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MANAGING INTEGRITY OF UNDERGROUND FIBERGLASS PIPELINES

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ABSTRACT

The majority of Husky's fiberglass pipelines in Canada have been used in upstream oil gathering systems to carry corrosive substances. When properly designed and installed, fiberglass pipelines can be maintenance-free (i.e., no requirements for corrosion inhibition and cathodic protection, etc.) However, similar to many other upstream producers, Husky has experienced frequent fiberglass pipeline failures.

A pipeline risk assessment was conducted using a load-resistance methodology for the likelihood assessment. Major threats and resistance-to-failure attributes were identified. The significance of each threat and resistance attribute, such as type and grade of pipe, and construction methods (e.g., joining, backfill, and riser connection) were analyzed based on failure statistical correlations. The risk assessment concluded that the most significant threat is construction activity interfering with the existing fiberglass pipe zone embedment. The most important resistance attribute to a fiberglass pipeline failure is appropriate bedding, backfill and compaction, especially at tie-in points. Proper backfilling provides most resistance to ground settlement, frost-heaving, thaw-unstable soil, or pipe movement due to residual stress or thermal, and pressure shocks.

A technical analysis to identify risk mitigation options with the support of fiberglass pipe supplier and distributors was conducted. To reduce the risk of fiberglass pipeline failures, a formal backfill review process was adopted; and a general pipeline tie-in/repair procedure checklist was developed and incorporated into the maintenance procedure manual to improve the workmanship quality. Proactive mitigation options were also investigated to prevent failures on high risk fiberglass pipelines.

INTRODUCTION

Fiberglass pipe, or in technical words, glass-fiber (or fiberglass) reinforced thermosetting plastics (GRP/FRP) pipe, has been in use since the 1950s [1]. Fiberglass has been used in the municipal water and sewage applications, and also in the gathering and transmission of produced oil field fluids.

Over the years, there had been variety of non-metallic products developed utilizing fiberglass as reinforcement material. These types of materials include the traditional stick fiberglass pipe that have joint length of ~ 10 metre, also the spoolable product that uses dry layers of fiberglass for hoop stress reinforcement, or allows a thermo-set fiberglass resin matrix system to be flexible enough for spool-on constructions.

This study focuses on the oil field fiberglass pipelines joined by the rigid stick fiberglass pipes, in particular small diameter lines (<=210 mm). These pipes were typically made using epoxy resin reinforced by the continuous unidirectional or bidirectional winding of the resin impregnated glass fiber filaments. The study also focuses on the buried construction that is common to the industry in Canada.

Fiberglass pipelines in general have been considered a corrosion resistant alternative to carbon steel, or carbon steel with an internal lining or coating, due to the chemical inertness of the fiberglass and the resin with most oil field produced fluids and injection water.

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In Canada, fiberglass has been used for years in the oil and gas pipeline industry, and has experienced more frequent failures than steel pipelines [2]. Common issues identified are associated with the construction practices and workmanship quality control of the early fiberglass pipeline installations.

Husky has performed root-cause failure analysis, technical analysis, risk assessment and has enforced critical processes to ensure that activities that would cause high-risk failure of the similar mechanism be proactively mitigated.

This paper will first review the relevant industry design, construction, and operating requirements of fiberglass pipelines. Secondly, the paper will discuss the root-cause analysis, risk assessment and technical analysis that Husky conducted, and the action items implemented to manage the integrity of the existing fiberglass pipelines.

MATERIAL AND CONSTRUCTION

Material

Fiberglass pipe is a composite product of chemically cured resin and fiberglass matrix, with small amount of other additives.

Resin

Polyester or vinyl ester is used for large diameter water and sewage piping; epoxy resin, on the other hand, is commonly used for smaller diameter (<780 mm) pipes in oil field with pressure up to twenty thousand kilopascals.

Three types of curing chemicals would cure the epoxy type resins into increasing temperature performance ratings, i.e., anhydride cured resin (60-80 ^{o}C), aliphatic amine cured resin (~90 ^{o}C) and aromatic amine cured resin (100-110 ^{o}C).

Glass-fibers

Three types of glass fibers can be used for resin enforcement. These are the Type E glass fiber (low electrical conductivity), Type ECR or S glass fiber (high strength for special use) and Type C glass fiber (for high chemical durability fiber). Type ECR and C glass fibers provide improved acid and chemical resistance. Type C glass fibers are generally used to reinforce chemical-resistant liners for highly corrosive chemicals at high temperature. In general, type E glass fiber reinforced resin structure offers economical and sufficient chemical resistance, without the need of a chemical-resistant liner for oilfield gathering pipelines [1].

Pipe Manufacturing

Modern epoxy resin based fiberglass pipes are manufactured through filament winding processes. The most common process is the single-angle winding of resin impregnated fibers. This winding will provide about 2:1 hoop to axial strength ratio, if the fiber wrapping angle is near 55-70 degrees to the pipe longitudinal direction [3]. Dual angle wrapping was also used. For example, the CIBA-Geigy fiberglass has a layer of fiberglass reinforced resin with 90 degrees of angle in hoop direction, and alternated with one layer of fiberglass reinforced resin in axial direction. This type of structure may have provided higher modulus of elasticity in both axial and hoop directions than the product with single-angle winding process. It may have also provided higher strength in axial direction, and lower thermal expansion coefficient [3].

PIPE DESIGN RATING

Manufacturer's Pressure Rating

The history of the development of the pressure rating standard of fiberglass pipe was discussed in a benchmark paper by Huntoon [4]. He pointed out that in contrast to steel material, fiberglass pipe can be susceptible to creep at any temperature in the oil field. Creep is a time-dependent phenomenon depending on the operating history, i.e., the thermal and stress cyclic loadings thus affect the design life of the fiberglass products.

Huntoon [4] explained that the intent of developing standard test procedures and design specifications was to ensure that the eventual creep failure of the fiberglass pipe can be designed beyond the desired service life. Standards or specifications such as API 15HR [6] and 15LR [7] were developed. These specifications commonly require that the pipes be designed for Hydrostatic Design Basis (HDB) hoop strength rating for a minimum of 20 years design life, and for a minimum of 66 ^{o}C temperature rating in accordance with the ASTM D 2996 [5] procedure B. API 15LR [7] also requires the cyclic stress rating at 150 million cycles under the rated HDB-cyclic be established in accordance with the ASTM D 2996 [5] procedure A.

A safety scaling factor of 0.67 is used in API 15HR and API 15LR static pressure rating methods to account for the hoop stress scaling factors that include cyclic pressure, service environment, temperature and axial loads, etc. The rated pressure then can be calculated from the rated HDB according to Barlow's thin-wall pipeline equation.

Manufacturers can determine the required minimal wall thickness for their pipe sizes based on the minimal required pipe pressure rating. Fiberglass pipes may also contain an internal resin-only liner; the thickness of such liner shall not be included in the minimal wall thickness calculations.

Huntoon [4] explained the differences between the LR and HR standards. It was mentioned that the API 15LR cyclic design specification was developed for hydrostatic rating below 6900 kPa, intended to cover most beam pump well flowlines, which may have low amplitude but highly cyclic stresses, i.e., cyclic pressure ranges between 1000 kPa to 2000 kPa. API 15HR, on the other hand, is for FRP tubular designed to operate at pressure in excess of 6900 kPa. It is thought that these lines will be operated much different from the low pressure well flowline system thus cyclic load effects are not as significant.

