Protecting Existing PCCP Subject to External Transient Loads

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ABSTRACT

As more land areas are urbanized, the need for Tarrant Regional Water District (TRWD) to protect or maintain their pipelines and for construction contractors and utility companies to cross existing pipelines will increase. The contractors performing the work will often request to cross or work over pipelines with heavy equipment; these crossings should be evaluated to determine if the pipe will withstand the additional loading. This paper presents a process for reviewing crossing requests and how to analyze transient loads through the soil and how to use the Unified Design Procedure (UDP) software to determine the pipe’s allowable dead and transient load capacity. In addition, this paper presents a discussion on the crossing construction and the crossing reliability based upon the loading frequency.

Freese and Nichols, Inc. (FNI) recently investigated construction loads over prestressed concrete cylinder pipe (PCCP) for a paralleled construction project. The preferred construction sequence required operating and staging large construction equipment and materials over the existing pipeline. Therefore, the loads generated by the construction equipment were analyzed and compared to the capacity of the pipeline, which was determined by the UDP software. The pipe was found to be adequate if the equipment is treated as a transient load, but inadequate if the equipment is treated as a dead load. Since parked equipment and staged materials were assumed to cause dead loads on the pipe, no equipment or materials were allowed to be operated or staged over the pipeline.

The results of this study led to subsequent pipeline crossing studies for a concrete-aggregate mining operation and a new business development center. The crossing for the mining operation required a slab bridge to protect the PCCP by spanning across the pipe. The crossing for the business development required the installation of Geofoam to offset the additional weight of four feet of fill over the pipeline. A later
project was undertaken to standardize a crossing design procedure and standardize crossing details to speed up the application and approval process for third parties’ permit requests to cross TRWD’s 90-inch and 72-inch PCCP pipelines.

INTRODUCTION

Tarrant Regional Water District (TRWD) owns and operates 90-inch and 72-inch pipelines made of prestressed concrete cylinder pipe (PCCP) that deliver water from their East Texas reservoirs to Tarrant County. The combined 350 MGD capacity accounts for a large percentage of the areas raw water supply. Although the pipelines were constructed in predominantly rural environments in the 1970s and 1980s, the pipeline corridor has become increasingly urbanized over time. As system growth occurs and more areas are developed, the need for TRWD to expand, maintain and protect their pipelines becomes more essential and increasingly difficult.

The original PCCP lines were designed in accordance with the American Water Works Association (AWWA) C301 standard of the time; however, new and more conservative standards have replaced the Design Appendices in earlier versions of this standard. Although the existing pipes were designed under the earlier version of C301, they were analyzed by the newer AWWA C304 standard. This paper presents how to determine and distribute transient loads through the soil and how to use the Unified Design Procedure (UDP) software to determine the pipe’s allowable dead and transient load capacity.

THE NEED TO DESIGN PIPELINE CROSSINGS

TRWD recently installed a 96-inch diameter steel bypass parallel to an existing 90-inch diameter PCCP pipeline. The preferred construction sequence was to operate heavy construction equipment such as a crawler crane, a wheel loader, a bulldozer and HS-20 vehicles directly over the existing PCCP pipeline because of right-of-way restrictions. In addition to the heavy equipment, materials such as the pipe segments and the gravel bedding material were intended to be staged over, or near, the existing 90-inch PCCP pipeline. FNI provided the consulting engineering services and determined it was necessary to study if the pipe would be able to support the applied external loads without damage.

FNI concluded from their study that the crawler crane created the largest applied load and that some of the serviceability limit states were not satisfied under this loading. Due to this, FNI recommend that no construction traffic or staging of materials over the pipeline should be allowed with the exception of HS-20 loads, which were only allowed to cross at designated areas. During the parallel pipeline construction the contractor requested permission to temporarily operate a crane near the existing pipeline. FNI reviewed this specific request and determined that the existing pipe would not be damaged by the crane placed where the contractor needed it.
In addition to the paralleled construction project, TRWD receives several requests from third parties requesting to cross their 90-inch and 72-inch diameter pipelines. FNI studied a few of these situations and determined that they required engineered crossings to protect the pipe from the applied loadings. This led to a project intended to standardize crossing details to speed up the application and approval process for third parties requesting permits to cross TRWD’s PCCP pipelines. The design considerations for these crossings will be discussed below.

DETERMINING APPLIED EXTERNAL LOADS

FNI classified the external loads into two categories: dead loads and transient loads. Dead loads are permanent or remain on the pipe for an extended period of time. Transient loads, however, are transient and are only applied to the pipe for short durations. The proper classification of loads is critical because PCCP has differing capacities for dead and transient loads.

