PEARL CITY FORCE MAIN EMERGENCY REPAIR USES SLIPLINING INSTALLATION METHODOLOGY

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ABSTRACT: The City and County of Honolulu faced a serious public health and environmental problem with one of its large diameter dual force main systems after experiencing four breaks over a four-year period. The breaks occurred within a 250 l.f. stretch of the 11,500 +/- l.f. Pearl City Force Main system comprised primarily of 30”, 36”, and 42” ductile iron pipe. At the location of the breaks, both pipes were installed in corrosive soil conditions and were subject to changing groundwater levels influenced by sea level changes. The Limtiaco Consulting Group was contracted to engineer a solution shortly after the City and County of Honolulu declared the project to be an emergency repair.

Several construction alternatives were evaluated: slip-lining, cured-in-place-pipe (steam, water, and ultraviolet curing methods), horizontal directional drilling, tight fit liners, and shallow bury open cut pipe replacement. The slip-lining rehabilitation method using fusible PVC pipe was selected as the preferred method to meet challenging site constraints and the aggressive schedule tied to the emergency declaration. To accelerate the project, a construction contract was awarded with pre-final design drawings. The strategy was to make engineering adjustments during construction as unknown conditions were encountered, such as existing bends, fittings and thrust blocks.

This paper describes the unique engineering process and critical decisions needed to fast-track the construction of the slip-lining project. It also examines the need for timely adjustments needed during construction through effective collaboration between the owner, contractor and engineer.

INTRODUCTION

The Pearl City Force Main (PCFM) was constructed in the late 1970’s as a part of a large diameter dual force main system serving an urban region of the City and County of Honolulu. The force main system consists of two parallel lines composed of ductile iron (DI) pipe ranging from 30” to 48” in diameter. The force main system was constructed utilizing typical open cut trench installation and laying a system of ball joints along the bed of the channel crossings. The PCFM transports daily maximum dry weather flows of approximately 27 million gallons per day (MGD) from the Pearl City Sewer Pump Station (SPS) to a junction box located at the Waipahu SPS. There, flows from the Waipahu SPS combine with the PCFM system and discharge into a manhole leading to the Hono‘uli‘uli Wastewater Treatment Plant.

The PCFM spans approximately 11,500 +/- l.f. along a portion of Pearl Harbor Middle Loch, crossing under several storm drainage channels, and installed in ground water influenced by tidal changes. Typical operations utilize both of the force mains to transport the daily wastewater flow demand (hydraulically, only one force main is required). During high storm event wet weather flows, operations require the use both force mains to accommodate peak flows as high as 47 MGD. The complexity of the system layout, including the addition of flows from the Waipahu SPS, also makes it a challenge for operations. Throttling of pumps and manipulation of system valves require advance planning as flows from one SPS affects the hydraulics of the other.
At the time of the project, a separate assessment of PCFM was concurrently under way to determine the improvements required to meet future wastewater flow requirements. Preliminary findings suggested that size upgrades were required for the force main system between the Pearl City SPS and Waipahu SPS. Initial planning anticipated the improvements within the following 8-10 years.

**THE BREAK(S)**

Over a span of 4 years, from 2006 to 2010, a 250 (+/-) foot section of the PCFM system experienced four breaks, with three breaks occurring on the system’s 30” DI force main and one break occurring on the system’s 42” DI force main. In April of 2006, the first break on the force main system occurred near the lower side wall of the 30” force main.

Figure 1. First break occurs in April, 2006, on the 30” line at the 7:00 position.

Based on the condition of the pipe, the break was believed to be caused by external corrosion. Figure 1 shows the April 2006 rupture of the 30” DI force main.

Figure 2. Second break occurs in January, 2010, on the 30” line at the 12:00 position.
In January of 2010, a second break occurred on the 30” DI force main approximately 150’ upstream of the 2006 break. The condition of the pipe revealed that failure was located near the crown of the pipe and was also likely due to external corrosion. Soil samples collected at the break location revealed that the soil in the vicinity was “Severely” corrosive. Figure 2 illustrates the January, 2010 rupture of the 30” DI force main.

![Figure 2. January, 2010 rupture of the 30” DI force main.](image)

Figure 3. Third break occurs in July, 2010, on the 42” line at the 5:00 position.

