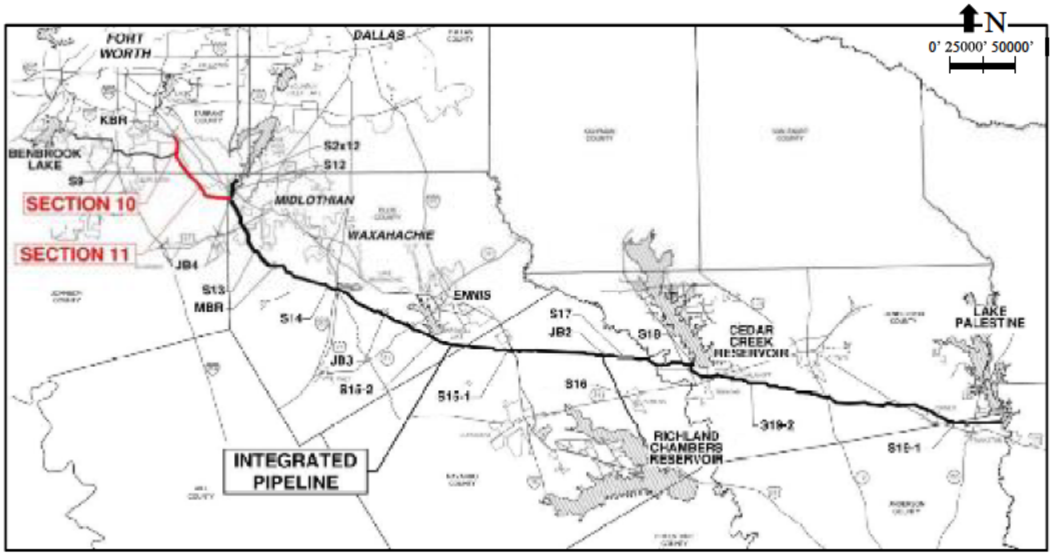

Figure 1: Location Map

IPL Sections 10 and 11 provided the contractor the opportunity to use native material for embedment for a sustainable construction solution to importing embedment material. Most of the completed sections of the IPL Project were constructed in soils that were not conducive for use as pipe embedment without extensive screening and processing to create controlled low strength material (CLSM) for fat clay soils or crushing and screening of limestone.

IPL Sections 10 and 11 partly runs through sandy soils that can be processed and mixed with cement to make cement stabilized sand (CSS). The southern end of IPL Section 11 ends at the JB4 Booster Pump Station located between IPL Sections 12 and 13. The soil in this area of Section 11 is primarily fat clay. As the pipeline continues to the northern end of Section 11 the soils are sandy, and all of Section 10 is in sandy soils. Additionally, there are several sand borrow sites in the area including one that the pipeline runs through. This sand borrow site was active prior to and during construction of the pipeline.

The contractor proposed using the native sandy soil excavated along the pipe alignment to make CSS in lieu of granular embedment. Allowing the contractor to use native excavated soil from along the pipe alignment would significantly reduce the number of embedment deliveries to the project site and reduce the amount of spoil material that would need to be hauled off. To evaluate the contractor's proposal for using CSS for embedment, the project construction team which included the IPL Program construction team and B&V, required that they submit a plan detailing the cement content to be used for the CSS along with triaxial test results to estimate Young's Modulus values for the CSS. From the Young's Modulus values, modulus of soil reaction, E', values for a standard trench width could be approximated.

EXISTING SOIL CONDITIONS

On this project the existing soils vary from weathered shale and fat clays in the south and east end of the project to sand in the north and west. The sandy areas are not loose-flowing sands but more like sandstone with one vertical faced plateau present along the pipe alignment (see

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figure 2 below). The sand borrow sites along the alignment also have many vertical faces with little to no erosion apparent.

Figure 2: Raised Plateau along Pipe Alignment

The sandy soils begin at the northern end of pipeline Section 10 and extend to the south and east into pipeline Section 11. The total approximate length of pipeline in sandy soil is about 4 miles. The remaining 8.5 miles of pipeline is in primarily fat clay soils. Figure 3 is a picture of a trench cut in this sandy soil.