Since the API 15LR and HR had been developed for guidance on fiberglass pipeline long-term performance design, the manufacturers follow such recommended practices to develop premium type of "API designed" pipelines. However, majority of the oil field pipelines may have been the standard type "Non-API" designs, which according to manufacturers' experience may be sufficient for the 20 year service life or 150 million fatigue cycles. The "Non-API" designed pipes include proprietary designs of flange and pipe end finishes, which were acclaimed to be convenient and reliable for material make-up and joining. Nevertheless, many of these "Non-API" design pipes have been subjected to the long-term hydrostatic and/or cyclic test requirements of ASTM D 2996 procedures B and A, that qualify themselves as API 15HR or API 15LR pressure rated pipes.

Regardless of the detailed design and test result specifications outlined in manufacturers' product specifications, the grade of modern fiberglass pipe specified by the manufacturers may be the long-term hydrostatic pressure rating of the pipe at 20 years design life, and at 66 ^{o}C or higher temperature, for water. Manufacturers' recommended pressure rating thus must be scaled down or derated depending on the actual service fluids and cyclic service conditions for static rated pipe.

Pressure Rating due to Other Factors

CSA Z662-07 considers type of fluids and cyclic pressure as two major factors for pipes under hydrostatic pressure rating.

Fluid Factors

In general, CSA Z662-07 recommends stick fiberglass pipe be used only in Low Vapor Pressure (LVP) gas service, and a 67% of the hydrostatic pressure rating shall be applied for its maximum operating pressure. For LVP multiphase fluids, 80% of the manufacturers' hydrostatic pressure rating shall be applied.

Cyclic Pressure

CSA Z662-07 recommends a 50% derating of the hydrostatic pressure rating, in addition to the fluid factor. Pipelines used in the oilfield water injection service that were not derated due to the fluid factor may be derated 50%, if the injection system is in cyclic services.

Temperature Rating due to Chemical Compatibility

Compatibility of fiberglass material with oil field effluent or water is generally good. However, the wet sour (H_2S) or acid gas (CO_2) environments may limit the maximum nominal operating temperature, but usually not the hydrostatic pressure rating of the pipeline.

CSA Z662-07 allows less than 50 kPa partial pressure H_2S and not exceeding 9930 kPa for gas service pipeline. Some fiberglass pipe manufacturers also do not recommend fiberglass for any type of fluids containing wet H_2S beyond 5mol% level.

Although CSA Z662-07 recommended that composite fiberglass can be used for LVP gas gathering, concerns and failures in the industry have shown that some LVP light end liquid hydrocarbons and aromatic compounds could cause some resin systems, especially the anhydride type resins to go through structural changes and deteriorations.

Chemical compatibility also comes into play with sour or acid gas applications when gaskets, O-rings are used in the pipeline joining. Many old pipelines especially the old mechanical type joined pipelines that have used Nitrile gaskets, O-rings or rubber bearings may not have sufficient resistance to long-term sour service conditions at elevated temperatures.

PIPELINE DESIGN AND CONSTRUCTION

Design Stress Calculations

Pipelines constructed underground are subjected to a number of external stress situations that could be analyzed based on the AWWA M45 [1] guideline. The guideline provides both strain and stress based designs of the pipeline for maximum allowable ring bending strain, and maximum allowable deflections from external soil load, live load, and water buoyancy. The stress design also includes the determination of the combined external and internal pressure loading, and allowable buckling pressure calculations. Such calculations take consideration of the type of the native soil, depth of cover of backfill soil, soil shape factor, pipe geometry, and long-term pipe hydrostatic design basis for evaluation of the load resistance in the hoop direction of the constructed pipeline.

For axial load resistance (or axial strength requirement) calculations, uneven bedding, differential soil settlement or subsidence of soil can result in pipe “beam” bending that contribute to a bending failure of the pipe. The design strength requirement for axial strengths are outlined in ANSI/AWWA C950 [8] for low pressure classes (up to 3100 kPa).

Pipeline Joining

There are three main types of fiberglass to fiberglass pipe joining methods, i.e., threaded, bonded and mechanical joining. Pipes are manufactured such that pipe ends are finished with threads for threaded or mechanical joining; and beveled or tapered for bonded joining.

Threaded Joining

Many manufacturers of threaded pipe provide their non-API standard thread types, majority of those are coarser threads (3 to 4 threads/inch), which can also be used in combination of a pressure sealing O-ring. Coarse threads are less prompt to cross-treading and the make-up does not require as high torques. For some low grade pipes, threads may merely function to guide the make-up of pipes, and the O-ring is the only pressure-sealing mechanism. Manufacturers also provide API standard thread products that do not come with the use of O-rings.

Bonded Joining

An epoxy-based adhesive is applied on the spigot or bell ends of the pipe, upon make-up, the curing is typically assisted with heat generated by a chemical heat pack or a electric heat blanket. Bonded joining requires excellent workmanship, and bonding procedure for performing the work, especially in sub-freezing conditions. Heat-assisted curing is always recommended as curing in ambient condition would at least take hours in Canada.

Mechanical Joining

The mechanical type of joining includes the pronto-lock joining method that is nowadays mostly used for large diameter pipes. However, the method was also used joining small pipes in the past. The joint type incorporates flexibility and bending allowances during construction. Mechanical type of joining differs from threaded joining by allowing tensile, neutral or compressive axial load at the boot or O-ring connected between the bell and pin ends of the pipe joints to provide pressure sealing. Threads here typically provide guidance of make-up but limited or no effect in pressure sealing.

Flange Joining at Tie-in or to other Pipe Materials

It is very common that a flange connection is provided to join fiberglass and steel pipe. At the transition point, the fiberglass pipe was threaded or glued to a fiberglass flange, and the steel pipe is welded onto a steel flange of the same ANSI class. The fiberglass flange, gasket, and steel flange are then bolted together to complete the transition. Flanges are also commonly used to tie into another constructed pipeline, or simply after a repair for its convenience of installation and reliability of the seal. Joining other types of non-metallic pipelines usually is accomplished by joining to a steel flange set and then to the other types of non-metallic pipeline joining fittings.

Risers

Both steel and fiberglass material have been used to construct risers to tie into surface facilities or piping. High grade fiberglass piping and fiberglass flange material are usually used for the riser construction. The fiberglass material is known to have good resistance from freezing weather (-45 ^{o}C) and UV degradations. The UV radiation has cosmetic effects only at the surface, and not to the structural integrity of the pipe.

The static hazard is not a considerable concern as the exposed piping has very limited surface area.

When a steel riser is used, typically an underground flange transition to fiberglass pipeline is installed. Historically, rigid piling structures have been constructed to support the weight and prevent movements of the steel riser; however, this configuration has been problematic in some areas where fiberglass line pipe settles but the piling prevents riser from settling. The steel riser also requires a good internal coating, and stand-alone cathodic protection for the buried portion of the riser, typically from a local bonded sacrificial anode.

Steel components such as y-laterals, flanges, tees and short sections of steel pipes may be used for tie-in and transitions. Such components are required to be internally coated, fully externally coated or tape wrapped and protected by the sacrificial anodes.

Road and Water Crossings

Typically steel or concrete casings or conduits are used for fiberglass pipelines to cross through the road or small water crossings. The pipeline is centralized in the casing by the spatially distributed centralizers so that pipeline is supported with acceptable axial stresses and safe from the external live load under the road or water crossings. Crossing construction without casings is also available.

OPERATING FIBERGLASS PIPELINES

Pressure Testing Existing Pipelines

CSA Z662-07 allows testing with a gaseous medium with limited maximum operating pressure. However, local jurisdictions may prohibit testing of composite pipelines with gaseous medium. Manufacturers may allow the hydrostatic test pressure of the existing pipelines at maximum of 1.25 times their pipe grade, i.e., their hydrostatic rated pressure for 24 hrs. This limitation indicates a potential MOP derate when converting a sweet to sour gas service pipeline, if the hydrotest is required to be 1.4 times their original MOP.

