ABSTRACT: The completion of a 7,000 LF, single insertion, slipline rehabilitation project of an industrial pipeline in Northern California represents another example of the expansion and adaptation of trenchless methodology in the industry. An existing 20” steel pipeline which conveys an industrial fluid stream under a large body of water showed signs of wear and aging. Because of the importance of the existing alignment and its environmentally sensitive location, a reliable rehabilitation method was pursued as a first course of action.

A team was developed to evaluate various options; among them sliplining the existing pipe with another pipeline. This quickly became the preferred option in terms of limiting impact to existing operations and the local area. The most critical aspect of the project centered on the design of the installation. Characterizing the existing pipeline, and then the logistics and construction challenges, including fusing and staging 7,000 LF of 14” diameter FPVC® pipe, aligning and inserting the fused string into the host pipe, properly cleaning and lubricating the host pipe, and ballasting the new pipeline to facilitate successful completion of the installation. These and many other details were contemplated on the project.

This paper will focus on the design and installation challenges met with this unique and industry expanding installation opportunity for slipline installation methodology. The critical design aspects of the assembly and installation of this length of product pipe into an existing alignment will be reviewed, along with the lessons learned from the experience.

1. INTRODUCTION

An existing 20-inch steel pipeline which conveys an industrial fluid stream under a large body of water in Northern California was showing signs of age. The owner and operator of the pipeline feared that corrosion of the steel line would soon result in a break or a leak, which would mean an environmental black-eye and a major impediment to operations. An adequate rehabilitation method was evaluated as a first and potentially only course of action to assure the integrity of the pipeline and its reliable operation going forward.

A team was assembled to analyze the situation and recommend a fully engineered solution. That team included Galindo Construction (Galindo) as the general contractor, J-C General Engineering, Inc. (J-C) as the trenchless subcontractor, and the client’s own engineering and operations group. The project from the outside was daunting: the existing 20-inch steel pipeline was originally installed by ‘tow-in’ method across the body of water in the early 1960’s, and was nearly 7,000 feet in length. Because of the original installation method, the exact alignment of the pipeline was not known, aside from some early as-built information that showed sketched renditions of the final placement (see Figure 1). The horizontal alignment was known to be fairly straight, but the vertical alignment followed the bottom elevation of the water body floor. This was particularly important for the deepest section of the crossing that was located roughly in the middle. The alignment variations at this location caused the pipe to curve downward, curve back to cross the deeper location, then curve back up and finally, to bend flat again. This
particular alignment variation meant that the pipeline couldn’t be drained, and further, would require the ability to navigate a curvilinear alignment in a proposed solution.

The owner’s engineering and operations team had evaluated the required pipeline solution in terms of design flow and determined that they would not need the existing capacity of the 20-inch steel pipeline going forward due to alternations in the operational scheme that would be instituted. Therefore, a smaller pipeline would work for the future required operational duty. This fact led the team to consider sliplining as a possible rehabilitation method.

![Figure 1. The existing ‘as-built’ recorded vertical alignment – a ‘sketch’ relative to the existing pipeline location. Note the location of the four major known bends in the pipeline in the deepest section of the water body, numbered as they would be encountered during the slipline insertion.](image)

2. **SLIPLINING AS THE PREFERRED ALTERNATIVE AND REQUIRED DESIGN ELEMENTS**

Sliplining, as a trenchless rehabilitation method, is a very simple concept: a smaller, completely restrained pipeline is pulled inside of the larger pipe that is in need of rehabilitation. Connections are made at either end of the new sliplined pipe, and it takes over the duties of original line. The primary drawback to sliplining is that the new pipeline that is drawn into the existing pipe must be smaller, therefore it will have a smaller flow area than the original line. If this primary drawback can be overcome, whether by operational adjustments, better hydraulics from the sliplined pipe or other means, then sliplining becomes a very elegant solution.

With the viability of a slipline solution on the table, pipeline materials for use as the sliplined pipe were evaluated. The size and length of the existing pipe required a capable slipline pipe material along with a strong, low-profile joint. Additionally, since the primary concern with the original steel pipeline was corrosion, a non-corrosive material was desired. With these constraints in mind, the team’s analysis resulted in the selection of Fusible PVC™ pipe (FPVCP). The butt-fused PVC product afforded the required strength and minimal outer diameter of the pipe and joint and also met the non-corrosion requirement. A 14” DIPS, DR 21 pipe section was selected to meet the requirements of the pipeline operation, both required pressure and flow area. The unknowns regarding this installation also demanded that a capable material be used with enough strength to provide a reasonable safety factor in terms of installation success. The track record of FPVCP in long and difficult HDD installations, along with the experience of the construction team with the material in the past provided this assurance.