Figure 3: Trench Cut in Sandy Soil

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PROJECT TRENCH SECTION DESIGN

As with all flexible pipe design it is critical to evaluate trench width, embedment, and existing soil conditions to provide adequate pipe support. This project was bid with multiple acceptable options for trench width and embedment and backfill type. This allowed the contractor to choose the best suited trench condition for their pipe laying operations. Table 1 summarizes only the trench options for granular embedment (trench type C) and flowable fill (trench type F).

Table 1: Trench Section Dimension Schedule

Trench Type	a (inches)	b (inches)	c (inches)	w (inches)
C1	6	12	58.8	OD+24
C2	6	18	58.8	OD+36
C3	6	24	58.8	OD+48
F1	6	12	58.8	OD+24
F2	6	18	58.8	OD+36
F3	6	24	58.8	OD+48

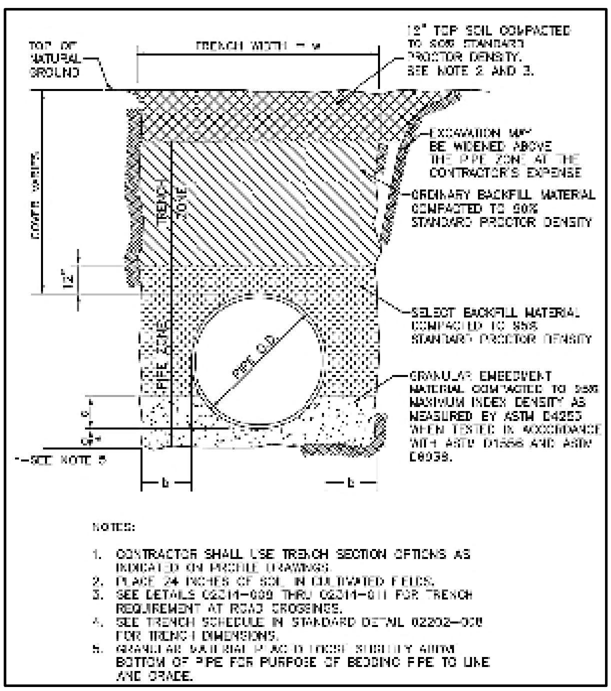

Figure 4: Standard Trench Section

Acceptable pipe embedment and backfill for this project included granular embedment and flowable fill from 6-inches below invert of pipe to a height equal to 70% of the outside diameter of the pipe. Column c shows 58.8-inches which is 70% of the outside diameter of the pipe

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diameter of 84-inches. Figure 4 is the standard granular embedment and backfill detail used on this project. Columns a, b, c, and w from Table 1 are defined in this figure.

Depending on pipe depth and native modulus of soil reaction, the "b" dimension varied from 12 inches to 24 inches. Based on B&V's experience on constructing approximately 30 miles of 108-inch pipe and the overall IPL Team's experience of constructing approximately 60 miles of 108-inch pipe, the optimum trench width for getting embedment under the pipe haunches with no voids was found to be pipe outside diameter plus 18 inches to 24 inches on both sides of pipe. Prior to construction beginning on any of the IPL Sections the contractor was required to prove-out their construction methods for installing embedment around the pipe to the proper compaction with no voids. For granular embedment, a wheel compactor with wedges worked best at spreading embedment material under the pipe haunches. See Figure 5 below for wheel compactor used for granular embedment on this project.

Figure 5: Wheel Compactor for Granular Embedment

IPL PROGRAM DESIGN STANDARDS AND DESIGN APPROACH

The IPL Program provided design guidance for all projects. The design criteria required the pipe to be designed using AWWA M11 (AWWA 2004). The design criteria included E' values for granular embedment and flowable fill, deflection lag factor of 1.1, and bedding constant of 0.10 to be used for pipe deflection calculations under various dead and live load conditions. The E' values for granular embedment and flowable fill were 1,500 psi and 3,000 psi respectively. The IPL Program geotechnical consultant also provided a geotechnical design memorandum and data reports for each IPL project. These geotechnical documents included native E' values for the soil samples taken at each bore location as well as guidance on evaluating pipe soil interaction for various trench widths using composite E' values. Use of composite E' for determining deflection of flexible pipe has been documented in *Pipeline Installation* (Howard 1996) and in AWWA M45 (AWWA 2005). By applying composite E' values in the pipe deflection formula for various trench widths, pipe deflection could be approximated for the various trench widths and checked against allowable pipe deflection to determine appropriate trench widths and embedment type.