Hot Oiling

Typically manufacturers allow hot-oiling up to 100 ^{o}C, over its recommended nominal operating temperature for a short period of time. Hot-oiling in the gathering system pipelines does not typically exceed 80 ^{o}C.

Pipeline Pigging

The pipeline may be designed for regular pigging with risers configured and all fiberglass or steel component fittings scheduled for piggability. Although not typically an integrity issue, pigging does contribute to rapid pressure fluctuations and mechanical loading that may initiate pipeline leaks if there are defects in the pipeline.

Repair and Re-Habilitation

Although patching small defects has been a method of repairing pipelines with small imperfections, CSA Z662-07 recommends cutting out the segment with defected areas as a cylinder and replace in kind. For threaded pipes where the joining is not permanent, the whole pipe joint that contains the defective area may be removed and threaded with a new pipe joint. The repair usually has to be completed with a flange set to tie in both pipe ends.

HUSKY FIBERGLASS PIPELINE FAILURE ANALYSIS

A root cause analysis conducted by Husky in 2007 showed that about 50% of Husky's fiberglass pipeline failures were mechanical type of failures. Close to 90% of these failures were in delayed failure mode within 3 years of its initial backfill due to external interference. The failures typically showed a structural break of the pipe body initiated from 6 or 12 O' clock position of the pipe, due to the excessive localized bending near risers, and transitions between steel and fiberglass tie-ins. A typical bending type of failure is shown in Figure 1.

From the failure analysis reports, the failure mechanism implied that these bending types of failures mostly resulted from the initial settlement of the fiberglass line pipe after the backfill; or in some cases where the piling structure is used to support the steel riser, the transition is too rigid to allow even settlement of the large component flange with the fiberglass line pipe.

The analysis also concluded that about 10% of the failures had been attributed to rock abrasion and impingement, due to poor bedding and backfill soil control (see an example in Figure 2). The pipelines with nominal operating pressure close to the manufacturers' pressure rating may have seen earlier failures than the lower operating pressure lines.

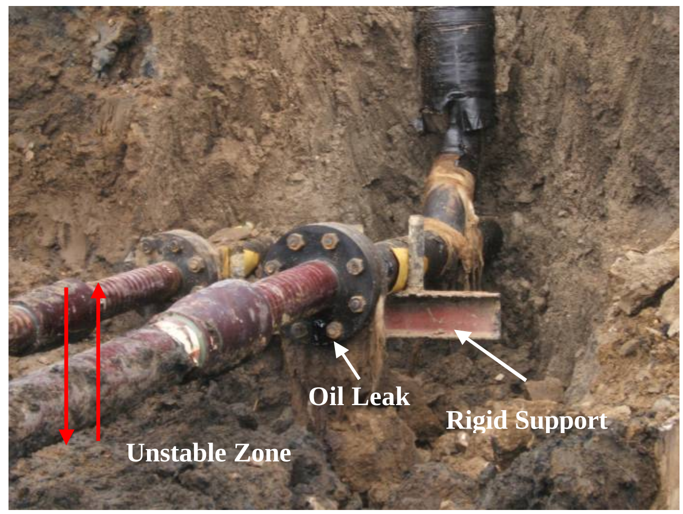

Figure 1 Typical Bending Type of Failure near a Tie-in Location

Figure 2 An Example Rock Impingement Failure

The analysis indicated that many of these failed fiberglass pipelines may have not been constructed to meet the fiberglass pipeline bedding and backfill requirements, and potentially also the workmanship quality control of the early installations.

As a result of the findings, a risk assessment of all fiberglass pipelines was initiated in 2008 to identify and mitigate the risks associated with existing operating fiberglass pipelines.

RISK ASSESSMENT

Consequence Analysis

The consequence analysis focused on the environmental impact, as 90% of the lines are small diameter pipelines carrying a liquid substance, and located in remote areas.

The consequence score was a multiplication of five factors:

- the packed internal volume of the pipeline segment;
- the hazard index of the substance in the line;
- the proximity to a water body;
- the environmental sensitivity of the water body; and
- the maximum operating pressure (MOP).

Volume Factor

This factor considered how much product would be potentially released if there was a pipeline failure. The released volume included the volume released through the gravity drain-down after the pipeline system shut-down and isolation. A larger diameter pipeline means more volume is available for gravity drain-down and, consequently, larger size of spill.

Substance Factor

The substance factor represented the severity of damage by the spilled substance to the area (receptor sensitivity). A liquid substance such as salt water or oil effluent that contain large amount of chloride, or crude oil presents the most prolonged environmental contamination. Pure hydrocarbon gases such as fuel gas were ranked lower as they readily disperse into air and do not leave prolonged environmental effects. Natural gas was ranked higher than fuel gas, as most natural gas contains produced water that may have high amounts of chlorides.

Location Factor

The location factor was based on the proximity of the line to a water body and the type of water body nearby. A pipeline crossing a water body was given the highest proximity ranking, and a large lake or main river was given the largest water type ranking. The proximity ranking and the water type ranking were combined to produce the location factor.

Maximum Operating Pressure Factor

This factor was based on the maximum operating pressure the pipeline was licensed to operate. Higher operating pressures have higher rates of release given a pipeline failure. Therefore, in a higher MOP line, more liquid would be released in the time required to stop the pump and isolate the line.

Likelihood Analysis

Likelihood of failure is the product of load (or threat) to initiate a failure and resistance to a failure. Load indicates identified threats encountered for the pipeline being put into services. Resistance refers to the pipeline properties that may help reduce the likelihood of failure subjected to such loads.

A number of major external and inherent threats were identified, and their relevant resistances are discussed in this section. In summary, the major threats identified were external construction interference (ECI), natural and geotechnical hazards (NH), construction/third-party line strike (LS), surface load (SL) and threats in operation and equipment (OE). A detailed risk algorithm of the weighting factors of each threat was also evaluated also based on the quantitative bending, deflection stress analysis methodology, which takes into account of the soil type and soil modulus per ASCE guideline [9] and AWWA M45 [1]. The weighting factor on the resistance characteristics of the pipe was also evaluated according to Husky's fiberglass pipeline failure statistics based on pipe size, grade, manufacturer, and type of joining.

External Construction Interference (ECI) Threat

Ground disturbance that interferes with the stable pipe zone embedment of the existing pipelines is a threat. The ground disturbance opens up a localized excavated area in the pipeline that requires re-establishment of the new pipe bedding and backfill. The re-establishment of the backfill soil may undergo significant settlement due to rain, ambient and ground temperature, snow cover, and ground water variations. These could affect the backfilled soil saturation and compaction, and generate localized settlement.

Fiberglass pipelines are also susceptible to any above ground servicing and maintenance work that may cause piping misalignment, residual tension/compression stresses that may propagate to the fiberglass line pipe through the risers.

Events that produce such threat could be any ground disturbance events such as open-trench line crossings, abandonment and discontinuations, line tie-in's, line repairs, and any unknown third-party ground disturbance that have not resulted in an immediate line strike failure.

At pipeline crossings where multiple pipes are buried, the backfill is typically of less uniform soil resistance and compactness. Differential soil settlement usually occurs. Crossing is also a natural location for overbends for the lines installed later, as they may have to be buried deeper. As a rule of thumb, a minimum of 150-300 mm clearance between pipelines at crossings is required.