Now, the proposed section would need to be vetted for the most critical aspect of the entire project – could it be installed successfully for this particular project?

3. **EXISTING PIPELINE ALIGNMENT EVALUATION**

The success of the proposed project now hinged on making sure that the required sliplined pipe could be physically installed within its material limits. This included three main components:

1.) The existing pipeline needed to be characterized to assure that the minimum bend radius of the sliplined pipe would be met.
2.) There also needed to be assurance that there were no obstructions or deformations in the existing line that would stop the installation.
3.) The insertion action and technique would need to assure that the safe allowable pull force for the sliplined pipe section would not be exceeded.
It was proposed early on in the process to utilize a horizontal directional drilling (HDD) rig to perform the insertion and pullback operations for the slipline. J-C also utilized the HDD rig to perform a wireline alignment verification as a first pass alignment investigation on the existing pipeline. The wireline information only included inclination and distance as the drill rod was advanced. Limitations on access to the body of water meant that no coils could be placed to locate the steering tool along the crossing. The resultant wireline survey data was compared to the available as-built information based on a progressing direction and distance. It did show fairly close agreement to make reasonably sure that the existing alignment could be characterized as shown in the as-built information. Most importantly, it provided areas of maximum bending in the existing alignment, which were then compared to the capabilities of the FPVCP section for bend radius compatibility. The existing alignment contained four primary known bends, labeled in series as they would be encountered as the sliplined pipe was installed (see Figure 1). Particular attention was paid to these areas of the alignment to assure that the minimum bend radius of the FPVCP was met. In general, alignment undulations were of a bend radius of 1,500 feet or greater. The tightest bend was recorded at location 1 on Figure 1, with a radius of ~600 feet. With a minimum recommended bend radius of ~320 feet for the 14” DIPS FPVCP section, the alignment was found to be within the required bending limits.

After this initial wireline verification of the alignment, J-C used the drill rig with a reaming setup and a bentonite based drilling slurry to ream, swab and flush the pipeline in order to extricate any tuberculation or build up in the line, as well as ensure that there were no major deformations or obstructions in the line. Materials removed from the pipeline included evidence of corrosion and a small amount of fine, sediment build up. As a final check on the applicability of the slipline technique, an eighty foot length of pipe (two forty foot lengths of FPVCP with one fusion joint in the middle) was pulled through the entire length of the line and then checked for damage. With this operation successfully completed, the team turned their attention to the final insertion and potential loading on the pipe section during installation.

4. CONSTRUCTION DESIGN AND PROCESS PREDICTIONS

With the understanding that the alignment and condition of the existing pipe were conducive to sliplining, a check was needed to compare the required installation loading on the sliplined pipe and assure, with a reasonable safety factor, that it would be capable. Due to the nature of the installation, this would not be a straightforward exercise. Tensile loading on the pipe section as it was being installed would be comprised of the following items:

1. The drag of the pipe in the existing steel pipe as it is being inserted,
2. The drag of the pipe at grade, prior to it being inserted into the host pipe,
3. The increased drag realized at the four major bends in the existing steel pipe, and
4. The cumulative drag created by the known and unknown undulations in the existing pipe.

![Comparison of buoyancy loading for a non-ballasted cross-section and a ‘self-ballasted’ cross-section for the slipline insertion.](image-url)
Previous experience, including sliplining and horizontal directional drilling projects with FPVCP provided guidance for the first three items contributing to drag and installation loading for the pipe section. The unknown element would be the effect of cumulative drag from all of the undulations in the pipeline. A very conservative evaluation of this element was used to make reasonably sure that the pipe section would not be overloaded during the installation.