The third force main break occurred several months later in late July of 2010. This time, the 42” DI force main had ruptured near its lower side wall approximately 100’ upstream of the January 2010 break. Again, external corrosion seemed to be the cause of failure. During excavation for its repair, it was discovered that the 30” force main, just several feet away, had also suffered a break. The fracture on the 30” force main was located on the upper side wall of the pipe. It was speculated that possible stress on the pipe from the excavation caused the pipe to rupture; however, external corrosion seems to have played a major role in its failure. Figures 3 & 4 reveal the July 2010 breaks of the 42” and 30” force mains, respectively.

![Figure 3. Third break occurs in July, 2010, on the 42” line at the 5:00 position.](image)

![Figure 4. The fourth break occurred in July, 2010 on the 30” line at the 10:00 position.](image)

Figure 4. The fourth break occurred in July, 2010 on the 30” line at the 10:00 position.
THE ISSUES

The PCFM runs along Pearl Harbor’s Middle Loch, crossing through the Pearl City and Waipahu town districts. Proximity to the ocean leaves the force main system exposed to ground (ocean) water conditions influenced by tidal changes. The force main system shares a utility corridor easement with other utilities including gravity sewers, drainage systems, and multiple fuel lines. Based on soil resistivity testing performed along the system, the PCFM is generally located in highly corrosive soils. Investigation also revealed that the force main system is susceptible to stray current interference from the neighboring lines in the utility corridor. Although Cathodic Protection (CP) was installed in the mid 1990’s, it was discovered that the CP system had electrical discontinuities and lack of maintenance had left the system in disrepair.

THE EMERGENCY

In November 2010, the City and County of Honolulu deemed the portion of PCFM between Wailani Drainage Channel and the Waipahu SPS in need of immediate repair. An emergency declaration was made that would allow project funding and an expedited procurement process. A unique design/construction approach was utilized to meet the aggressive project schedule. Design drawings and specifications were prepared to approximately 80% (Pre-Final) and were bid out to a minimum of three (3) selected contractors. The design engineers were then expected to play a large role during construction, working closely with the selected contractor to resolve outstanding design issues as construction progressed.

PROJECT OBJECTIVES

The Limtiaco Consulting Group (TLCG) was tasked to investigate a repair solution for a section of the PCFM with a limited construction budget. The task included assessment of the force main system, analysis of repair alternatives, development of a project scope, and design of the repair solution. Based on the number of breaks within the last few years, the public’s health and safety was deemed to be in eminent danger. Repair of the force main system was required immediately.

Prior to the breaks in 2010, a preliminary force main/pump station condition assessment analysis had been initiated. Preliminary findings suggested that the PCFM system should be upgraded to increase flow capacity within the next 10 years. As a result, TLCG identified the following as the project objectives:

- An immediate repair/replacement solution with a service life of 10 years minimum;
- Construction Budget: Limited – Emergency Repair Funding;
- Have a minimum impact on flow capacity;
- Minimize the use of ferrous material and provide corrosion protection for the ferrous material existing in the system or being introduced;
- Address the poor quality of existing soil conditions; and
- Maintain flow capacity during construction.

ALTERNATIVE ANALYSIS

Several alternatives were evaluated to repair the force main system. The recommended alternative would have to provide a fully structural standalone system to accommodate the questionable conditions of the existing DI force main. After consulting with the owners, five main criteria would be used to evaluate each alternative: Capital Cost, Service Life, Maintenance, Hydraulic Capacity, and Constructability. Upon evaluation, TLCG assigned each criterion a score between 0 and 5, with 0 being the least beneficial and 5 being the most beneficial. The alternatives included the following:

- Alternative No. 1 Slip-Lining utilizing HDPE or Fusible PVC;
- Alternative No. 2 Cured-in-Place-Pipe utilizing steam, water, or ultraviolet curing methods;
- Alternative No. 3 Tight Fit Liner (Fold-and-Form/ Pipe Roll-down);
- Alternative No. 4 Shallow Bury Open Cut utilizing HDPE or Fusible PVC; and
- Alternative No. 5 Horizontal Directional Drilling (HDD) utilizing HDPE or Fusible PVC.
Table 1. Alternative analysis and evaluation decision matrix

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<th>PARAMETER</th>
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- Alternative No. 1 scored the highest of all alternatives. The long pipe runs being considered and high groundwater table made trenchless methods a preferred alternative. Nominal ground disturbance minimized capital cost and allowed access to surrounding properties to be maintained during construction. This was critical, especially for the neighboring fire department facility which was in very close proximity to the project. The use of plastic pipes provided the longest service life and least maintenance requirements. Slip-Lining did have the most impact on hydraulic capacity mainly due to the reduced diameter of the slip-lining material. However, hydraulic analysis revealed that impact to the overall system would be minimal and would not have a significant effect on capacity.