Resistances to ECI Threat

The resistance to the external construction interference relates first to the quality of the original line construction, these include:

Backfill soil and compaction: It is well known that soft clays and generally fine grained soils offer poor resistance to displacement. As they absorb water and have poor drainage properties, they are more susceptible to frost-heave and unstable thawing of soil. On the other hand, the granular soil such as dense sands and gravels would offer increasingly better stability and resistance to soil movements, and better resistance to frost-heave. Compaction helps to improve the resistance and stability of the soil from movement. Cohesive soil backfill requires more compaction, and is more difficult to achieve a high compaction level. On the other hand, well graded granular backfill soil needs less or no energy to achieve required compactness.

Backfilling the pipeline properly in the trench involves a number of factors: backfill material; proper and sufficient compaction application to the bedding; embedment; and cover layers in proper lifts and weights.

Pipelines found with rock impingement failures are at high risk of repeat failures, as the failure indicated that the backfill material may contain sharp and hard rocks elsewhere in the line.

Native Soil: The native soil that forms the trench is also important. It is indicated in ASCE guideline [9] that native soil is also important as only axial soil resistance is mostly affected by backfill material. The vertical uplift and settlement resistances are mostly related to the native soils. For example, granular native soil has better drainage and soil modulus, and offers better resistance to pipe movements.

Alignment of Installation: Installation or repair of the pipeline shall ensure good alignment of the pipeline make-up components without excessive bending or axial compression or tension. Fiberglass pipe does not accommodate bending, as it has ten times higher allowable minimal bending radii than the spoolable composite products. Excavation to expose more area of pipe may often be required to achieve alignment without stressing the pipeline during repair or tie-ins.

Material Defects: Material defects may be found for older pipelines that have not passed the stringent industry qualification standard. API 15HR and 15LR provided visual inspection criteria of the pipe for acceptance of material. Failure analysis also can be used to determine if there is incomplete chemical curing of the fiberglass resin, and other defects that may not be obvious through visual inspections.

Inherent Strength: Overall analysis of the pipelines indicates that small diameter pipes are more rigid and resistant to through-wall bends. Small diameter pipes allow bend with smaller bend radii, and are less susceptible to water buoyancy uplift bend failures. However, most threats are from localized displacement of soil either by frost-heave (upward bending), or by unstable thawing (downward bending) in combination with thermal compression/tension stresses. For small pipes, as the wall is thinner, the overall bending load they can resist is lower. However, for bigger and thicker pipes, as epoxy resin is elastic-plastic material, when the pipe is thicker, it may be more prone to crack and fatigue type of failures.

As indicated by Figure 3, Husky's fiberglass pipeline failure history indicated that pipelines having OD of less than 3 inch have had more failures than pipelines with an OD of 3 inch to 5 inch pipelines. On the other hand, pipelines that have OD larger than 5 inches also exhibited high failure rates.

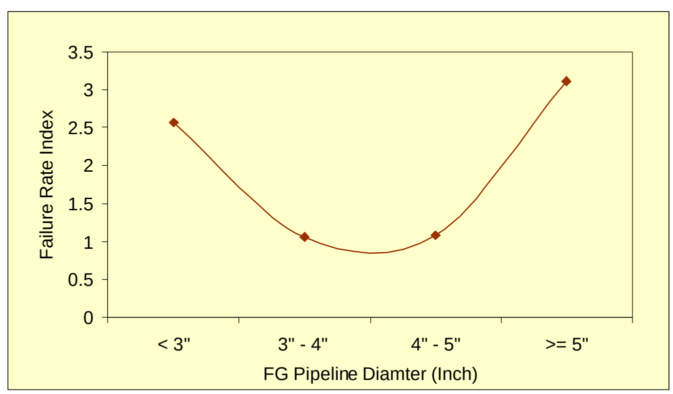

Figure 3 Husky Fiberglass Pipeline Failure Incidents vs. Pipe Diameter

Joining Type: Statistics has shown that fiberglass pipeline failure depend on type of joining. Pronto lock type mechanical joining installed on low pressure rating pipelines has issues with the sealing at the boot or rubber bearings. The majority of Husky's pipelines have been thread joined and have shown the lowest frequency of failure, as illustrated in Figure 4.

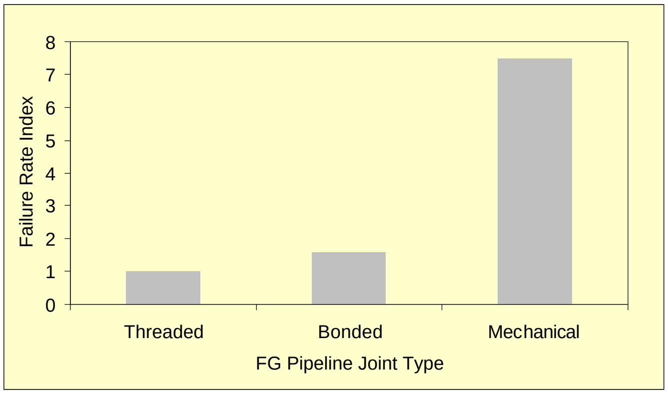

Figure 4 Husky Fiberglass Pipeline Failure Incidents vs. Type of Joining

Stress Discontinuities: Buried flanges, tees, y-laterals, pilings under the risers etc. are larger diameter thicker wall components which impose discontinuities of the stress field amongst the connected pipelines. These components can act as pivot points that promote deflections of the stressed pipe, if the pipe is not restrained fully by the soil embedment.

<u>Surface Load (SL) Threat</u>

Surface load takes into consideration the weight of soil; the weight of the pipe and its content; the live load such as vehicle crossing; and any other potential impact load. Significant surface load are relevant if there are major roads, railway crossings, and if the pipelines have not been cased by steel or concrete conduits.

Resistances to such impacts include pipe grade, depth of cover, pipe diameter, backfill material and compaction. Larger diameter pipe is more susceptible to surface load through-wall bending as the ovality changes more rapidly with a large diameter than with a small diameter pipe.

<u>Construction/Third-party Line Strike (LS) Threat</u>

Potential of line strikes by construction or unknown third parties are affected by how effective construction/third-party activities are monitored and controlled. As fiberglass pipe is brittle, it does not have any resistance to a line strike and a line strike always leads to a pipe failure.

The construction control measures include ground disturbance polices, line survey, and use of hydrovac to expose all lines in proximity. Control of third-party events include signage, marking, patrol, protection of exposed equipment, crossing agreements as well as community awareness. Deadlegs may potentially increase the inherent potential of a line strike, as deadlegs may not have received the same active attention comparing to the flowing lines.

<u>Geotechnical and Natural Hazard (NH) Threat</u>

Land Type: Unless with special reinforcements, fiberglass pipelines should not be installed in Muskeg, permafrost areas as they are very susceptible to failures due to bending and ground movements. Abrupt soil changes can also generate stresses in the pipelines. Construction over extensive range of wetland or abrupt soil changes should be avoided. Pipelines crossing wetlands may be constructed, but according to special trenching, anchoring, backfill procedures and reinforcements based on industry guidelines.

Unstable Terrain or Soil: Special procedures should be followed, and should avoid extensive zones of unstable soils (e.g., landslides).

Earthquake and Blasting: Both are of high risk to existing fiberglass pipelines.

Water Buoyancy: where water table level is high and seasonal flooding is possible, water buoyancy may create uplift bending forces. As the line sizes in gathering system are relatively small, this threat may not likely be significant.