The overarching mechanisms governing the primary installation loads for this application are well understood. Frictional drag between the existing steel pipe and the new sliplined pipe would represent the largest loading factor. Since the existing pipeline could not be drained, insertion logistics needed to account for some sort of ballasting in the pipeline, especially for the critical, deeper ‘U-shaped’ section in the middle of the alignment. Since the annular space between the host pipe and the new sliplined pipe is filled with fluid, both from the cleaning operation and present from the previous use of the pipeline, it creates an undesirable buoyancy force and resultant friction during the installation for an empty FPVCP sliplined pipe (see Figure 2). In a typical HDD installation, this same principal holds for a drilling slurry filled bore hole during the insertion of the product pipe (Ariaratnam, 2010). In these situations, ballasting is performed by adding clean water to the back end of the pipe as it is inserted. This is usually done with a fill pipe so that the water is only applied to the section of the pipe that has been inserted into the bore hole, applying the ballasting water where it will have a positive impact on reducing the buoyancy loading in the fluid filled bore hole, as opposed to adding weight and drag to the pipe string as it would if the pipe were filled with water at grade.

The idea of ‘self-ballasting’ the FPVCP was discussed within the team as a way to simplify the ballasting issue. Utilizing an ‘open’ pull-head on the FPVCP would allow the drilling slurry in the host pipe to filter into the new pipe as it is installed (see Figure 3). While this fills the new pipe with the slurry, which may not be desirable, it also creates as close to a neutrally buoyant installation as possible (See Figure 2). This also saves any complicated means of ballasting with a 7,000 foot long fill pipe and pumping mechanism if ballasted in the traditional manner. As a final means of cleanup, J-C and Galindo planned to pig the line, to flush out the slurry taken on during the
installation, and backfill it with clean water, ready for hydrostatic pressure test and acceptance of the rehabilitated pipeline.

A comparison of self-ballasted loading per foot compared to non-ballasted loading per foot buoyancy effects on the 14” DR 21 FPVCP cross-sections within the host pipe are included in Table 1. Measurements were not taken of the drilling slurry unit weights or densities, therefore a range of expected specific gravities of the drilling slurry is assumed for comparison’s sake. A negative loading indicates that the pipe section would actually sink to the bottom of the host pipe, since it will have a ‘negative’ buoyancy effect. A positive value indicates that the cross-section will rise to the top of the host pipe, with a ‘positive’ buoyancy effect. As can be seen in the data on a per linear foot basis, an unballasted pipeline will see a very large buoyancy load when it is installed compared to a self-ballasted installation.

Table 1. Comparison of self-ballasted and unballasted buoyancy loading per foot of pipe length, based on a range of assumed fluid densities of the drilling slurry.

<table>
<thead>
<tr>
<th>Drilling Fluid Density [specific gravity]</th>
<th>Self-Ballasted</th>
<th>Unballasted</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Water) 1.0</td>
<td>15.32</td>
<td>-6.51</td>
</tr>
<tr>
<td>1.1</td>
<td>16.86</td>
<td>-4.97</td>
</tr>
<tr>
<td>1.2</td>
<td>18.39</td>
<td>-3.44</td>
</tr>
<tr>
<td>1.3</td>
<td>19.92</td>
<td>-1.91</td>
</tr>
<tr>
<td>1.4</td>
<td>21.45</td>
<td>-0.38</td>
</tr>
<tr>
<td>1.5</td>
<td>22.98</td>
<td>1.15</td>
</tr>
</tbody>
</table>

| Pipe Weight = 21.83 lbs/LF |
| Notes: [-] negative value means that the sliplined pipe will sink |
| [+ ] positive value means that the the sliplined pipe will rise to the top of the host pipe |

Aside from self-ballasting, expected pull force to install the pipe was also evaluated for other additive aspects of the insertion. These included the required force to pull the pipe at grade prior to the insertion, as well as the actual alignment set up at the host pipe entry. 7,000 feet of 14” DR 21 FPVCP has a dead weight of ~153,000 lbs. Reducing the drag of this weight at grade is critical to keeping the pull force requirements down at the beginning of the installation. Luckily, the project site provided an easy means to reduce this as much as practical, as the insertion alignment was adjacent to water. Therefore, the bulk of the pipeline both while being assembled during fusion and while being inserted into the host pipe during installation was floated on the water, effectively reducing the at-grade drag significantly. The insertion set up also used rollers and a crane supported pipe cradle to provide the smooth arc needed to align the pipe with the existing host pipe outlet (see Figure 4). The outlet for the insertion of the pipe into the host pipe utilized a ‘roller flange’ bolted onto the end of it to reduce drag and damage to the pipe as it was pulled into the alignment. These considerations reduced the drag realized at grade and through the insertion alignment to the greatest extent possible.
Figure 4. Insertion alignment assembly and configuration into the host pipe and extension spool piece. Picture shows the initial insertion of the FPVCP pipe into the host pipe, note the pull head about to enter. Inset shows the roller assembly at the mouth of the extension spool piece.

