Assessment of Seam integrity of an aging petroleum pipeline constructed with Low Frequency ERW line pipes.

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INTRODUCTION
A 669 km long, 12.75” diameter cross-country petroleum products pipeline is in operation since September 1966. This cross country pipeline consisted of 4 segments. Later a 69 km branch line was laid, hooked up to the 4th segment and commissioned in 2002. The said pipeline transports petroleum products such as petrol, kerosene and diesel from a refinery to various demand centers in North India.

The pipeline was constructed by an international EPC contractor in the year 1963-64 in accordance with the then prevailing requirements of ANSI B 31.41 and other applicable API2 codes. The Mainline pipes conforming to API 5L X46 were procured from Japanese and Indian pipe mills. The pipes were manufactured through the then prevailing low frequency electric resistance welding (LF-ERW) process.

The pipeline was designed for a Maximum Allowable Operating Pressure (MAOP) of 82.45 kg/cm², corresponding to 65% of the Specified Minimum Yield Stress (SMYS). The pipeline was subjected to a pre-commissioning hydrostatic test at 114 kg/Cm² corresponding to 90% SMYS.

BACKGROUND
The 197km long, 4th segment of the said pipeline has experienced few cases of in-service seam failures starting with 1980. Due to the recurrence of the failures in this particular segment and potential hazards such failure posed, it became imperative to take urgent steps to check such in-service failures to ensure safe operation. As part of the Pipeline Integrity Management programme, seam integrity assessments using hydrostatic testing were embarked upon.

1st Hydrostatic Test: To eliminate structurally significant defects of the pipe seam and to ensure safe operation, the first post commissioning hydrostatic test was conducted in the year 1983 during which one seam failure and two leaks were encountered and repaired.

1 ANSI B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
2 API - American Petroleum Institute
2nd Hydrostatic test: The said segment of the pipeline experienced next in-service seam failure in December 1997. Subsequent to repair, the Maximum Operating Pressure (MOP) of the pipeline was reduced to ensure safe operation.

The 2nd post commissioning Hydrostatic test, up to a pressure of 87.5kg/cm², was successfully conducted in May 1998, during which 7 seam failures were encountered and repaired by pipe replacement. Subsequently, the MOP of the pipeline segment was enhanced to 70 kg/cm². Since the 1998 hydrostatic test, the pipeline segment has been in-service and no incidence of seam failure was encountered.

In 2009, it was felt that a re-assessment of the seam integrity of the pipeline segment was necessary for reassurance of safe operation. Hydrostatic testing was again chosen as the preferred method for this planned seam integrity assessment based on its advantages and successful past experience. The 3rd post commissioning Hydrostatic test was scheduled for May 2010.

LOW FREQUENCY ERW PIPES – SUSCEPTIBILITY TO SEAM FAILURES

LF-ERW line pipes began to be produced & used as line pipes for cross country hydrocarbon pipelines since the 1920s. The LF-ERW process required plates or strips of low-carbon steels to be cold formed into circular sections and the longitudinal edges to be joined by applying localized electrical resistance heating using low frequency alternating current (< 360 cycles) and mechanical pressure. The edges of the plates or strips softened by application of heat were then fused by application of mechanical pressure. LF-ERW pipes are generally characterized by a narrow bond line and an associated local heat affected zone (HAZ).

Problems associated with the LF-ERW process are known and have been well documented. Low HAZ toughness, hook cracks, and grooving corrosion are some problems that have globally been reported to have occurred in conjunction with LF-ERW seams resulting in failures. Presence of such anomalies and factors significantly increases the risk of seam failures in LF-ERW pipes.

Seam failures due to pressure cycle induced fatigue and grooving corrosion of the seam area would necessitate a seam integrity assessment. The factors that affect growth of seam defects by pressure cycle induced fatigue are pressure cycles, presence of family of initial flaws, environmental factors and the toughness of the pipe.

Manufacturers slowly shifted from the old LF-ERW to the modern high-frequency induction (HFI also called HFERW) seam welding process. In modern ERW pipes, the bond line and HAZ gets subjected to a post-weld heat treatment, to eliminate any zones with excessive hardness unlike the earlier ERW process.

Seam integrity is therefore, a concern for those pipeline operators operating aging pipelines constructed with such LF-ERW pipes. Pipelines using LF-ERW pipes have been constructed till around the mid to late 80’s in India.

A decision tree, for determination of susceptibility of pipe seam of a particular pipeline to failure, was brought out by Kiefner in 2002. This process was further revised and included in the TTO Number 5 report. This decision tree is an excellent tool for pipeline operators to assess the susceptibility of their pipelines to seam failures and to plan for seam integrity assessments.