Frost-Heaving: Frost-heaving hazard occurs when the soil expands and contracts due to freezing and thawing, and this typically shows as uplift bending failure. The hazard can damage structures, even below the frost line. Moist, fine-grained or cohesive soils at certain temperature are most susceptible to frost heaving. Three conditions are necessary for frost heave to occur: freezing temperatures, a supply of water, and frost-susceptible soils (high content of fine grained particles). Manufacturers' installation manuals require that the line should always be buried below the freeze depth, as the line placed within freeze zone would potentially be exposed to frost heave. The hazard introduces flexion and shear stresses that reduce the performance of the fiberglass pipelines. The frost depth in many areas in Alberta has been estimated to range approximately from 2.57 to 2.79m deep. Some of the pipelines had been found to be between 1.22 to 2.43 m, which is well within the freeze zone, thus frost-heaving can be expected in extreme freezing conditions.

Thaw-Unstable Soil: if the ground near the pipe is frozen, and the operating temperature of the pipe is higher than the freezing temperature, the pipeline will thaw the frozen soil around it, and will settle as the thawed soil consolidates. Intermittent thaw-stable and unstable soils will cause differential settlement and cause pipe bending.

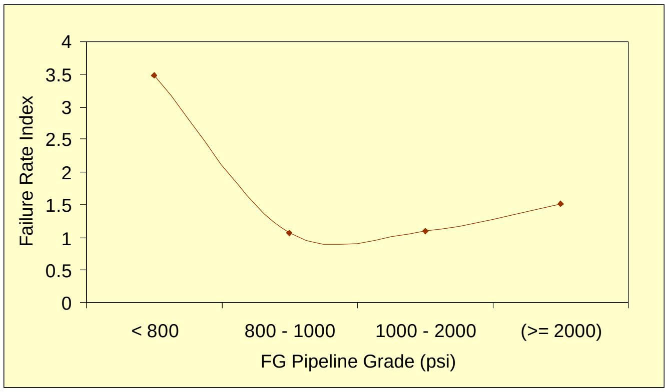

Figure 5 Husky FG Pipeline Failure Incidents vs. Pipe Grade

Resistances to such threats depend on the grade of the pipe (i.e., the maximum tensile stress and bending stress it can resist before significant plastic bending strain). Depth of cover contributes to resistance to failure, since burying deeper means frost and frozen soil may be less likely. Good backfill material and compaction are important, as they not only provide good bearing resistance to the pipe, but also drain the water easily and are less susceptible to frost-heave. Pipe grade is also a parameter as stronger pipes resist pipe-bends prior-to plastic failures better than lower grade pipes. Figure 5 shows the failure rates of Husky's fiberglass pipelines and its dependence on pipe grade.

<u>Operation and Equipment (OE) Threat</u>

This includes overpressure, over-temperature, startup/shutdown controls, ESD/PSV and isolation valve emergency shut-down or relief mechanisms, hot-oiling effect and equipment vibrations. Resistance to such threat includes pipe grade, size of pipe etc., similar to the previously discussed items. Additionally, the operating pressure, the distance downstream from high pressure points such as a pump or valves indicates the extent of liquid hammer it may be subjected to in the event of shut-down or start up.

Risk Assessment Result

The assessment results indicated that considering the integrity resistance properties in terms of design, construction, operating and maintenance of the existing pipelines, a mechanical type failure may most likely be a result of construction external interference (80%), then natural hazard (60%), line strike (20%), surface load (10%) or issues with operation and equipment (10%), see Figure 6.

The results suggested that a process needed to be implemented to ensure that external interference of the existing fiberglass pipelines be minimized. To minimize the interference of the existing fiberglass pipelines, for example, Husky has utilized Horizontal Directional Drilling (HDD) and direct boring techniques to cross under the existing fiberglass pipelines for pipeline crossings.

If direct interference of the existing fiberglass pipeline is inevitable, reliable bedding and backfilling procedure will ensure that risk of delay-failure due to ground movement is minimized.

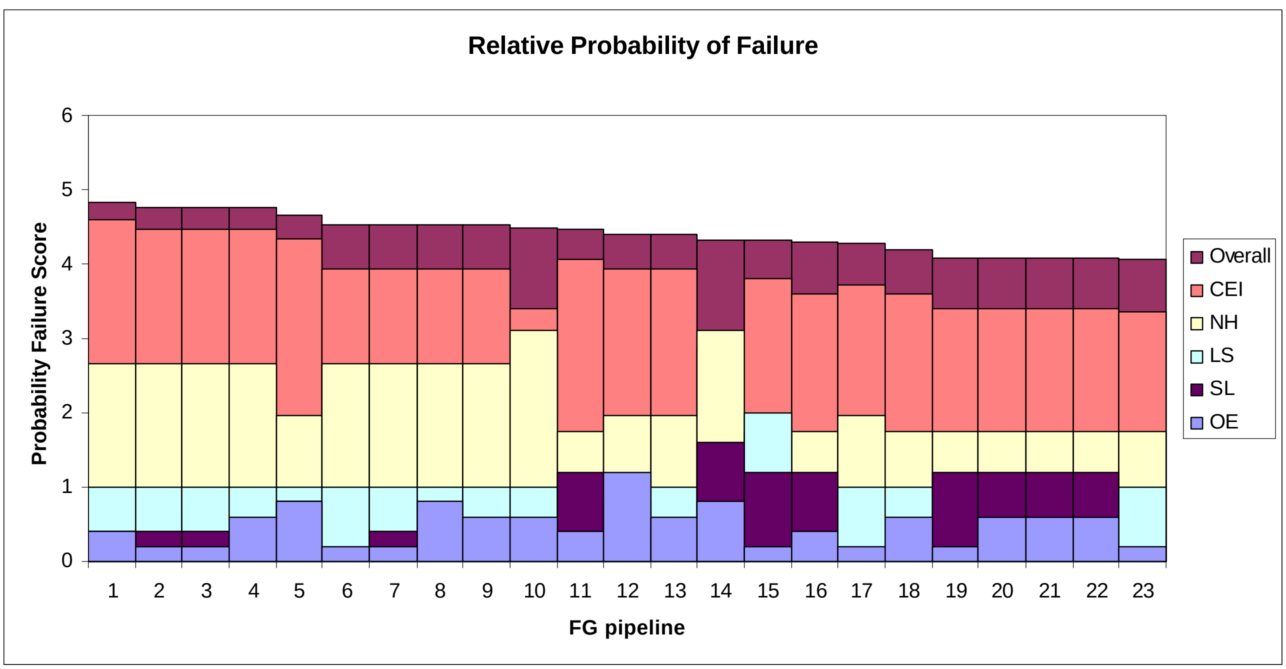

Figure 6 Likelihood of Failure Due to Different Threats for 23 Pipelines

RISK MITIGATION IMPLEMENTATIONS

Fiberglass distributors and manufacturers were consulted on the construction and workmanship requirements for material make-up, alignment and installations. In particular, critical issues with bedding and backfill for risers, at flange tie-in locations and at crossings were discussed.

Two technical procedures have since been developed:

- Checklist for fiberglass pipeline repairs or tie-ins; and
- Engineering backfill review procedure for FG pipeline backfill requirement.

Checklist for Fiberglass Tie-ins/ Repairs

The check-list was developed for Husky's field representatives or project leads to ensure the quality of the installations.

The condensed version of the check list includes the following steps:

- Application Review
  - § Confirm the grade and joint type of the existing pipeline
  - § Determine material make-up
  - § Determine cold-weather installation requirement
- Identify live pipelines, utility lines, and deadlegs
- Inspection of integrity of existing pipeline body and pipe ends
- Inspection of joining for material make-up, alignment and CP protection of steel components.
- Post-joining:
  - § Check if bonded joints are cured with chemical heat pak or electrical heat blanket.
  - § Check if the leak test and full hydrotest procedures are followed.