- Alternative No. 2 provided the next highest score. Like slip-lining, CIPP requires nominal ground disturbance during construction. Its profile, however, maintains more of the original pipe diameter allowing for better hydraulic characteristics. CIPP liners have had some success in pressure pipe rehabilitation, but primarily in potable water lines. It was unknown how the liners would hold up against long-term pressure exposure to the grit and solids that are present in wastewater.

- Alternative No. 3, Tight Fit Liners, including Fold-and-Form and Pipe Roll-down methods were given low scores for service life and maintenance due to its limited use and history.

- Alternative No. 4, Shallow Bury Open Cut Replacement would provide the longest service life, least maintenance, and best hydraulic capacity utilizing fusible plastic pipe. However, this alternative would have one of the highest capital cost due to the amount of excavation and high groundwater table (dewatering). Furthermore, this alternative would take the longest to construct increasing the liability for further impact from a sewer spill.

- Alternative No. 5, HDD also provided the highest scores for service life and maintenance with the use of fusible plastic pipes. Hydraulic capacity could also be maintained by providing pipe sizes equivalent to the original force main system. Constructability and capital cost, however, limited the success for HDD. The limited space in the utility corridor housing the PCFM drove the capital cost and would prolong the design and construction process by requiring additional space.

**SLIP-LINING WITH FUSIBLE PVC**

The alternative analysis performed by TLCG indicated that slip-lining with plastic pipe would prove to be the preferred solution. It was estimated that this alternative would realize a cost savings just under $1,000,000 compared to the conventional open-cut/shallow-bury installation. Although there have been few slip-lining projects locally, the simplistic nature of the work, minimal impact to the surrounding area, and expeditious process made it an appealing alternative. Slip-lining using plastic pipe also revealed a minimum amount of maintenance required with a long service life.
Selection of the slip-line pipe material was based on cost, flow capacity, pressure rating, and tensile strength. The pipe material would have to accommodate the maximum estimated system surge pressures in addition to the daily flow conditions. Based on an assessment of the system hydraulics, a minimum pipe pressure class 125 psi was determined. Utilizing comparable pipe pressure ratings, an assessment comparing HDPE and Fusible PVC was performed. The study indicated that, on average, the use of Fusible PVC would provide a 20% greater flow area to HDPE. The investigation also revealed that the Fusible PVC would have a higher tensile strength allowing for possible longer pull lengths. A quick analysis was performed for the material and fusing cost. The analysis indicated that the cost for Fusible PVC was approximately 15% higher than HPDE.

Although the material cost of Fusible PVC and fusing was approximately 15% higher than HDPE, the greater hydraulic capacity reduced the impact to the force main system making Fusible PVC more appealing. To maximize capacity of the existing force main system and provide a pressure class of pipe to accommodate the working conditions, 36” DR 32.5 Fusible PVC was selected to line the 42” DI force main and 24” DR 25 Fusible PVC pipe was selected to line the 30” DI force main.

QUALITY CONTROL

The project incorporated various measures to ensure quality control of the material provided and pipe installation. Suppliers of the Fusible PVC were required to have successfully supplied at least 250,000 linear feet of pipe for at least three years and provide an onsite construction manager licensed as an engineer in the United States. The pipe material also needed to meet ASTM D1784 while manufacturing of the pipe was required to meet AWWA C905 standards.

Pipe segments were allowed to be assembled in the field with butt-fused joints by a qualified fusion technician. Heat Fusion Technicians needed to be trained and fully qualified by an approved supplier’s representative and in accordance with the supplier’s recommended fusion procedures. Training or re-qualification was required to have been obtained within the 12 months prior to the beginning of work. Heat Fusion Technicians were also required to have performed fusion on at least 3 prior projects of similar size and length and pipe material.

To insure the quality of work and installation, the contractor was obligated to provide electronic data logging of each fusion and conduct a visual inspection of each joint. A two (2) hour, 1½ x working pressure test outlined in AWWA C605 was also required as part of the acceptance process.