If a seam related in-service or hydrostatic test failure has occurred in a segment, the segment is considered susceptible, and if time-dependent growth is seen to be a factor in the occurrence of the failure, re-assessment becomes necessary.

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4 TTO Number 5 “Low Frequency ERW and Lap Welded Longitudinal Seam Evaluation” submitted to the Office of Pipeline Safety under Department of Transportation, USA in April 2004.
METHODS TO ASSESS SEAM INTEGRITY OF LF-ERW PIPES

Hydrostatic testing is one of the most accepted and widely used methods to assess seam integrity of LF-ERW pipes. Hydrostatic testing is usually conducted at a minimum of 125% of the required MOP of the pipeline and as per guidelines in API, RP 1110.

Over the last decade, In Line Inspection (ILI) slowly emerged as a more preferable alternative to hydrostatic testing for assessment of seam integrity of LF-ERW pipes due to various perceived advantages. Different technologies like Axial & Transverse Magnetic Flux Leakage (MFL), Ultrasonic (UT), and Electro-Magnetic Acoustic Transducers (EMAT) are being employed for ILI, each with its inherent advantages and disadvantages.

There remains a dearth of adequate published research or industry guidelines for ILI specifically aimed at seam integrity of LF-ERW pipes. It still remains difficult to assess and verify claims of ILI vendors with respect to the capability of various technologies and tools to identify and characterize all defects which affect seam integrity. Therefore, pipeline operators may have to employ more than one type of tool, to assess seam integrity, significantly raising costs.

The devastating accident at Carmichael, Mississippi, USA on 1st November, 2007 due to failure of a LF-ERW pipeline transporting liquid propane operated by the Dixie Pipeline Company has significantly eroded confidence in ILI for assessment of seam integrity of LF-ERW pipes. The Pipeline Accident Report prepared & submitted by the National Transportation Safety Board (NTSB) USA in October 2009 states that ‘accumulated data from the three in-line inspections of the Carmichael pipeline and from the examination of the pipe joints that were removed and subjected to hydrostatic testing illustrate the limitations of current in-line inspection technology for detecting significant flaws in low-frequency ERW pipe’.

3rd SEAM INTEGRITY ASSESSMENT (2010)

Based on experience of the failure history, outcome of earlier hydrostatic tests and limitation of available ILI technology for complete detection of seam defects, it was decided to conduct the 3rd seam integrity assessment of the subject pipeline segment through a combination of ILI by an Axial MFL tool to detect and repair corrosion defects followed by a hydrostatic test to eliminate any structurally significant seam defects that may have grown/deteriorated since the 1998 hydrostatic test.

It is accepted that higher the hydrostatic test pressure (above MOP), the smaller will be the possible surviving flaws. Even if surviving flaws grow in severity over time on account of operating pressure cycles, a higher test pressure would mean that it takes a longer time for these smaller flaws to grow to a size that will fail at the MOP.

Throughput targets in this pipeline segment, considering the demands at the two connected terminals, require operating the pipeline segment at a maximum operating pressure of 70 kg/cm². Accordingly, the target pressure for this hydrostatic test would be 87.5 kg/cm². However, the option for testing the line at a higher hydrostatic test pressure up to 90 kg/cm² was also envisaged depending on actual failure trend that would be encountered and availability of time.

IN LINE INSPECTION

ILI using an Axial MFL tool was conducted in December 2009. Structurally significant corrosion defects were identified and repaired prior to the hydrostatic test.

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5 ANSI/API RP 1110, Pressure Testing of Steel Pipelines for the Transportation of Gas, Petroleum Gas, Hazardous Liquids, Highly Volatile Liquids or Carbon Dioxide.
MODALITIES, PLANNING & PREPARATION

The hydrostatic testing was planned to be conducted in three stages – a) 50 kg/cm² for 4 hours, b) 75 kg/cm² for 4 hours and c) 90 kg/cm² (if attainable) or else 87.5 kg/cm² for 4 hours. The pipeline segment was planned to be taken out of service for the hydrostatic test for 25 days. All other segments of the pipeline system were to remain operational during the duration of hydrostatic testing.

Detailed plans were made for all preparatory activities, resource mobilization and logistics such as piping modification, water arrangement, pressurization equipment, personnel, selection of field camps for patrol and repair crew, lining-up of repair agencies, patrolling, communication, safety & security, liaison with outside agencies etc. and also the operation of other segments of Pipeline. A central control station and two mini control stations at strategic locations along the route were set up and manned to facilitate quick mobilization of men & material for any required repairs. Mock drills for line patrolling were conducted beforehand to check the efficacy of the system. Government agencies including District Administration & Police, local bodies, and villagers were also duly informed regarding the planned hydrostatic test.