Engineering Backfill Procedure

When an existing fiberglass pipeline is required to be excavated, or exposed for any purposes, an Engineering Backfill Procedure is developed to ensure the fiberglass pipelines is not susceptible to repeat failures due to geotechnical issues. Husky has initiated a construction work request process that will automatically involve the lead civil engineer to develop a backfill procedure on case-by-case basis.

Husky implemented an engineering backfill process since late 2008. A number of backfills had been implemented with this process in one of Husky's most susceptible fiberglass pipeline failure areas. It has been positive in that none of the backfills fail due to initial settlements. In total 60% of failure reductions have been seen in the area in 2009 compared to 2008.

The procedures are developed based mainly on the AWWA M45 [1], ASTM D3839 [10] and the manufacturers' installation manuals, particularly, the chapters related to pipe burial.

<u>Geotechnical Issues with Fiberglass Pipeline Failures</u>

After reviewing recent and historic failure cases, it was possible to establish that most failures were related to poor pipe support, inappropriate embedment material, and lack of backfill soil confinement and in many cases installation within the frozen zone. A typical failure mechanism is illustrated in Figure 7, which shows a steel riser anchored on a rigid steel pile that provides a vertical movement restriction. When the fiberglass embedded on the frozen zone moves vertically due to freeze-thaw cycle or simply due to poor bedding compaction, a shear stress is generated on the fiberglass pipe, near the rigid bulky flange.

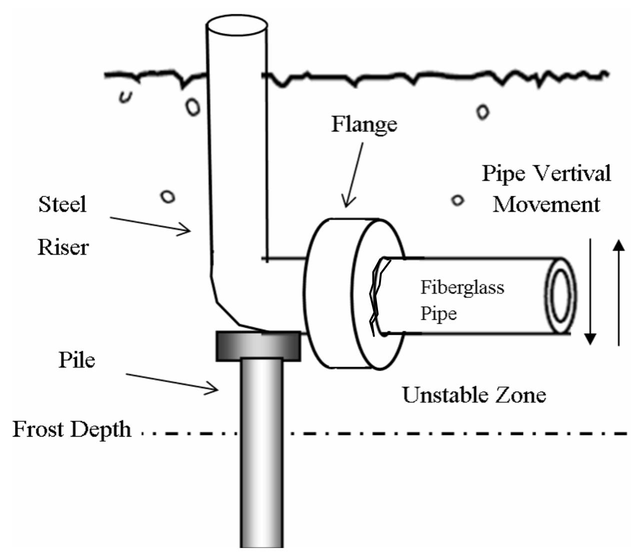

Figure 7: Typical Fiberglass Pipe Failure Close to a Riser

Similarly, shear failures may have been generated on fiberglass pipes close to tie-in steel spools that have been installed in similar conditions as described above.

Preventing these issues from impairing the long-term fiberglass integrity is feasible, starting with the evaluation of the native soil condition where the fiberglass pipelines were constructed.

Soil Classification and Uses

Most of Husky's fiberglass lines were installed on the Western Canadian Prairies, with a wide variety of soil deposits, including glacial clay till, lacustrine clays and glacial/alluvial sands among others. The soils are cataloged according to the AWWA Manual M45 [1], which organizes the soil in stiffness categories as shown in Table 1. This classification provides the equivalent classification according to the Unified Soil Classification System.

Once soil stiffness is defined according to Table 1 (after AWWA M45 Table 6-1), the recommendations for installation and use soils and aggregates for foundation and pipe zone embedment are obtained from Table 2 (after AWWA M45 Table 6-2).

Table 1: AWWA M45 Soil Stiffness Categories

(partially reprinted from M45: Fiberglass Pipe Design, by permission. Copyright ©2005, American Water Works Association)

Soil Stiffness Category	Unified Soil Classification System Soil Groups (note 1)
SC1	Crushed rock: ≤15% sand, maximum 25% passing the 3/8-in. sieve and maximum 5% passing No. 200 sieve (note 3)
SC2	Clean, coarse-grained soils: SW, SP, GW, GP, or any soil beginning with one of these symbols with 12% or less passing No. 200 sieve (note 4)
SC3	Coarse-grained soils with fines: GM, GC, SM, SC, or any soil beginning with one of these symbols with more than 12% fines
	Sandy or gravelly fine-grained soils: CL, ML (or CL-ML, CL/ML, ML/CL) with more than 30% retained on a No. 200 sieve
SC4	Fine-grained soils: CL, ML (or CL-ML, CL/ML, ML/CL) with 30% or less retained on a No. 200 sieve
SC5	Highly plastic and organic soils: MH, CH, OL, OH, PT

NOTES:
1. ASTM D2487, *Standard Classification of Soils for Engineering Purposes*

Foundation, Bedding and Embedment

The soil foundation and bedding material shall provide a firm, stable and uniform support for the pipe haunch and other joint or control elements. This will prevent generation of additional bending and shear stress on the pipe.

Medium to high and high plastic soils usually are associated with high moisture content representing highly compressible materials. These materials are not suitable for backfill, and are replaced by more competent soils with soil stiffness ranging from SC1 to SC3, depending on local availability.

After studying in-situ and commercially available granular materials in our operational areas, it was concluded that clean pea gravel (maximum particle size of 13 mm) was an optimum material for bedding purpose, as the material requires little or no compaction to achieve the specified minimum density of the backfill by as-dump placement.

The installation of joints and in particular bulky flanges requires the excavation of a bell-hole on the bedding material to allow for the pipe to rest on the haunches as shown in Figure 8.

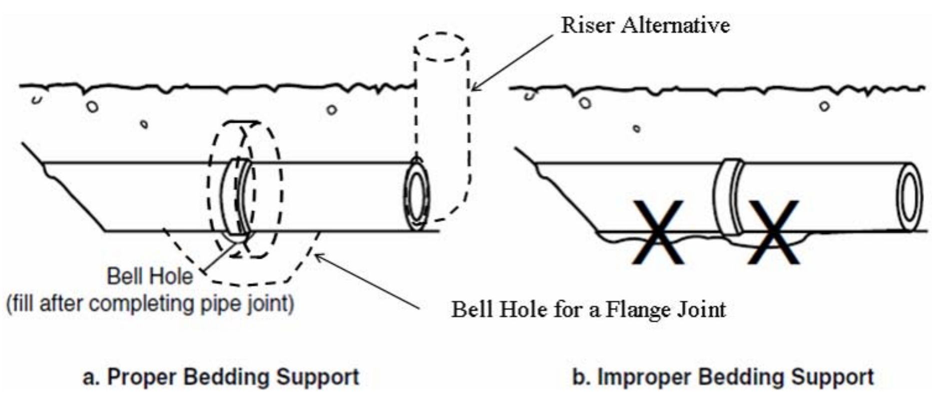

Figure 8: Bell Hole Sketch *(modified from Source: Flowtite Technology, Sandefjord, Norway)*

Table 2: AWWA M45 Recommendations for Installation and Use of Soils and Aggregates for Foundation and Pipe Zone Embedment *(partially reprinted from M45: Fiberglass Pipe Design, by permission. Copyright ©2005, American Water Works Association)*

Soil Stiffness Category*	SC1	SC2	SC3	SC4
Foundation	Suitable as foundation and for replacing overexcavated and unstable trench bottom	Suitable as foundation and for replacing overexcavated and unstable trench bottom	Suitable for replacing overexcavated trench bottom	Not suitable.
Pipe zone embedment	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Difficult to place and compact in the haunch zone.	Suitable as restricted above. Difficult to place and compact in the haunch zone.
Embedment compaction				
Minimum recommended density, SPD†	Minimum density typically achieved by dumped placement.	85%	90%	95%
Relative compactive effort required to achieve minimum density	Low	Moderate	High	Very high
Compaction methods	Vibration or impact	Vibration or impact	Impact	Impact
Required moisture control	None	None	Maintain near optimum to minimize compactive effort.	Maintain near optimum to minimize compactive effort.

