types and depths were interpreted from geotechnical borings taken within the area of the crossing. The backfilled pipe analysis assumed that the CLSM had reached a 28-day cure strength.

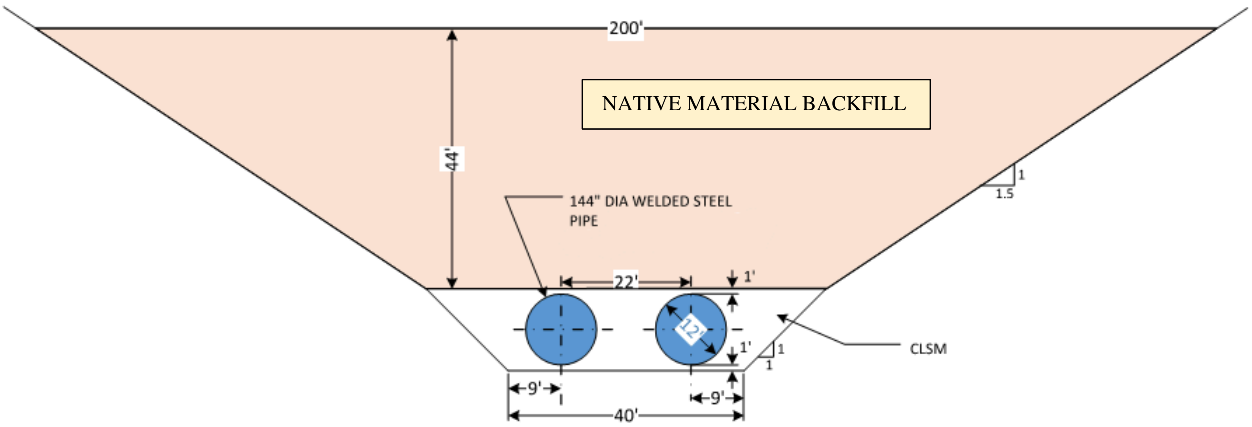

Figure 3- Anticipated Geometry of the Excavation in the Causeway

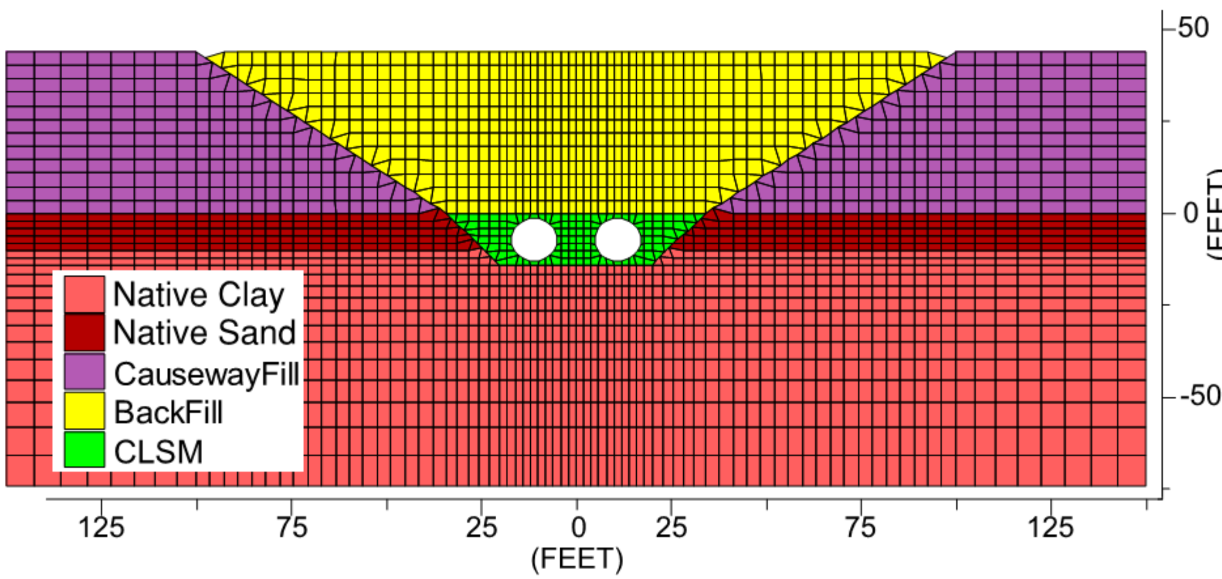

Figure 4- Backfilled Pipe Finite Difference Grid

The causeway analysis was performed on the following four installation conditions:
Case 1: Undrained analyses with full slip between the pipe and CLSM.
Case 2: Drained analyses with full slip between the pipe and CLSM.
Case 3: Undrained analyses with full bond between the pipe and CLSM.
Case 4: Drained analyses with full bond between the pipe and CLSM.