Dead Loads

Soil is commonly the only dead load applied to the pipe. FNI reviewed the contract drawings to determine the trench width and approximate depth of cover and then calculated the soil loads in accordance with Chapter Five of AWWA M9. Not all of the variables used to determine the soil loads were known; therefore, the conservative values suggested in AWWA M9 were used. In addition, the pipes were originally designed for a soil unit weight of 120 pounds per cubic foot (pcf), however, FNI used a conservative soil unit weight of 130 pcf to account for unknown conditions that may be less than ideal.

Although moving equipment is normally considered a transient load, the crane proposed to be used on the paralleled construction job would be in place for a minimum of a few minutes, but more likely it would be operating in place over the pipeline for a few hours. Therefore, FNI took a conservative approach and determined that the crane load should be classified as a dead load rather than a transient load.

Transient Loads

FNI classified any load that continuously moves across the top of the pipeline to be a transient load. Other than the crane, bulldozers, wheel loaders and HS-20 trucks were proposed to be used on the paralleled construction project. Wheel loads and continuous track loads will be discussed separately because the soil distributes them differently.

Wheel Loads

AWWA C304 governs PCCP design. This standard requires that all buried pipes be designed to resist HS-20 loading. Therefore, FNI assumed that HS-20 loads would not damage the existing pipe.
The wheel loader, however, can apply large loads to buried pipe. FNI used AWWA M9 to calculate the applied wheel loading on the pipe. The AWWA M9 model to distribute the applied wheel load is based on the contact area of an HS-20 tire. The wheel loader tire has a different contact area than the HS-20 tires; however, FNI calculated the contact area by dividing the standard tire pressure into the wheel load. FNI then calculated the applied loading for travel parallel and perpendicular to the longitudinal axis of the pipe.

Track Loads

Both the bulldozer and the crane are driven on tracks. FNI modified the AWWA M9 model for distributing wheel loads by assuming zero load distribution parallel to the long axis of the tracks. In addition to this modification, the applied load per linear foot was conservatively calculated by dividing the length of the track into the total applied load.

The methods to calculate applied external loads discussed above are approximate methods and can be refined by using the Boussinesq formulas or charts for loads on square areas and infinitely long rectangles.

USING UDP TO DETERMINE THE PIPE LOAD CAPACITY

The UDP is a program written by Simpson Gumpertz and Heger (SGH) for the purpose of designing and analyzing PCCP. After looking at the AWWA C304 standard, the program can be greatly appreciated because the design/analysis is rigorous and iterative.

The existing buried pipe for the paralleled construction project was designed in accordance with the AWWA C301-84 Standard; however, in 1992, AWWA created the new AWWA C304 standard that addresses the design of PCCP. The UDP establishes several serviceability and strength limit states for the pipe, including: cracking of the inner core and cracking of the outer mortar coating.

FNI reviewed the existing pipe shop drawings and found the critical information for the PCCP segments under consideration. After analyzing the pipes with the UDP, FNI found that the conservative dead loads exceeded the pipe’s static load capacity. However, the existing pipes have been in place and working properly for several years under the soil dead load, so FNI decided to assume that the full dead load capacity of the pipe was being utilized and only transient loads should be allowed over the pipe. FNI recommended that the crane not be operated over the pipe since it was classified as a dead load.

In general, the UDP will provide an envelope relating the pipe internal pressure to the applied dead load, and the internal pressure to the applied dead load plus the transient load, as shown in Figure 1. The UDP program can also calculate the allowable dead and transient loads if the internal pressure is given. The transient load capacity equals the difference between the transient envelope and the static envelope at the same pressure.
DETERMINING CROSSING DESIGN CRITERIA

FNI also analyzed a pipeline crossing for a concrete-aggregate mining operation. This crossing would be utilized multiple times a day for several years by a large mining dump truck. FNI evaluated the transient load the wheels applied to the pipe and actually found that the vehicle did not require a protective crossing even though the total operating weight exceeded 145,000 pounds. However, FNI felt that continuous driving over the pipeline could cause ruts and reduce the clear cover over the pipe, and thus increase the transient load. FNI also evaluated the situation in which the truck stopped over the pipe, making it a dead load rather than transient load, and found that this condition could damage the existing pipe. Therefore, FNI designed a concrete slab-bridge to isolate the pipe from the applied loading. This option was the most expensive, but it was also appropriate given the rural location of the crossing, the high frequency that it will be crossed and the required reliability of the pipeline.