* SC5 materials are unsuitable as embedment. They may be used as final backfill as permitted by the engineer.

† SPD is standard Proctor density as determined by ASTM Test Method D698 (AASHTO T-99).

Final Backfill

Native soil, mainly clays of low and medium plasticity were found suitable for final backfill. In few cases, materials of high plasticity or saturated due to ground or weather conditions were found, and were replaced by locally available medium plasticity clays, compacted according to the requirements of Table 2.

A training program was developed and launched to field personnel on good practices to install and repair fiberglass pipelines. Such training opportunity provides them knowledge why soil settlement can be an issue for fiberglass pipelines, and how the lines be confined and protected from soil settlements by following the backfill procedures.

An Example Backfill Procedure

An example backfill procedure is attached in Appendix A. The first page of a typical backfill procedure contains the pipeline identification, location information, description of the proposed work, soil conditions and the description of the pipe failure. In the case of a tie-in project mechanism of failure section is not applicable.

This procedure was issued for a complex backfill at a multiple pipeline-crossing, see Figure 9. It was noted that the vertical distance between pipes shown in Figure 9 is less than 300 mm on the pipe cross-over.

Figure 9: Pipe Configuration and Trench Bottom of an Example Backfill at Crossing

Proactive Measures

Other than minimizing construction interference over the existing fiberglass pipelines, Husky also is investigating the options to proactively reduce the risk for the high risk lines identified in the risk assessment.

These options have included the following:

1. Perform integrity digs and visual inspections near risers and potential tie-in locations to confirm soil settlement and stresses near the flanged joints. Prior to excavation, the civil engineer will be consulted if the line can be safely excavated and can be backfilled in time with reliable procedures.
2. Perform geotechnical studies on native soil, bedding and backfill materials, ground water issues and evaluate the soil stability and vulnerability to soil settlement and frost-heaving.
3. Perform periodic hydrostatic testing, if effective and reliable leakage locating methods can be used. Such option is still under investigation as concerns exist if frequent pressure testing will result in deteriorations in material strength and defect initiations.
4. Operational and Maintenance support activities below may help to reduce the risk of failure:
   a. Reduce operating pressure
   b. Reduce temperature and pressure cyclic loads
   c. Reduce frequency of hot-oiling.
   d. More frequent ROW inspection and maintenance.

CONCLUSION

In conclusion, Husky has implemented failure analysis, risk assessment and technical analysis to analyze the critical risk factors governing the frequent failures on fiberglass pipelines. It was found that the external interferences by the first or second party construction activities on existing fiberglass pipelines have posed the most threats contributing to delayed-mode failures. A process was established to mitigate such risk by incorporating an engineering review of case-by-case backfilling procedures and by implementing a checklist for tie-in and repairs. Husky has since seen improvements of preventing fiberglass pipeline failures.

ACKNOWLEDGEMENT

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REFERENCES

[1] AWWA Manual M45- Fiberglass Pipe Design, 2nd edition, American Water Works Association, 2005

[2] Best Management Practice: Use of Reinforced Composite Pipe (Non-Metallic Pipelines), Canadian Association of Petroleum Products, Nov 2009

[3] Fiberglass Reinforced Piping for Shipboard Systems, Uberti, G. A. and Evans, K. National Steel and Shipbuilding Company, 1976

[4] Design and Performance Properties of Oilfield Fiberglass Tubulars, SPE 19728, Huntoon, G. G., Society of Petroleum Engineers, 1989

[5] ASTM D2996-01(2007): Standard Specification for Filament-Wound “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe (Applicable to epoxy, polyester, and furan resins in sizes from 1 in. to 16 in. [25 mm to 400 mm].)

[6] Specification for High Pressure Fiberglass Line Pipe, API Specification 15HR, 3rd Edition, August 2001

[7] Specification for Low Pressure Fiberglass Line Pipe and Fittings, API Specification 15LR, 3rd Edition, August 2001

[8] ANSI/AWWA C950 -Standard for Fiberglass Pressure Pipe, 2nd edition, American Water Works Association , 2007

[9] Guideline for the Design of Buried Steel Pipe, American Lifelines Alliance, July 2001

[10] ASTM D3839-08 Standard Guide for Underground Installation of “Fiberglass” Pipe, ASTM International, 2008

APPENDIX A –AN EXAMPLE BACKFILL PROCEDURE

1.0 Ensure the stability of the excavation by following Husky Safe Work Practice for Excavation and Trenches # PRC-PRO-014. Conduct monitoring for cracks during backfill procedure to prevent falling material into the excavation.

2.0 Control groundwater ponds and seepage through the use of sumps and pumps (if required). Excavate sumps outside the pipe support zone (it is recommended to start pumping operation days in advance to the backfill operation).

3.0 Re-establish the trench bottom through the removal of any rocks, soft soil and mud from the trench bottom, under all exposed pipes. Provide adequate pipe support by exposing native, undisturbed soils. Additional excavation of bedding under the pipes is required as shown in Sketch 1.

4.0 The slopes along the bedding trench shall be excavated 3H: 1V, to provide a gradual transition from (*) pea gravel bedding to existing bedding, see Sketch 2. This transition also applies for the two perpendicular pipes to be tied in later.

5.0 Carefully place and "manually" compact (*) pea gravel for pipe bedding upon native, undisturbed soils. The pea gravel shall be free of any organic and other deleterious materials, contamination, debris and stones greater than 13 mm in diameter. Pea gravel should not be placed in a frozen state. Bedding must be as uniform and continuous as possible (I)

6.0 Carefully place and compact pea gravel on either side of the pipes and above the pipe (II). Ensure that pea gravel is placed under the haunches and flanges or joints, by carefully sliding the shovel 30 mm under the exposed length of pipe, see Sketch 3.

7.0 Place and compact 300 mm lifts of clean native backfill, free of any organic and other deleterious materials, contamination, debris and stones greater than 75mm in diameter, above the pea gravel and up to final grade. The backfill should not be placed in a frozen state (III). Minimum temporary pipe cover is 600 mm, if required.

8.0 Refer to Sketch 4 Typical Trench Cross-section below for lift thicknesses and compaction requirements.

(I), (II), (III), See Sketch 4 for backfill procedure details.

Pipeline Protection

A. Fiberglass pipes shall be protected with Rockshield Tape. Protection shall be wrapped tightly

(*) Pea Gravel shall be clean, well graded and with maximum particle size of 13 mm (1/2 inch)

NOTE: Vertical distance between crossing pipes shall be at least 300 mm from edge to edge (AWWA M45 and ASTM D 3839 – 08).