These discrete cases were selected to provide the design team with the widest array of data to interpret. 'Full slip' assumes the pipe is completely unbonded from the pipe zone material, which would be the case if the CLSM were to shrink after placement. 'Full bond' assumes the pipe is completely bonded to the pipe zone material which may be the case if the CLSM does not shrink. The actual case is likely to fall between the two cases considered. The 'undrained analysis' was completed to reflect a condition of high lake level where the pipe would be submerged, and soils of the causeway would be saturated. The 'drained analysis' reflected current conditions with no groundwater influence.

The results from the four cases are shown below in Table 3. The results are presented in terms of the empty pipe's hoop force, maximum bending moment, crown and invert vertical displacement, and the vertical displacement of the backfill at the ground surface.

Table 3-Finite Analysis Results

	Maximum Pipe Response						
Case	Hoop Force[a] (kips/ft)	Bending Moment (lbs-ft/ft)	Crown Deflection[b] (inch)	Invert Deflection[b] (inch)	Resulting Deflection (inch)	Deflection (% of Pipe Diameter)	Surface Vertical Movement[b] (inch)
1	26.1	232	-0.85	-0.45	0.4	0.27	-1.5
2	31.4	384.4	-1.11	-0.67	0.44	0.30	-1.9
3	39.5	239.6	-0.87	-0.44	0.43	0.30	-1.4
4	40.2	212	-1.2	-0.81	0.39	0.27	-1.8

a. Circumferential axial force

b. Negative values indicate downward movement (i.e. settlement)

kips/ft = kips per foot

lbs-ft/ft = foot pounds per foot

The analysis of Case 2 predicted the greatest deflection and stressing of the pipe. The hoop force and bending moment from each case were combined to find the resulting pipe stress. The calculated results of the pipe deflection are well within the maximum allowable deflection of 2.25 percent of the pipe diameter (2.25% of the nominally 144-inch diameter pipe = 3.27 inches). The utilizing the outputs from the model, the tensile stress (-1.233 ksi) and compressive stress (8.71 ksi) were calculated and found to be significantly below the yield stress (42 ksi) of the pipe. To evaluate the uncertainty of the analysis, the Case 2 system was put through a sensitivity study by modulating the CLSM properties. The sensitivity study results were not drastically different than the original calculation which provided additional confidence of the selected trench dimensions and use of CLSM.

CONSTRUCTION AND FIELD DATA

The constructed system was evaluated in the field to monitor its performance and verify the pipe-trench system reaction in actual practice.

CLSM mix testing was completed on site during construction to ensure the design criteria was met. It was determined that a minimum of 1.5 cubic foot of cement was required per cubic yard of CLSM produced. Monitoring of the soil and CLSM strengths was done throughout the project to ensure strengths remained within the specified range. Trench conditions were also monitored to verify that the trench was constructed in the configuration required by the design, which matched the configuration used in the FEA analysis. The CLSM zone was poured in lifts at an approximate pace of 2-feet of depth a day. Once CLSM placement was completed roughly

7 days passed prior to backfilling in lifts of 6-feet of depth in a day. Figure 5 shows a portion of the CSLM pipe zone being placed.

Figure 5- CLSM Placement

Figure 6 shows the dual aqueduct trench excavation passing through the causeway area. Located above the aqueducts in the photograph is a pipe bridge that was constructed to support existing utilities that run along the causeway.

Figure 6- Aqueduct Trench at Causeway

During the backfill process, pipe deflection measurements were taken within the aqueducts at various depths of backfill. Three stations for collecting measurements were selected in the High Lift and four in the Low Lift. At each station, four measurements were taken at four orientations of the pipe cross-section. Figure 7 shows the typical measurement orientations for each of the stations.