PROJECT CHALLENGES

As in the case with many municipal projects, time, money, and permitting often play a big role on the project’s design and success. This project was no exception. In addition, the project had many other challenges:

- Stringent guidelines to the project scope based on the emergency declaration and project status;
- Maintaining full capacity of the force main system during construction;
- Bypassing flows around the project area without an existing connection point for approximately 2-miles;
- Maintaining 24-hour access around the project area for the neighboring fire department facility;
- Fragility of the existing DI force main and their proximity (8”) to one another (See Figure 5);
- Minimizing impact to structures located within a few feet from the force main system (See Figure 6);
- Addressing extremely poor soil conditions and tidal influenced ground water;
- Accommodating non-traditional bend angles (74° and 60°);
- Long lead time for fittings and appurtenances; and
- Coordinating work with multiple private and government agencies including the Department of Navy, Army Corps. of Engineers, the State Department of Transportation, the State Department of Education, the Honolulu Fire Department, the City Department of Environmental Services, the City Department of Parks and Recreation, the City Department of Transportation Services, and the Hawaiian Electric Company.
DESIGN APPROACH

To expedite the repair, a decision was made to develop construction documents to only 80% completion (pre-final) prior to bidding to contractors. Declaration of the project as an emergency repair allowed for an alternative procurement processes including closed bid procedures. This declaration allowed the City to work with a select group of contractors while allowing the design engineers to play a larger role during construction, working closely with the selected contractor to resolve outstanding design issues.

In addition to stray currents from the adjacent fuel lines, the lack of maintenance on the CP system, highly corrosive soils, and tidal influence on the ground water elevations are all elements believed to contribute to the DI force main external corrosion conditions. Due to these factors contributing to its failure, the repair solution also involved minimizing the use of ferrous items in the system and/or corrosion protection of any existing or new ferrous items.

Review of the as-built drawings indicated two main horizontal bends in the project area. The horizontal bends were non-standard 74° and 60° deflections. No indications existed on how the 74° bend was constructed, however, record drawings of the 60° bend revealed a system of ball joints. Staying in line with minimizing ferrous material in the project, the design approach for the 74° and 60° bends was to replace the bends with customized PVC bends, restrained at their joints and encased in concrete. However, the approach also included assessing the existing bends in the field as a final solution.

Based on the large quantity of flows and operation of the system, flow capacity of the force mains needed to be maintained. Typically, normal operations include the use of both force mains in the system; however, dry weather flows could be accommodated by using just one of its lines. Wet weather peak flows, on the other hand, required the use of both force mains. To address the fragile condition of the existing pipe and maintain capacity for wet weather peak flows, a single HDPE bypass system sized for a maximum dry weather flow of 27 MGD was proposed. This approach would allow the daily dry weather flows to be transported around the repair area through the bypass system. While taking one of existing force main offline to be slip-lined, the other existing force main could be kept connected within the force main system, remaining off and isolated until required to help transport wet weather peak flows. This would physically isolate the sewer flows from the working areas, minimizing construction risk and the possibility of any spills.

The project called for slip-lining of approximately 1,240 feet of the existing 42” and 30” DI force mains utilizing two pulls for each pipe. The same entry and exit pits were to be used for both pipes. The estimated pulling force for the slip-line installation was estimated to be well within the limitations of the pipe material. As such, measuring of the actual pulling force was not required as part of the installation procedures. The last 50 feet on the downstream side of the project area was proposed using open cut excavation. The annular space between the host pipe and slip-line was required to be grouted. The new Fusible PVC pipes would connect to the existing system using restrained ductile iron fittings along with corrosion protection measures including cathodic protection and/or a wax tape
system. Additional measures including concrete encasement were also provided at some locations. A schematic layout of the design is shown in Figure 7.

![Diagram of sliplining operations](image)

**Figure 7.** Design concept schematic of the sliplining operations including bypass and mainline repair.

During the design of the project, settlement issues were discovered just downstream of the project area, at the Waipahu SPS. Pipe deflection and separation of the joint was observed at the pipe fittings immediately downstream of the junction box. To address potential settlement issues of the new fittings near the junction box, a flexible expansion joint was proposed at the tie in point into the existing system.