BACKFILL REVIEW PROCEDURE

AFE, EWR, Work Order #:		**Date:**	

Project Name		**Installation Date**	
Wellsite/Facility Location		**LSD/UWI**	

Pipeline Installation Contractor			
Company Name			
Contact Name		**Contact Number**	
Signature		**Signature Date**	

Construction Superintendent			
Name		**Contact Number**	
Signature		**Signature Date**	

The following information to be filled in by Construction Superintendent:

Site Description – Include detailed description of conditions and surrounding area

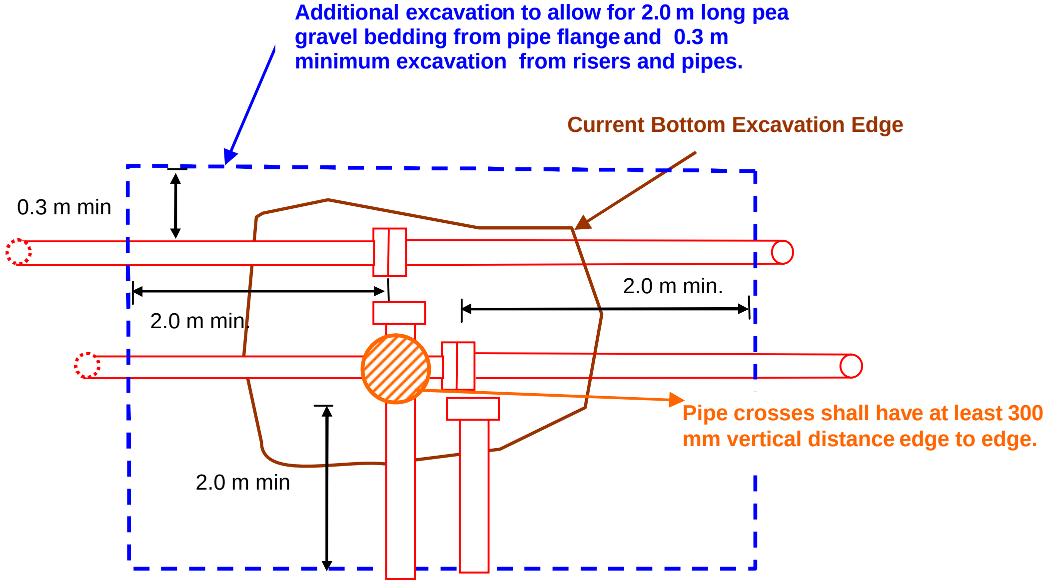
Information Required

Season	☒ Winter	☐ Spring		☐ Summer	☐ Fall	
Pipeline Material	☐ Carbon Steel	☒ Fiberglass		☐ HDPE	☐ Flex-pipe	
Pipeline Material – if not listed above:						
Free Standing Water in Trench		☐ Yes	☐☐ No	Mud In Trench	☐ Yes	☒ No
Length of Open Trench				meter		
Ambient Temperature				°C		

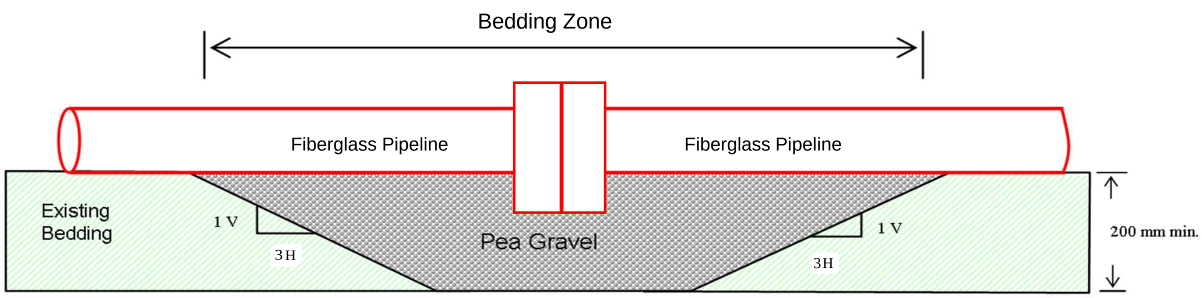
Failure Mechanisms – Select all that apply

Failure Due To:	☐ Settlement	☐ Installation	☐ Backfill Material	☐ Drainage
Other – Describe				

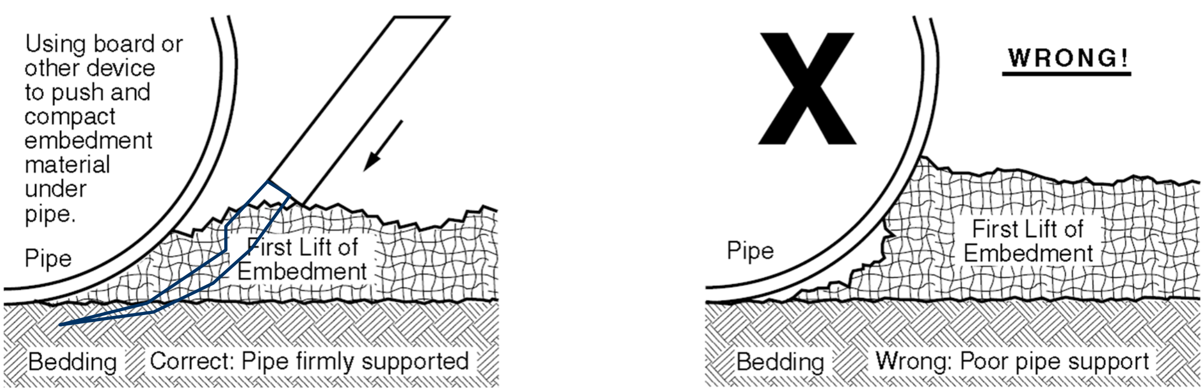
Figure A.1 First Page of Backfill Review Procedure of Fiberglass Pipelines



Sketch 1: Pipeline Configuration and Bottom Trench Plan View (not to scale).

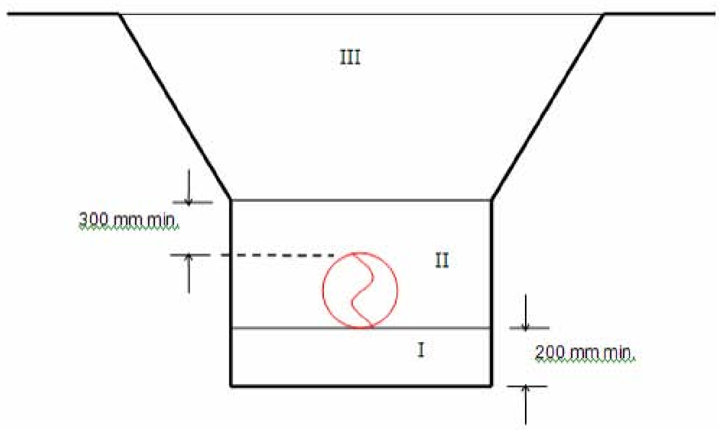


Sketch 2: Bedding Transition along the Pipe



a. Ensuring Firm Pipe Support **b. Improper Haunch**

Sketch 3: Proper Compaction under Haunches
(modified from Source: Flowtite Technology, Sandefjord, Norway)

<table>
<tr><th colspan="2">Typical Trench Cross-Section (photos shall be taken before and after each backfill step)</th></tr>
<tr><td rowspan="3">

Sketch 4: Typical Trench Cross-Section</td><td>I. Place pea gravel for pipe bedding and compact manually. Maximum lift thickness of 200mm (no vibrating equipment).</td></tr>
<tr><td>II. Place pea gravel within the pipe zone on either side and above the pipe in maximum 200mm thick lifts. Manually compact each lift of pea gravel adjacent to the pipe (no vibrating equipment). Ensure a minimum thickness of 300mm of pea gravel over the pipe. Once the 300 mm layer over the pipe is placed, compact with vibrating equipment to 95% of SPMDD.</td></tr>
<tr><td>III. Place and compact 300mm lifts of native clay backfill or imported clay to 95% of SPMDD. Imported clay 50% passing No. 200 Sieve.</td></tr>
</table>