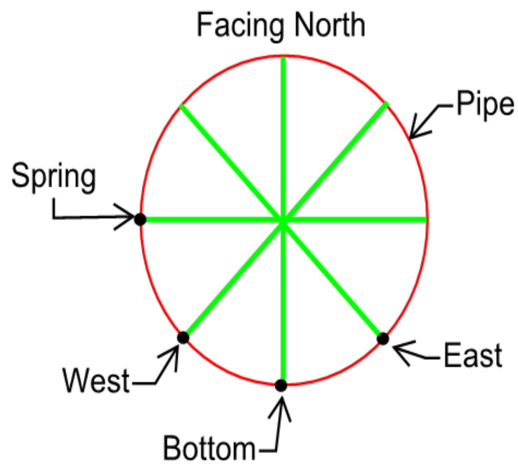

Figure 7- Cross-Section of Measurement Orientations

Table 4 tabulates the data associated with the stations which had the largest overall change from initial installation to completely backfilled from both the High Lift and the Low Lift.

Table 4- Pipe Roundness Differential at Various Stages of Trench Fill (inches)

		CLSM	10-ft of Backfill	20-ft of Backfill	Backfill Complete
High Lift	West	-0.07	-0.08	-0.10	-0.29
	Bottom	-0.06	-0.04	0.09	-0.17
	East	0.18	0.16	0.17	0.04
	Spring	0.06	0.03	0.01	0.01
Low Lift	West	-0.15	-0.13	-0.13	-0.27
	Bottom	-0.15	-0.01	0.08	-0.25
	East	0.28	0.14	0.21	0.19
	Spring	0.10	0.08	0.06	-0.31

Notes:

1. Roundness is relative measurement of pipe diameter at time of measurement to diameter before placing any backfill. Unlined pipe had an original inside diameter of 145.5-inches.

The largest measured overall deflection was 0.213%. Comparing the field measured data to the predicted data, the installed pipe deflected even less than what was calculated by both the traditional calculation and the finite difference model.

CONCLUSION

The traditional calculation methods for large diameter welded steel pipe at deep cover depths did not accurately predict pipe deflections for the High and Low Lift Aqueducts associated with SNWA's L3PS project. Initially, the traditional methods lead designers in the direction of an overly conservative and expensive trench section design. Use of a 2D FEA analysis provided a more realistic design which reduced risk and saved considerable time and cost. Field measurements verified the legitimacy and relative accuracy of utilizing the FEA approach.

CLSM proved to provide excellent pipe support in typical pipe embedment conditions. For the non-typical (deep installation) described in this paper, CLSM was very effective in providing proper support while limiting trench widths.

For this project, the narrower trench design resulting from the FEA analysis and the use of CLSM provided the following benefits:

- Less excavation and backfill which reduced cost and time.
- Narrower width of trench which minimized the length of the bridge that supported the utilities high in the causeway.
- Quicker time to backfill which limited exposure of the trench walls to raveling or sloughing.
- Less construction risk to the contractor, owner, and involved utility providers.

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Revising the City of Houston's Standard Butterfly Valve Detail for Large Diameter Butterfly Valves

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ABSTRACT

Approximately 16 mi of 108-in. diameter water transmission main is being constructed across northeast Houston to supply various regional water authorities to meet their projected 2060 water supply demands. Historically, the City of Houston has installed butterfly valves for isolation in large diameter water transmission mains. Typically, the City of Houston requires the butterfly valve to be connected to the pipe via flange and bolts and the assembly supported with bank run sand embedment. Butterfly valves have been a constant maintenance concern for the City's operations department for a variety of reasons. Recent studies have indicated butterfly valves cannot be fully closed if the adjoining pipe is deflected over 1% of the diameter. The City allows a maximum deflection of 3% which can be problematic for a butterfly valve. Therefore, special design considerations were implemented for the proposed 108-in. pipeline project. The adjoining pipe was designed to ensure the pipe and soil loading would not negatively affect the integrity of the valve. Pipe wrappers and saddle supports were designed to keep the pipe from deflecting. The steel wrappers not only provided stiffness to the pipe, but also assisted with supporting the pipe over the concrete saddles. The load is then transmitted to the concrete foundation. Many factors were considered in the design of the support including soil loads, valve weight, water weight, and associated pipe loads. A flowable fill material is proposed as the embedment material to proper support for the pipe and valve. Future maintenance was also considered in the design of the valve. The seat was designed to be mechanically retained to allow for the seat to be field repaired in place rather than remove the valve entirely. A vault was designed to allow for future access of the worm gear actuator and packing. The concrete foundation extended under the pipe saddles and the actuator vault to avoid differential settlement issues. Six butterfly valves have been installed according to the revised detail and are operating as designed.