Figure 5. Estimated pipe pull force values and drill rig pull force values versus the length of the insertion as a percentage of the safe allowable pull force for the pipe section.

The total expected pull force on the section of estimated ‘known’ loading was compared to the safe allowable pull force for the FPVCP cross-section. The estimated force included pipe drag at grade, insertion alignment drag, drag
within the host pipe for buoyancy loading (considering the self-ballasting mechanism employed), and capstan effect of the pipe being pulled through the four large curves of the alignment. Preliminary estimates showed that the expected ‘known’ forces would comprise about 25% of the safe allowable pull force capability of the FPVCP cross-section being used. Since a load cell or other means to monitor the actual tensile loading on the pipe as it was being installed would not be feasible, estimates of the drilling rig pull values were also calculated to provide comparison to what would actually be measured on site at the drill rig. These values included the force needed to pull the drill string and tooling, as well as overcome the carriage losses on the drill rig itself. The original estimates are as shown in Figure 5 as a percentage of the allowable safe pull force for the pipe cross section. The estimated pull force on the sliplined pipe increases slightly as it is being installed, which is logical as the loading on the pipe increases as longer lengths of it are inserted into the existing steel line, but is traded for the drag that is present at grade. The drill rig pull force value decrease slightly, since the tooling load for the drilling rig decreases with installation, but is traded for increased pipe friction.

In order to make a ‘go, no-go’ decision on whether it was thought that the pipe could be installed successfully, the final element of the equation, which was the total load realized by the undulations in the line, including any reasonable safety factor, needed to be assumed. The original steel pipeline, while assembled at grade with fully welded construction at the joints, which included no short radius bends or specials, was installed by dragging it into place along the uneven floor of the large body of water. It was shown on the wireline survey and expected by the team that there would be many undulations in the alignment, and these would have some sort of cumulative effect on the installation of the sliplined pipe. The other ‘unknown’ pull forces included any caveats to the assumptions that governed the ‘known’ pull force estimates. One of the major assumptions governing the self-ballasted estimated loading was that the fluid would completely fill the new pipeline as it was being inserted. This would not necessarily be so, given the alignment of the existing pipe and the dynamics of the fluid flow in the ‘pipe-in-a-pipe’ scenario. If the sliplined pipe did not completely fill with fluid, the result would be the higher buoyancy and drag values as previously described. Considerations of these contingent loads, along with cumulative drag resulted in an estimated safety factor of two to be applied to the calculated values in order to make a ‘go, no-go’ decision for the project.

This resulted in a predicted load that could look like something closer to Figure 6. As can be seen, the increase of estimated loading within the host pipe now created a situation where the pulling loads are increasing throughout the
insertion and culminating in the greatest loading at the end of the installation. Utilizing both of these predictive curves, a range of values were assessed as reasonable guesses as to the pull force that might be expected for the installation both at the HDD drill rig and on the pipe itself. Most critically, this expected range of pull forces for the pipe topped out at about half of the safe allowable pull force for the cross section and with this understanding, the installation was considered a ‘go’.

5. RESULTS OF THE INSTALLATION

Based on the calculated buoyancy of the FPVCP section, pull force values on the pipe were expected to top out between 25% and 50% of the SPF as a worst case scenario. As previously mentioned, this accounted for self-ballasted buoyancy loading, anticipated capstan loading on the curved sections and drag at grade and insertion. This also included a factor of safety for the unknown alignment undulations present and their effect on the insertion. Additionally, this was assuming that the drilling fluid used was close to water in terms of specific gravity and that a standard friction factor common for HDD installations of 0.3 would be realized to model the in-pipe friction.

Figure 7 shows the range of drill rig pull forces expected based on the assumptions described, as well as those assumptions with the additional factor for the cumulative alignment variations along the length of the installation. The actual pull forces recorded at the drill rig at key locations were also gathered and shown in the figure. While these recorded and estimated forces include the actual force of pulling the drilling string, reamer and tooling along with the pipe, it represents a rough estimate or characterization of the force required as it is applied to the pipe string as well. As can be noted from the figure at the end of the pull, when the rig and string have the least impact on the pulling force registered, the expected pulling forces fell in between the two estimates of the force required. This indicates that the alignment variations did have a significant impact on the pulling forces required, however, they were below the ‘safety factor’ case considered during the evaluation of the installation. The pipe was inspected within the first 15 feet behind the pull head for signs of any excessive scratching or gouging to assure that the pipeline did not pass through an area that would have damaged the pipe after the initial cleaning and proofing.

