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UNUSUAL FAILURE OF SPOOLABLE COMPOSITE LINE PIPE INSTALLED IN WINTER

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ABSTRACT

A failure occurred on a spoolable composite line pipe (SCP) riser after two years in service. The riser was installed under the manufacturer's supervision. The operating conditions were within specified limits. The riser failed due to external wear of selected areas on the buried (2 meter depth) horizontal section. The area was low traffic and vibrations due to pumping or fluid flow were negligible.

Investigation details such as the effects of construction practices, thermal factors, material properties and the field solution are reviewed.

Keywords: SCP pipe, thermal expansion, buckling, surface wear, winter time installation.

INTRODUCTION

The 3.5 inch nominal, 1,500 psi series SCP line pipe with a high density polyethylene (HDPE) pressure barrier failed after two years in service. Figure 1 shows the dig site at the location of the failure. Operating conditions were:

- Type of media: sour produced water. The water contained about 97,000 ppm of NaCl.
- Daily injection rate: 500 m^3/day of water. Water velocity: 1.4 m/s.
- Operating temperature: 18°C. Temperature at time of installation: -12°C.
- Design pressure: 9,930 kPa. Operating pressure: 7,584 kPa.
- Upset conditions prior to the failure: none.
- Pigging: none. Chemical programs: none.
- Soil conditions: sand and clay.

VISUAL EXAMINATION

Visual examination revealed that the failed SCP contained a glass fiber reinforced epoxy laminate (fiberglass) as the external layer. The top part of the failed fiberglass pipe was mechanically damaged (see Figures 2 through 4). The amount of mechanical damage on the top external surface increased closer to the failure. A good and shiny surface away from the failure transformed to the areas of discoloration due to wear, broken glass fibers, delamination, and areas missing two or three layers of winding. Visibly, in the locations of delamination, the fiberglass pipe was “dry” and contained an insufficient amount of epoxy between layers.

The external surface of the fiberglass pipe did not contain indications of bruising or an application of a localized compressive load, which would indicate improper handling or damage during backfilling.

The failure initiated from the top part of the external surface along the winding direction of glass fiber, which is typical. The fiberglass pipe adjacent to the failure was affected by erosion, which was the post-failure phenomenon caused by fluids flowing out of the pipe. The erosion removed the original evidence of the mechanical failure.

The internal surface of the HDPE was smooth and shiny, in a like-new condition. There were no indications of chemical attack or mechanical deterioration of the HDPE liner. There were no indications of damage to the liner due to high fluid velocity. The failed SCP pipe was bent in a vertical plane, as shown in Figure 5.

TESTING RESULTS

Differential scanning calorimetry (DSC) analysis (per by ASTM E794 “Melting and Crystallization Temperature by Thermal Analysis”) showed that the glass transition temperature of the SCP pipe thermoset resin (119 to 124°C) corresponded to the manufacturer’s specifications (115°C minimum).

Testing by ASTM D2584-02 “Standard Test Method for Ignition Loss of Cured Reinforced Resins” of a sample from the undamaged location showed that the fiberglass pipe consisted of approximately 84.7% glass fiber and 15.3% epoxy resin by weight. This also corresponded to the manufacturer’s specifications (15-20% epoxy by weight.

DISCUSSION

The SCP pipe was installed in winter. Failure due to external damage during winter time installation and/or backfilling was discarded because the pipe was backfilled with sand, and the external surface of the SCP pipe exhibited no evidence of bruising.

Failure due to excessive bending and/or a combination of bending stress with internal pressure at the bent section was discarded; the calculated combined stress was too low to result in the failure.

Failure due to high bending stress at the end of the riser was discarded, as the bending radius was within the manufacturer’s specifications, and the failure took place 0.66 m away from the end of the riser chute.

Failure due to high tensile stress during the final tie-in was discarded, as the riser chute with the FRP pipe was installed as one unit.

Failure due to thermal stress was discarded, as the thermal stress in combination with internal pressure was below the allowed SCP pipe stress.

Failure due to ground movement was discarded, as the failed pipe was installed on flat terrain.

Failure due to incompatibility of HDPE liner with corrosive media was discarded, as the internal HDPE liner was in good, like-new condition.

Failure due to fluid flow conditions was discarded, as average water velocity was 1.4 m/s. This could result in lateral force in the S-shaped SCP of 15 N, which is negligible.