INTRODUCTION

The City of Houston(City), along with four regional water authority partners and in cooperation with the Texas Water Development Board (TWDB), are currently designing and constructing a water transmission main ranging in size from 120-inch to 54-inch diameter. The water main is entitled the Northeast Transmission Line (NETL), and is the second transmission line connecting the City's Northeast Water Purification Plant (NEWPP) near Lake Houston to the City's existing system. When complete, the project will provide treated water to the City along with various Water Authorities including but not limited to North Harris County Regional Water Authority (NHCRWA), Central Harris County Regional Water Authority (CHCRWA), West Harris County Regional Water Authority (WHCRWA), and North Fort Bend Water Authority (NFBWA).

Previous Butterfly Valve Design Standards

Historically, the City has used butterfly valves for isolation on their transmission mains. The City prefers isolation valves to be installed every 3,000 linear feet. Over the years, the City began experiencing maintenance issues with their valves. Investigations revealed butterfly valves would not operate if the adjacent pipe deflects or imposes loads on the valve body especially in deep bury conditions.

Based on the previous design approach, the butterfly valve is connected to the adjoining pipe with a flanged joint. Typically, the contractors would join the flanged pipe spools to the valve before lowering the assembly into the trench. The valve assembly is then connected to the pipeline in the trench.

The City standard butterfly valve specifications require horizontal shafts to be equipped with a short bonnet extension and a worm gear actuator. The actuator is installed in an adjacent manhole for maintenance purposes. The assembly, including the manhole, is embedded in a granular material. Figure 1 shows a typical installation of a butterfly valve.

Figure 1: Typical Butterfly Valve Installation

The granular embedment, bank run sand, is the main support of the pipe and valve. Bank run sand is a durable material classified as either well graded, poorly graded or silty sand mixtures by the Unified Soil Classification system. This material also consists of clay lump or balls under

2 percent. Bank run sand can provide an E' of 1,000 psi when compacted to 95%. The haunch zone is the most critical area in the steel pipe embedment zone. If the material is not properly compacted in this zone, then the steel pipe will be prone to deflection. As a result, the butterfly valve will not be able to operate as designed.

Major Pipeline Project and a New Approach

As discussed in previous papers, the American Water Works Association (AWWA) began publishing advisory warnings about large diameter pipe and valve connection issues. In the 2006 edition of ANSI/AWWA C504, the butterfly valve standard issued advisory warnings about transferring pipe loads to the valve body that could result in detrimental deflections causing the valve to become inoperable(ANSI/AWWA C504). In 2010, the AWWA publish a new standard, AWWA C516, limiting valve body deflection to 0.06 inches (1.5 mm) under a defined set of loading conditions for large diameter butterfly valves (ANSI/AWWA C516). This new standard also included an expanded advisory language concerning the pipe to valve connections, and advises the designer to:

1) Avoid subjecting the valve to pipe loads
2) Support piping as near to the valve as practical
3) Control differential settlement
4) Support or stiffen pipe to provide a round mating connection
5) Minimize the bending stress of the valve/pipe connection
6) Install at least one flexible joint on each side of the valve between the valve flange and the first pipe support
7) Do not support the valve body directly on a saddle or other structure

Theses valve issues were not unique to the City as problems were being experienced by other major water utilities nationwide. Each of these individual valve issues were being addressed on a case by case basis. Owners, engineers valve manufacturers, pipe fabricators and contractors started asking who is responsible for the pipe to valve connection.

Based on the preceding and with the City's valve maintenance history, it became obvious a new approach was needed for the largest diameter potable water line being put in service.

Proposed 108-inch Butterfly Valve Design

At this time, there is not an industry standard approach for designing large diameter butterfly valve installations in flexible pipelines. Industry professionals have differing opinions on how this should be accomplished. Some have proposed installing the valves in vaults to avoid imposed soil loads, which is a workable solution; however, some owners avoid using vaults for various reasons such as confined space entry and limited Right-of-Way. Other proposed solutions have included stiffing rings on the pipe to limit pipe deflection and others use supports under the pipe to avoid transferring loads to the valve body.