**CONSTRUCTION CHALLENGES**

Upon installation of the bypass system, construction of the project proceeded from the upstream side of the project. Slip-Lining of the existing 30” force main was performed first. The existing 74° bends were exposed and a section from the 30” line was cut open for internal/external assessment. The bend consisted of several flanged and mechanical joint fittings deflected to construct the 74° deflection. Figure 8 depicts the existing 74° bends.

![Image of 74° bends](image)

**Figure 8.** The 74° bends exposed and shown in current condition.
The system of bends was cast into a thrust block. Surprisingly, the fittings for both pipes appeared to be in good external condition with minimal damage from corrosion. The internal condition of the 30” pipe appeared to be adequate as well. Although the design drawings called for replacement of the bends, a decision was made to re-use the 74° bends of both pipes. The design drawings were modified to connect the Fusible PVC slip-line pipes to the existing bends using a system of reducers and joint restraints. Modifications to the existing thrust blocks were required to accommodate the anticipated thrust forces and address the poor soil conditions.

Figure 9. The existing 60° bends exposed and shown in current condition.

The existing 60° bends were exposed and a section from the 30” line was cut open for internal/external assessment. The existing 60° bend consisted of a flanged 45° fitting and several ball joints cast into a thrust block. Figure 9 illustrates the existing 60° bends. Similar to the upstream 74° bend, the fittings for both pipes appeared to be in good external condition with minor corrosion observed. The internal condition of the 30” pipe also appeared to be in good condition. Although the design drawings called for replacement of the bends and expansion of the thrust block, a decision was again made to re-use the 60° bends. No modification was required for the existing thrust block. The ball joint locking rings were deteriorated so the entire bend was required to be encased in concrete to prevent further corrosion. The design drawings again were modified to connect the slip-line fusible PVC pipe to the bends using restrained mechanical joint sleeves. Figure 9 depicts the existing 60° bends.

After completing the 1000 (+/-) foot section of slipline #1 on the 30” force main, the contractor began preparations for slip-lining 240 (+/-) foot section of slipline #2 for the 30” force main. While excavating for the entry pit, the contractor uncovered an existing concrete encased electrical duct bank directly above the existing force mains. The duct bank contained feeder lines from the Waipahu SPS emergency backup generator so relocation was not desired. The Contractor had to demolish and remove a portion of the concrete encasement and temporarily move the duct bank to facilitate the work. Figures 10 and 11 depict the slip-lining conditions of the 30” DI force main for the 1000 (+/-) foot section and 240 (+/-) foot section, respectively.
Although the conditions were similar to the slip-lining of the 30” force main, the electrical duct bank, existing emergency generator building, and alignment of the existing 42” force main made it very difficult during the slip-lining of the 240 (+/-) foot section of force main system. Figure 12 illustrates the obstructions and pipe alignment. The existing generator building and electrical duct bank prevented the contractor from taking a direct insertion angle. The contractor had to deflect the pipe around the generator building and electrical duct bank to insert the slip-line into the host pipe. To accomplish this, the contractor extended the entry pit and pushed the Fusible PVC pipe to its bending limits. Figure 13 illustrates the contractor’s use of hydraulic jacks to assist with the pipe insertion process. After several attempts, installation of the slip-line was completed.

Figure 10. Inserting the 24” Fusible PVC pipe into the 30” DI at the 1,000 (+/-) foot section.

Figure 11. Inserting the 24” Fusible PVC in the 30” DI at the 240 (+/-) foot section.

Figure 12. Slip-lining the 240 (+/-) foot section of 42” DI force main with 36” Fusible PVC pipe. Alignment issues due to the existing duct bank and generator building.

Figure 13. Hydraulic jacks being used to assist in the insertion due to the alignment.
CONCLUSIONS

The slip-lining was successful in restoring the service life of the pipe sections within the project area and mitigating potential force main breaks and spills. Initial discussions with the City and County of Honolulu wastewater operations staff indicated that the new fusible PVC pipes are performing adequately. Minimal impacts to system hydraulics, capacity, and pressure have been observed. The use of fusible PVC appears to be a success. The compatibility of the material with standard pipe mechanical joint and flanged fittings made design adjustments during construction efficient.

Prior to the project, the spills caused by the Pearl City Force Main breaks was a health hazard to the community. The frequent spills were also taxing for City and County of Honolulu engineers and wastewater maintenance staff. After successful completion of the project, the risk of a spill has been dramatically reduced.