The material properties of the fiberglass pipe could have contributed to the failure by accelerating the wear failure. The mode of failure was consistent with insufficient bonding between adjacent glass fiber layers.

Failure due to external damage due to vibration was discarded, as the closest source of vibration was a centrifugal water pump 2.5 km upstream. There were no conditions for mechanical resonance.

Failure due to pipe-soil interaction combined with buckling due to thermal expansion was considered to be the root cause for the failure. The failure scenario likely was as follows.

- The pipe was installed in winter, and the operating temperature was 18°C.
- Thus, the temperature difference between the installation and operating temperatures could be 30°C or more. This temperature difference was a driving force for thermal expansion.
- Thermal expansion of 4.4 m long fiberglass pipe due to a temperature difference of 30°C will result in the increase in length of 3 mm.
- This increase in length created internal stress in the pipe, which exceeded the critical buckling load.
- The pipe changed its shape by buckling. which resulted in movement of pipe surface up to 7 cm in the ground. Figure 6 shows four theoretical buckling modes.
- The movement of the fiberglass pipe -in the ground resulted in fiberglass surface wear.
- Cycling temperature in service from 18°C during operation to close to 0°C during shut-downs could also result in periodical movement of the buried SCP pipe.
- Weak bonding between the adjacent layers of the fiberglass pipe did not allow uniform wear and resulted in entire layers flaking off the external surface at one time. This accelerated the failure.
- As a result of the failure, water started flowing from the inside of the pipe, resulting in erosion of the external surface of the fiberglass pipe adjacent to the failure.

The location of the failure initiation in the fiberglass pipe was not available for examination, as it was removed by erosion. It is believed, that there was no manufacturing defect in the location of the failure initiation, and the maximum amount of wear was associated with the maximum deflection of this area and/or specific soil condition.

Figure 1 shows that the flange connection between the steel pipe and the SCP pipe was secured by a flag anchor (Anchor 1 in Figure 1). The flag anchor prevents vertical movement, but does not prevent longitudinal movement. Thus, thermal expansion of the steel pipe would result in additional compression of the SCP pipe, and contribute to the failure.

CONCLUSIONS

Thermal expansion followed by deflections due to buckling resulted in SCP pipe movement relative to the ground, which in turn caused the failure due to surface wear.

The following factors contributed to the failure:

- The SCP pipe was installed in winter, and the temperature difference between the installation and operating temperatures was 30°C. This temperature difference was a driving force for thermal expansion.
- The SCP pipe section was fixed between the riser chute and the steel pipe, so thermal expansion resulted in buckling and deflection of the SCP pipe.
- The flange connection between the SCP pipe and the steel pipe was secured by a flag anchor, which did not prevent lateral movement. Thermal expansion of the steel pipe absorbed by SCP pipe would also contribute to the failure.

This mode of failure is not expected for similar pipe with small temperature differences between the installation and the operating temperatures.