In developing a new approach for the NETL, the City stressed the importance of being able to isolate portions of the new pipeline and wanted to incorporate the latest information into the new design. The City was not in favor of installing these valves in vaults due to safety concerns and limit available space within the Right-of-Way. Therefore, the new approach would need to account for:

1) Limit transfer of pipe loads to valve
2 Control differential settlement
3 Maintain a round mating connection
4) Minimize bending at the pipe to valve connection
5) Provide to support to the pipe and valve assembly

As noted previously, butterfly valves are susceptible to deflection; thus, it became apparent that supporting the adjoining pipe is one of the most critical elements in keeping the butterfly valve operable. This major pipeline is to have a minimum bury depth of 10 feet to get under most of the existing utilities. This minimum bury depth creates significant loads on the pipe and valve assembly that must be mitigated and controlled. The developed design approach utilized a concrete base slab and pipe saddles to support the pipe and valve assembly. The design layout intends for the pipe to carry the valve weight.

The saddle support locations were determined by fixed end cantilever beam analysis of the pipe to valve assembly. The loads considered in the analysis included the weight of the steel pipe, cement mortar lining, water, flanges, bolts, dead and live loads. Saddle spacing was developed to provide sufficient area for providing access to the valve and flanges for maintenance. The saddle supports are spaced at 7 feet from the center of the butterfly valve on each side and the base slab is 2 feet below the flange. Pipe tip stress at the saddles is controlled by the addition of wrappers that are welded on at the fabrication site. The wrappers are designed to be 5 feet wide and ¾" thick. See Figure 2 for the proposed layout.

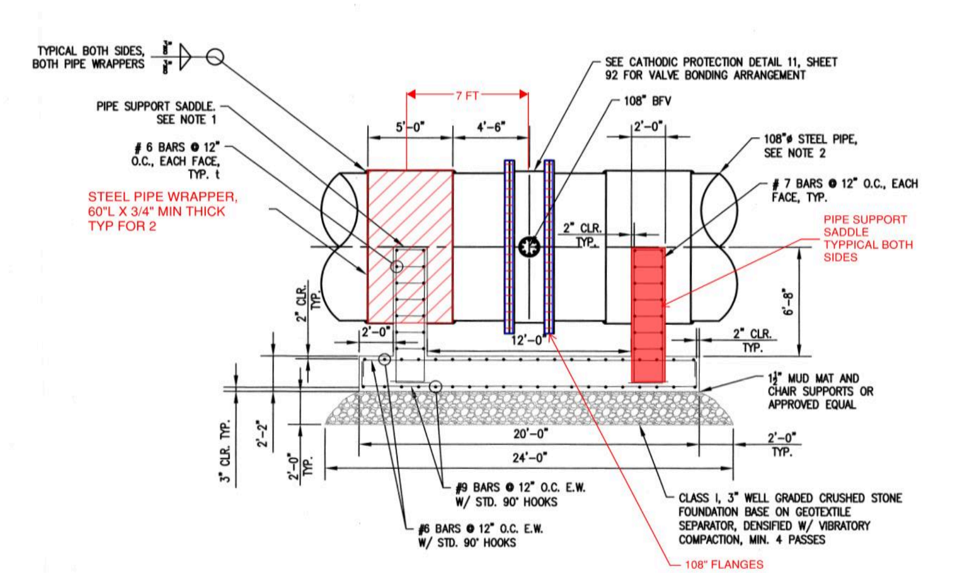

Figure 2: Proposed Butterfly Valve Section View

The base slab was designed to counteract the loading of the saddle supports, earth loading, and precast vault. See Figure 3 for the different variables considered in the analysis. Buoyancy was checked to ensure the loaded support system would not float after constructed in place. Based on the investigation, the weight of the valve and backfill exceeded the volume of the displaced soil; therefore, the slab was determined to be adequate for buoyancy. The bearing capacity of the soil was also checked to verify the existing soil can support the proposed structure.