![Predicted Pull Force Values with 2x Safety Factor](image)

Figure 7. Comparison of calculated pull forces from self-ballasting effort both with and without a safety factor included and actual pull force values recorded at the drill rig during installation. Pull forces ended in the range that was expected with the safety factor, accounting for the additional loading anticipated at the curved sections of the alignment. Values are shown in percentage of safe allowable pull force for the pipe section.

After the successful installation, the data was examined more closely in an effort to evaluate the impact of the alignment undulations on the required pull force. It is estimated that several of the peaks shown from the original
installation were manufactured by anomalies in the installation process itself. One such anomaly was created by the overnight work stoppage which occurred at the 3,000 foot mark. Upon start up the next day, a slight spike in pull force was required to get the insertion moving again. It is assumed that much like this effect when it is realized in HDD installations, additional force was required to sheer the bentonite slurry in the host pipe and get it flowing again after it had gelled overnight. This effect then dissipated with continued movement. Additionally, towards the end of the installation, fluid balance within the host pipe was not keeping up with the required volume to completely ballast the new pipeline. More fluid was being displaced and ‘drug’ out of the host pipe at the drill rig side, than was required to fill the new pipe as it was inserted. This was a result of the fluid dynamics of the ‘pipe-in-a-pipe’ arrangement as well as the alignment of the host pipe, particularly the ‘U’ shaped section in the middle of the line, acting as a trap for the fluid. To combat this, a packer valve was closed at the drill rig side around the drilling rod and fluid was pumped into the alignment to force slurry back down the sliplined pipe and restore some of the ballast on the back side of the alignment. This technique worked well, immediately reducing the pulling force realized at the drill rig. This effect during the installation was a direct correlation to the concern that inability of the fluid to completely fill the sliplined pipe would result in increased pull forces.

These particulars of the construction process, while increasing the pulling load on the installation, were normalized from the data to get a better idea as to the impact of the alignment variations on the actual pulling load realized. Figure 8 shows the resultant values against the installation length without the operational spikes included. Several important and interesting things can be noted from this figure. The first is that there are still appreciable gains of force at the locations of the four major bends in the alignment. This would lead one to believe, that while the capstan effect was accounted for at these locations, perhaps there was a bigger impact of these bends on the pulling force than accounted for. The second is that while some of the gains in the straight sections could be based on the assumptions used for the calculations, including specific gravity of the drilling slurry and friction factor, the undulations did provide an additive loading to the pipe as it was installed. Estimates from a trend line fitted to the data showed about a 0.3% increase per 100 feet of insertion in terms of percentage of safe pull force for the cross section used. This additional force is estimated to be due primarily to alignment variations – and represents a significant loading. By the time the insertion was complete, this additional loading accounted for about 1/3 of the drill rig forces seen and just under half of the ‘safety factor’ estimated forces for the installation.

Figure 8. Derived pull force values for the varying alignment. Values have been normalized from the construction values gathered and assume a 0.3 friction factor. Varying specific gravities for the drilling slurry are also shown as well as the four major curve locations.
The overall project was a success. The sliplined pipe was cleaned of the drilling slurry taken on by the self-ballasting operation using pigging technology and was backfilled with clean water. The pipe passed a hydrostatic pressure test and was then reconnected on either end and placed into service. The project took about 2 months to complete.

6. CONCLUSION

The success of this project was based largely on the honest and open collaboration of the project team. The end result of this teamwork was not only the successful rehabilitation of an inaccessible yet critical pipeline, but also delivering that solution in a very short window of time. The project was completed with minimal disturbance to the existing project area and the operations of the pipeline.

From a technical perspective, this installation provided a unique opportunity to test the current design practice for sliplining installations as well as a general comparison to other trenchless installation techniques. The data obtained provides more insight into how a curvilinear host pipe alignment impacts the expected drag and required installation forces needed to install the sliplined pipe. From a very general perspective, it appears that the capstan effect calculations based on current HDD practice are not conservative enough in terms of estimating additional pull force requirements for large radius bends in the existing pipe. Also, while this is only one case study, it is important to note that the cumulative undulations in the pipeline did add a significant loading to the inserted pipe during the installation.

Sliplining, one of the oldest and least environmentally intrusive forms of trenchless rehabilitation, has added another successful chapter to its story.

7. REFERENCES