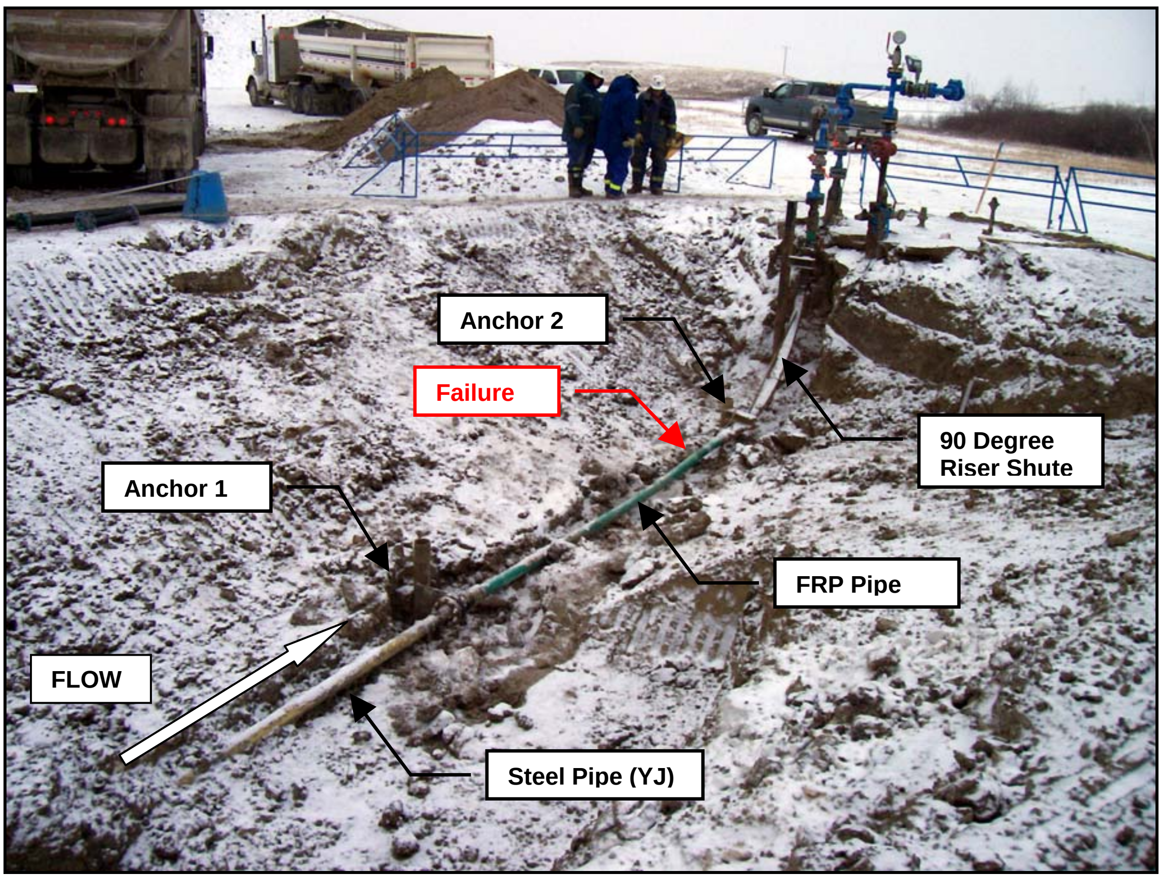

FIGURE 1 – Failure Site

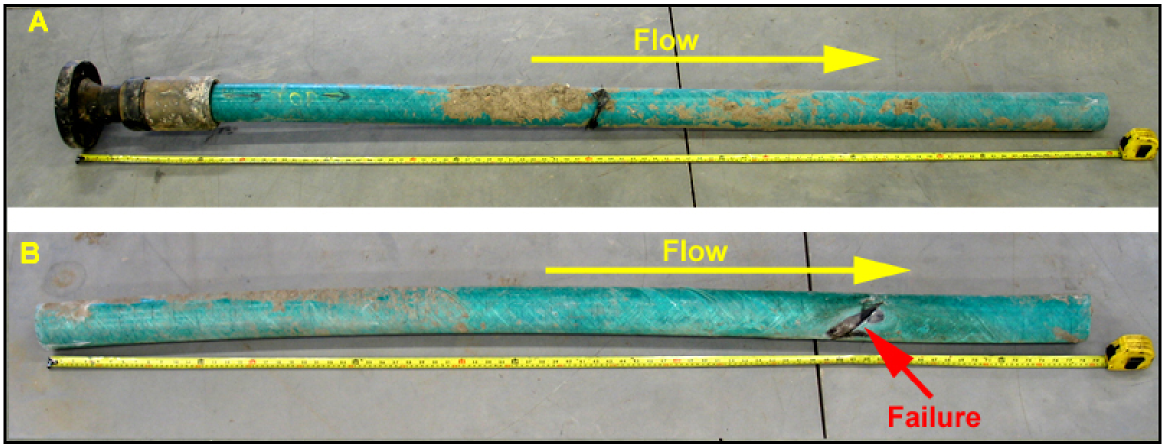

FIGURE 2 – SCP Pipe Sections "As Received"