EXECUTION

Water filling for hydrostatic testing commenced on 30th April 2010 and went on till 4th May 2010. During water filling two squeeze pigs each were launched in front & rear ends of water batch to avoid mixing of product and water. After completion of water filling and allowing requisite time for line stabilization, stage wise pressurization commenced. The details of the line failures that occurred at different stages of pressurization are given at Table 1. No failure was encountered during the first and second stages of the hydrostatic testing of this section.

During the 3rd stage pressurization, a total of 5 seam failures occurred. Each of the five failures could be located by line patrol teams in less than 2 hours of the pressure drops. The complete pipe replacement operation including excavation, cutting and removal of failed pipe, welding of pre-tested pipe, NDT etc. could be completed within 30-36 hours at most locations despite the adverse weather conditions due to meticulous planning.

Out of the 5 seam failures, last 3 failures were encountered in close pressure intervals i.e. at 88.5 kg/cm², 88 kg/cm², 89.6 kg/cm². After the 5th failure at 89.6 kg/cm², it was decided to conclude the hydrostatic test with a hold period of 4 hrs at 87.5 kg/cm² to meet the MOP requirement of the pipeline segment. The hydrostatic test was thus successfully concluded on 19th May 2010.

OBSERVATIONS & SUMMARY

All failures during the hydrostatic test were failures of the pipe seam. Physical inspection and UT thickness survey of pipe did not reveal any metal loss in the vicinity of the seam.

Growth of seam defects due to pressure-cycle-induced fatigue are governed by four factors namely pressure cycles, presence of a family of initial flaws, environmental effects and the toughness of the pipe.

The first two hydrostatic test failure pressures i.e. 78 kg/cm² and 81.5 kg/cm² encountered during the 2010 hydrostatic test are lower than the 1998 hydrostatic test pressure of 87.5 kg/cm² (though above the prevalent MOP) indicating the deterioration of seam integrity with passage of time i.e. 12 years since the last hydrostatic test. These could be attributed to growth of seam defects due to pressure cycle induced fatigue, since no grooving corrosion was evident at the seams of the failed pipes.

Successful completion of seam integrity assessment of the LF-ERW pipeline segment described above and analysis of the failure pressure plot given at figure 1 of all failures since 1983 corroborates the re-assessment interval and imparts confidence that the pipeline segment can continue to be safely operated at the prevailing MOP of 70 kg/cm² for at least another 12 years.
CONCLUSION

Many structurally significant imperfections of pipe such as loss of ductility and other metallurgical/ micro-structural defects are difficult to identify by NDT methods like ILI, Radiography, UT Thickness survey etc.

Pipeline operators concerned about the susceptibility of the seams of their LF-ERW pipes having a history of in-service failure could consider planned periodic Hydrostatic tests as a suitable means to re-assess seam integrity. The above described instance of successful completion of seam integrity re-assessment of the 197 km long LF-ERW pipeline segment through a hydrostatic test imparts confidence that, with proper planning and execution, hydrostatic testing is indeed a viable and effective method for seam integrity assessment of LF-ERW pipes. Intervals between assessments may be determined by the pipeline operator based on past experience, failure history and evaluation of any other known or identified risks.
Table 1. Failures during the 3rd Hydrostatic Test

<table>
<thead>
<tr>
<th>STAGE</th>
<th>FAILURE ORDER</th>
<th>CHAINAGE</th>
<th>FAILURE PRESSURE kg/cm²</th>
</tr>
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<tbody>
<tr>
<td>1st STAGE (50 kg/cm²)</td>
<td>1ˢᵗ</td>
<td>559.05 KM</td>
<td>78.0</td>
</tr>
<tr>
<td>2nd STAGE (75 kg/cm²)</td>
<td>2ⁿᵈ</td>
<td>555.56 KM</td>
<td>81.5</td>
</tr>
<tr>
<td>3rd STAGE (90 / 87.5 kg/cm²)</td>
<td>3ʳᵈ</td>
<td>580.40 KM</td>
<td>88.6</td>
</tr>
<tr>
<td></td>
<td>4ᵗʰ</td>
<td>580.50 KM</td>
<td>88.0</td>
</tr>
<tr>
<td></td>
<td>5ᵗʰ</td>
<td>605.50 KM</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Figure 1. Failure Pressure Plot of all failures since 1983 Hydrostatic Test
Photographs 1, 2 & 3: View of few seam failures that occurred during the 2010 hydrostatic test

Photograph 1.

Photograph 2.

Photograph 3.
REFERENCES

1. Sinha, J.P., Varghese, Cherian P. “Seam integrity assessments in an aging petroleum pipeline constructed with Low frequency welded ERW pipes” NACE CORCON - 2010, Goa India

2. ANSI B31.4 ‘Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids’