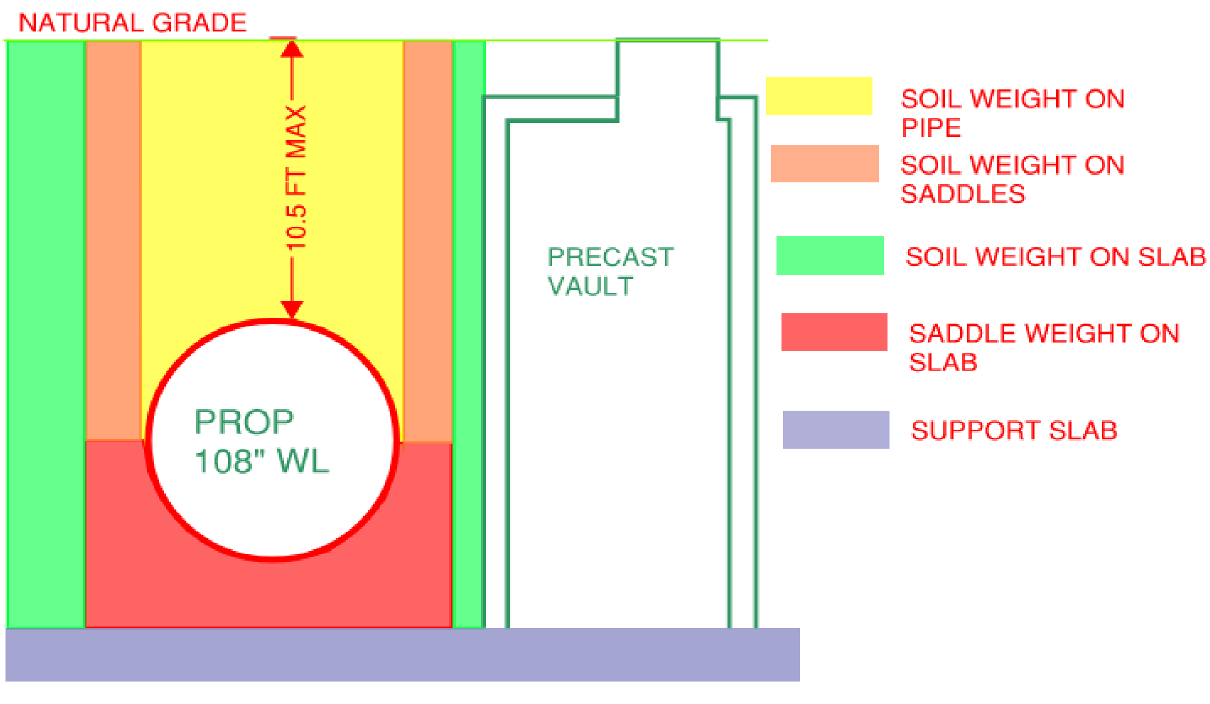

Figure 3: Slab loading sketch

The valve is to be installed horizontally with the actuator in a precast vault. The vault, which is 8-feet square, allows for future maintenance of the actuator. The vault is designed to be HS20 rated and watertight. Two 4-inch flanged outlets, one on each side of the butterfly valve, are provided on the 108-inch pipe for sampling and testing. Pipe from the 4-inch outlets extends into the vault for access. Refer to Figure 4 for the layout of the Butterfly Valve(Liga 2016).

The 108-inch valve seats are also specified to be mechanically retained on the valve body(Project Manual). The use of mechanically retained seats allows for adjustments to be made in the field with normal hand tools. Therefore, a minimal shutdown will be necessary for future maintenance if required.

Construction of 108-inch Butterfly Valves

The 108-inch butterfly valves required an approximate lead time of 7 months upon approved submittal for delivery. Consequently, the selected contractor submitted the valve for approval prior to receiving the Contract's Notice to Proceed. Given this, the contractor was operating at risk; however, the early review/approval avoided impacts to the project's critical path.

First and foremost, a shaft is constructed in place to begin assembling the forms for the support slab. Various kinds of shafts can be put in place to construct the support slab. The contractor used steel structure system to support the in-situ soil from undermining the concrete support slab. The support slab was then allowed to cure for a minimum of three days prior to pouring the concrete for the support saddles. See Figure 5 for the saddle supports being formed in place. At this time, the bottom section of the precast concrete vault was then doweled into the support slab.