CEMENT STABILIZED SAND EVALUATION

During the submittal review process the contractor requested that CSS be considered as an alternate embedment for the trench sections shown in Table 1. The contractor proposed bringing

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a pug mill onsite to make CSS using native excavated sand mixed with cement. Since the IPL Program did not have a CSS specification that had been adopted for use on the program, the project construction team agreed to require the contractor to provide a CSS mix design with an average compressive strength results between 80 psi and 150 psi with no individual test below 70 psi. This would be comparable to the required compressive strength for flowable fill as specified in the contract documents. The contractor was also required to submit CSS mix designs with cement content ranging from 1% to 5% and to provide consolidated undrained triaxial shear test results for each mix design.

The project construction team also required the contractor to provide a demonstration of the use of the pug mill for making CSS. This would allow the project inspectors to familiarize themselves with the pug mill operation and steps they would take to deliver CSS to the pipe installation crews. Below is a picture of the pug mill used on this project.

Figure 6: Pug Mill Demonstration

The contractor's proposed plan was to stockpile excavated sand from the pipeline excavation as well as from the nearby sand borrow sites on-site adjacent to the pug mill setup so that all CSS could be produced from one location without having to constantly move it as construction progressed. The pug mill would be located along the pipeline right-of-way, and dump trucks would deliver CSS to the pipe installation crews along the pipeline right-of-way.

The IPL Program's geotechnical subconsultant for this construction project provided controlled laboratory tests for the CSS mix designs with cement content ranging from 1% to 5%. Compressive strength test results showed that 3% cement content yielded the desired compressive strength. The project construction team requested triaxial test results to estimate Young's Modulus, E, for each submitted CSS mix design. Using the Young's Modulus values, modulus of soil reaction, E', values were approximated for the proposed CSS embedment using Constrained Modulus, M_s. AWWA M11 4th Edition acknowledges that many researchers have studied the relationship between E' and M_s and have determined that E'=0.7 to 1.5 M_s. It also acknowledges that it appears to be justified to assume the two values to be the same. Therefore E'=M. (AWWA 2004). AWWA M45 also indicates that E' and M values are close and M may be substituted directly for E' in the Iowa formula for calculating pipe deflection (AWWA 2005).

The equation below is taken from AWWA M11.

$$M_s = \frac{E*(1-v)}{(1+v)*(1-2v)}$$

$$E = \text{Young's Modulus, determined from triaxial test results}$$

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$$v = \text{Poisson's ratio, for concrete } v = 0.1 \text{ to } 0.2$$

Figure 7: Wheel Compactor for CSS Embedment

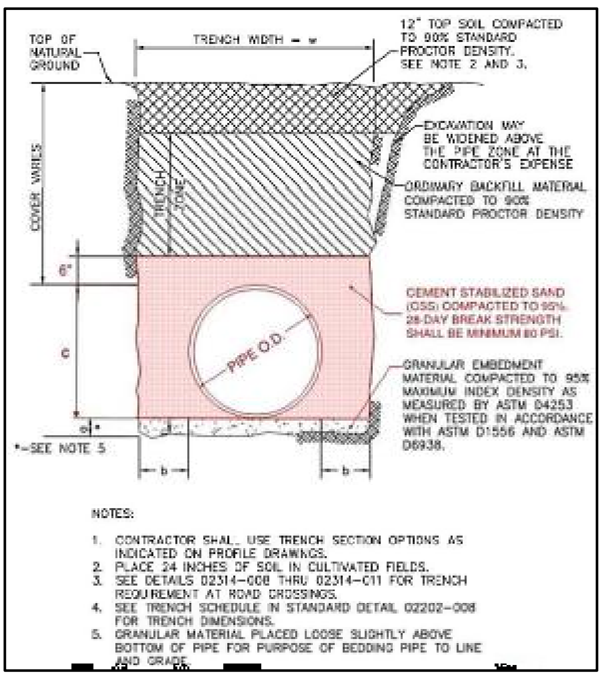

Figure 8: CSS Trench Section

At the time this analysis was performed, M11 5th Edition had not been published. This relationship has been removed from M11 5th Edition (AWWA 2017).