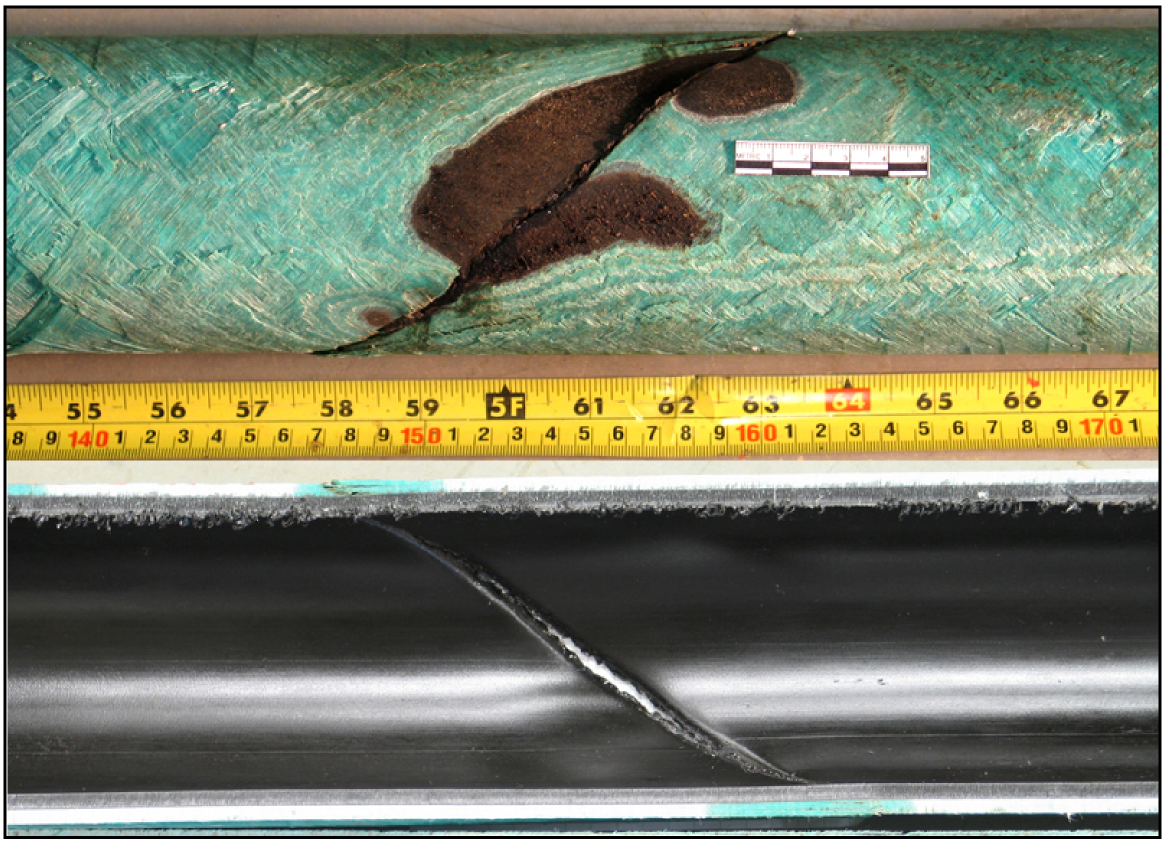

FIGURE 3 – Top Half External and Internal Surfaces: Area Of Failure

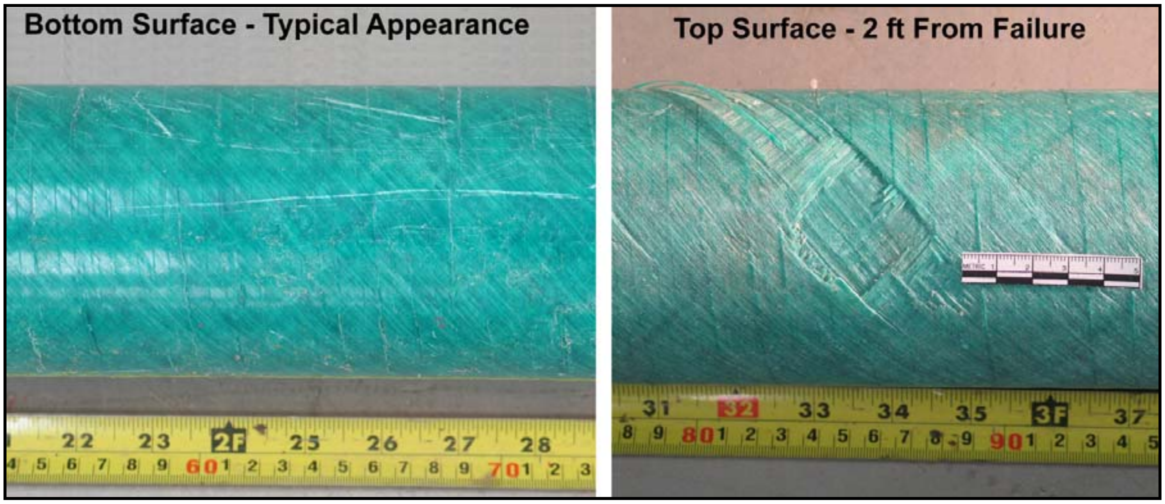

FIGURE 4 – Comparison of Top And Bottom Surfaces