FNI analyzed another crossing for a business development center. The vertical alignment for the new road required the addition of four feet of fill over the existing pipe in order to install water pipes below the road. The additional dead load exceeded the allowable dead load; however, the expected HS-20 loads did not exceed the allowable transient load capacity. FNI recommended four feet of Geofoam be installed below the roadway to offset the weight of the additional fill, refer to Figure 2. Geofoam has a unit weight less than three pounds per cubic foot, so it efficiently offsets the weight of the material it displaces but, at the same time, it easily floats and

![Figure 1. Sample Load Envelope from UDP Analysis](image)
can cause large uplift forces on the roadway. Therefore, FNI recommended that a drain also be installed below the Geofoam. Special consideration was given to the type of Geofoam used because ASTM D6817 is a structural block that has known compressive strength values at 1 percent deformation, whereas the ASTM C-578 is used typically used for insulation under roadways. FNI evaluated the influence of the applied load on the pipe because Geofoam directly transmits loads rather than distributing them like a typical soil. It was found that the Geofoam offsets the additional dead load but has no effect on the transient load. In the end it became a non-issue since all loads on the new road were to be HS-20 or less.

Figure 2. Typical Elevation of Geofoam Option

Later, FNI undertook a project for TRWD to standardize crossing details so they can quickly respond to third parties requesting to cross their pipeline. FNI determined that the classification of the loads, crossing frequency, crossing maintenance, the final crossing grade with respect to the exiting grade, the pipe’s internal pressure, and the pipe’s load capacity all affect the type of crossing required, if any crossing is required at all. The crossing frequency is important, because like the concrete-aggregate mining truck, the analysis may indicate that no protective crossing is needed; however, a protective crossing may be desirable if rutting is a concern or if the vehicle can stop on the pipe.
FNI prepared a matrix to assist in the selection of the appropriate crossing. Two major types of crossings are identified in the matrix: temporary—utilized for less than one year and permanent—utilized for more than one year. Temporary crossings are assumed to be at the current grade, with load effects less than HS-20 loads. If the crossing is occasionally used (less than 10 times per day) then no protective crossing is required. If the crossing is used more than 10 times per day, then an all-weather road, timber mats, or a reinforced concrete slab should be installed to prevent rutting over the pipe, which could increase the transient load on the pipe.

Permanent crossings should be used for crossings that will be in place for more than a year. If the crossing is at the current grade, or in a cut section, and the vehicle loads are less than HS-20 loads, then an all-weather road or concrete pavement should be installed. If the crossing requires fill to be added over the pipe, then Geofoam can be installed to offset the additional soil load. Alternatively, a slab bridge, precast concrete arch, or a cast-in-place concrete arch can be installed to completely isolate the pipe from all external loads.

More recently, a portion of the existing 90-inch and 72-inch PCCP pipelines was unexpectedly loaded with a seven-foot tall temporary soil stockpile and earth-moving equipment. The additional soil loads caused by the stockpile were determined using the negative-projecting conduit condition since the pipe was installed in a trench, and then the stockpile was added on top similar to an embankment. All of the transient loads caused by the earth-moving equipment were less than HS-20 loads on the pipe; therefore, they did not load the pipe beyond what it is designed for in the transient state. The soil load, however, was much larger than the design soil load. The 72-inch pipeline had been taken out of service for maintenance so it was not pressurized. Also, the parallel 90-inch pipeline was operating at a reduced capacity so the internal pressure was less than the design pressure. The UDP was utilized to determine that both pipelines could support the additional soil load at reduced operating pressures. The stockpile was recommended to be removed before increasing the pressure in the pipelines and a temporary timber-mat crossing was installed for the earth-work contractor to use.

CONCLUSION

TRWD’s recent construction of a 96-inch diameter steel bypass parallel to their existing 90-inch diameter PCCP pipeline introduced the prospect of operating large construction equipment over the existing 90-inch diameter PCCP pipeline. FNI studied the situation to determine if the equipment can be operated over the pipe without damaging it. First, the applied loads were calculated and classified as dead or transient loads. The crane load was treated as a dead load since it would need to be stationary over the pipe for extended periods of time. Then the UDP program was utilized to evaluate the strength of the existing PCCP and it was found that some limit states would not be satisfied under the applied loading. Therefore, FNI recommended that only HS-20 loads be applied to the pipe at designated areas since the pipe was originally designed for HS-20 loads. An alternative construction sequence was chosen.
to prevent construction loading on the existing pipe. However, FNI reviewed and approved the contractor’s specific request to temporarily operate their crane near the existing pipeline to complete one aspect of the construction.

FNI also evaluated the safety of two additional crossings. One crossing was for a concrete-aggregate mining company and the other for a new business development center. After evaluating the mining truck loads, and their repetitive nature, FNI decided that a slab bridge was required to isolate the PCCP from the mining truck. The crossing for the business development center required the final grade to be raised approximately four feet. Therefore, FNI recommended installing Geofoam to offset the additional weight of the fill.

Finally, FNI performed a project to standardize road crossing details to reduce the amount of time a third party’s request to cross the pipeline would take to get approved. It was determined that the classification of the loads, crossing frequency, crossing maintenance, the final grade of the crossing and the pipe’s load capacity should be considered in the selection and design of the crossing.

REFERENCES