The program construction team expected CSS to yield similar results to flowable fill. Using the relationship above, E' values for CSS were approximated to be similar to flowable fill with values above 3,000 psi. These results gave the owner's project team confidence to grant the contractor's request to use CSS on this project. B&V then evaluated composite E' values for varying trench widths and selected a trench width of pipe outside diameter plus 36-inches to 48-inches (OD+36" to 48"). The contractor was also required to bring the CSS embedment up to 6-inches above top of pipe to provide a uniform pipe embedment around the pipe.

Table 2: CSS Trench Section Dimension Schedule

Trench Type	a (inches)	b (inches)	c (inches)	w (inches)
C1	6	18	OD+6	OD+36
C2	6	18	OD+6	OD+36
C3	6	24	OD+6	OD+48
F1	6	18	OD+6	OD+36 to 48
F2	6	18	OD+6	OD+36 to 48
F3	6	24	OD+6	OD+48

Figure 9: CSS Being Compacted with Roller

Since CSS does not flow like flowable fill, the contractor was required to demonstrate their pipe embedment compaction procedure to ensure they could get the CSS under the pipe haunches with no voids. As noted previously, this prove-out procedure is an IPL Program requirement for all non-flowable fill pipe embedment. The contractor successfully demonstrated that they could achieve 95% compaction of the CSS pipe embedment using a trench width of pipe outside diameter plus 36-inches to 48-inches. During this prove-out, the project construction team noted that the moisture content would have to be carefully monitored especially during the hot and dry summer months to ensure the CSS does not dry out too much between the times the CSS is produced at the pug mill to when it is dumped around the pipe in lifts.

IMPLEMENTATION OF USING CSS FOR PIPE EMBEDMENT

The contractor's alternate for using CSS for pipe embedment was deemed acceptable, and they were provided the alternate trench section schedule shown in Table 2 below for using CSS. The w column was revised from Table 1 to provide a standard trench width for multiple native soil conditions. This was confirmed during pipe prove-out demonstration for getting compacted CSS to fill all voids under the pipe haunches, and a trench width of pipe outside diameter plus 36-inches to 48-inches work the best. The contractor had the option to either use the embedment

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options shown previously in Table 1 or to use CSS with the revised trench dimension as shown below in Table 2. Once the pipe crews had exhausted their stockpiled sand they would revert back to the original trench sections shown in Table 1 using granular embedment and flowable fill.

The trench section detail shown on the next page was developed for using CSS.

During construction the contractor had two pipeline crews with each working from either end of the project to meet in the middle. The pipe crew on the northern end of the project used most of the CSS produced on the project while the pipe crew on the southern end of the project used CSS only for the booster pump station yard piping at JB4. The pump station yard piping was originally designed for full flowable fill encasement which was changed to allow CSS.

Below are two pictures of the CSS placement during construction.

Figure 10: CSS Compaction Completed

There were some problems during construction. As part of the quality control measures for the project, compaction measurements were taken periodically of the CSS in the trench, and test cylinders were gathered to perform compressive strength tests. The compaction tests all came back at or above 95%, but the project construction team received compressive strength results that were lower than the required 80 psi in some areas. Because the CSS in these low compressive strength areas was well compacted, the project construction team agreed that we would accept the pipe in these areas. However, the contractor was required to monitor deflection from inside the pipe to confirm that the pipe was not continuing to deflect in these areas over time. The project construction team expects that the CSS with low breaks was likely on the dry side when placed in the trench, and the CSS may have absorbed some moisture from the surrounding trench wall. To date there has not been any reported pipe sections that are continuing to deflect and deflection measurements are well within the 2% deflection tolerances for polyurethane coated steel pipe. The contractor will continue performing deflection measurements of the pipe in the low strength CSS areas for verification that no additional deflection is occurring until the pipe has been hydrostatically tested.

SUMMARY AND CONCLUSIONS

Coordination with the contractor, owner, and geotechnical sub-consultant on this project was a team effort to provide a sustainable solution to reduce the number of granular embedment material deliveries to the pipeline project right-of-way and reduce the amount of spoil material

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that had to be hauled off. By working as a team, we were able to fully evaluate cement stabilized sand as a viable pipe embedment alternative by following established design criteria and then developing criteria for the contractor to adhere to during construction. Allowing the contractor to use sand excavated from the pipeline right-of-way to make CSS directly reduced the impact to existing roads and the environment by reducing truck traffic to and from the site. Pipeline construction is scheduled to be complete in early spring 2018 with hydrostatic testing and final completion later in 2018.

REFERENCES

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