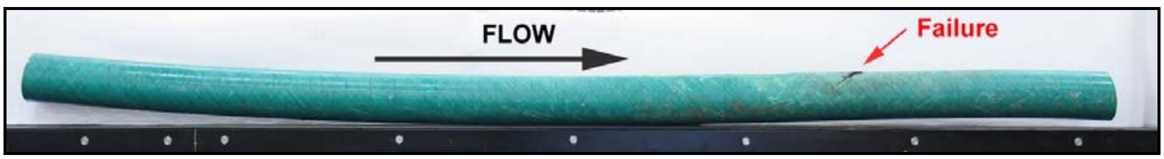

FIGURE 5 – Failed Section of SCP Pipe S-Shaped In Vertical Direction

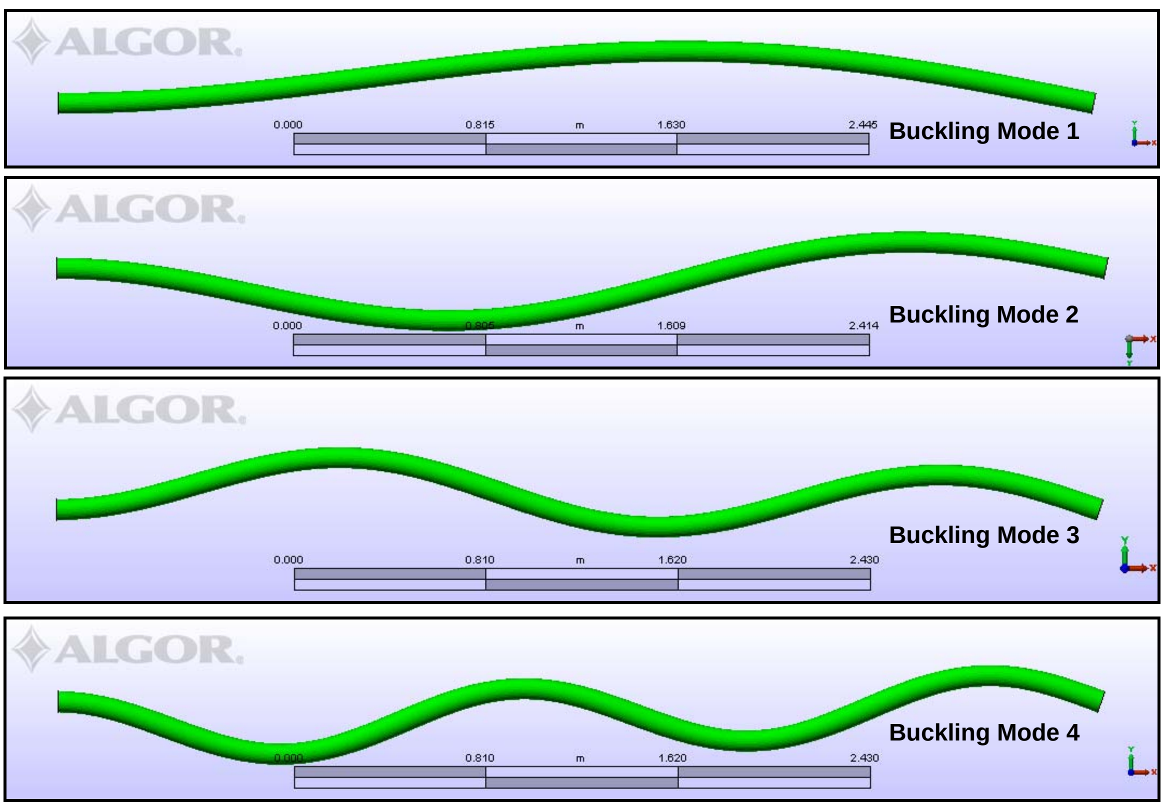

FIGURE 6 – Buckling Of SCP Pipe With Left End Fixed And Right End Pinned