Practical Aspects for the Development of Rehabilitation Strategies for Ageing Onshore Pipelines: A Case Study

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Pipeline Technology Conference 2011
4th & 5th April, 2011
Hannover Messe, Germany
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1.0 Abstract:

The practical aspects involved in the decision making process for selecting and implementing a repair strategy for the rehabilitation of an aging onshore pipeline are discussed. As part of the selection of the appropriate technology an overview of the different repair methods for in-service pipelines is introduced.

Different factors such as type of defect, operating conditions, field implementation, costs, etc for the different techniques are reviewed for the selection of the appropriate technique in relation to the severity of the defects found in conjunction with the operational requirements of the line in question at any one point in time. Methods used include Direct Deposition Welding to Live Lines, Bolted Clamps, Epoxy Resin Sleeve, Welded Sleeve, and composite repair materials. For the different repair technologies the associated surface preparation and final coating/wrapping is also discussed.

The approach discussed in the paper for the development of the rehabilitation strategy is applied to a number of the UK Ministry of Defence pipelines. These lines were originally manufactured for the British War effort in the 1940’s and were generally relayed with welded joints and coal tar enamel wrapping by the 1970’s. For some of these lines the original coating methods and the passage of time have allowed the ingress of water at the interface of flood coating and the Hot/Cold applied tapes used.

The key elements discussed in the paper are then applied to a case study to evaluate the immediate and future integrity condition of the line and for developing a strategy to rehabilitate the pipeline ensuring the future safe and reliable operation in relation to the MAOP.

2.0 Government Pipeline and Storage System (GPSS):

The UK Government Pipeline and Storage System (GPSS) is mandated to supply bulk distribution of refined petroleum products for the military. The Oil and Pipelines Agency (OPA) manages the GPSS on behalf of the Secretary of State. The operation and maintenance of the constituent GPSS facilities is contracted out to commercial operators. These contracts are managed by OPA.

OPA manages 2500km of pipelines and 15 active Petroleum Storage Depots (PSD). These pipelines are regularly/periodically inspected using In Line Inspection (ILI) Tools to assess the condition of each pipeline.

The ILI report is reviewed and locations highlighted to carry out validation digs. Once the validation digs have been reviewed an informed decision making process is used to decide on repair locations and methods.
3.0 Review of Repair Methods:

The OPA use the following repair methods on the GPSS:

- Reduction of Maximum Allowable Operating Pressure (MAOP)
- Dressing/Blending (Low Powered Grinder)
- Direct Deposition
- Welded Patch
- Encirclement Fitting (Sleeve) – Welded or Epoxy Resin
- Bolted Clamp (e.g. Plidco)

3.1 Reduction of Maximum Allowable Operating Pressure (MAOP):

Put simply, the Maximum Allowable Operating Pressure (MAOP) is reduced such that any defects assessed by the OPA Pipeline Integrity Engineer are reclassified as non-critical and hence the pipeline can continue in service but at a reduced pressure. The defect can either be left alone and monitored or repaired at a later date with the MAOP being restored to its original value.

3.2 Dressing/Blending Using Grinder:

Grinding/Blending (using skilled operators and low powered angle grinders) is used where superficial external damage exists. The grinder is used to remove any sharp stress raising features. An initial wall thickness assessment is carried out using either a pit gauge type tool or the Clock Spring Conformable Array equipment [1] (see Figure 1) to ensure that there is sufficient material to carry out the grinding/blending process.

![Figure 1: Clock Spring Conformable Array Set-Up (with Example of Software Corrosion Profile Output)](image)
The area is inspected using Visual and Magnetic Particle Inspection (MPI) before any grinding activity is started, periodically between grinding/blending runs and subsequently when the grinding/blending process has taken place to assess the area for any surface breaking or sub surface cracking.

The final area and depth of the blended area is then reported back to the OPA Pipeline Integrity Engineer to assess if any further works are required based on the final wall thickness/defect shape/area. Once the OPA Pipeline Integrity Engineer is satisfied that the remaining defect characteristics will not affect the MAOP related to the specific pipeline, the carrier pipe is prepared for re-wrapping.

The surface preparation is carried out to SIS 05 59 00:1967 ST 3 (very thorough power brushing) with the existing coat/wrap cleaned, bevelled and abraded back by minimum of 150mm. Area primed using Serviwrap Primer AB then wrapped using Serviwrap R30A. The interface areas for the R30A and existing Coat/Wrap is over wrapped again with Denso tape as an added precaution such that potentially no moisture can make its way under the newly installed Serviwrap R30A.

### 3.3.0 Welding to Live Lines Weld Procedure:

The Oil and Pipelines Agency conducted weld procedures by constructing a test rig that was set up to simulate a pipeline under pressure. Aviation Fuel was pumped through the rig at known pressure/temperature/flow rate to simulate on site conditions.

The complete fabrication was subjected to actual worst case pipeline condition cyclic fatigue testing of 30,000 cycles of 30 to 85 bar with MPI carried out on all welds at 5,200, 16,780, 22,685 and 30,000 cycles. The actual worst case condition was 35 to 70 bar twice a day for 20 years then doubled.

A number of welding procedures were then run to produce OPA’s internal specifications for the welding of fittings and repairs to the GPSS pipelines under pressure. These procedures are applicable to pipe wall thicknesses of ≥5mm.

### 3.3.1 Direct Deposition Weld Repair:

Pipe preparation before any Direct Deposition Weld Repair can commence involves removing wrapping material or paint to a length not less than 600mm from either end of the proposed location of the fitting, making allowance for the toe of the attaching weld to be not less than 100mm from the toe of any existing girth weld. Existing wall thickness at the repair location is then assessed (e.g. Clock Spring Conformable Array) to ensure that there is enough remaining wall thickness to carry out the procedure (i.e. 5mm Minimum).

The repair area is lightly dressed by grinding to give a shallow contour to the feature without further reduction of the minimum wall thickness already present. This is over an area approximately 50mm diameter. Then 100% ultrasonic inspection (BS 5996) and 100% MPI (BS 6072) is carried out to ensure freedom from laminations and
confirm adequate pipe thickness extending to 150mm around the area to be repaired.

Welding is carried out to approved OPA Welding Procedure Specifications by skilled and certificated welders with strict control over welding amperage (150amps Maximum). This is tested on a piece of scrap steel (of similar grade to the carrier pipe) before commencement of any welding to the live line is started. Inspection is also carried out by skilled and experienced personnel as controlled in the GPSS Specification Standard.

Once all the above criteria is adhered to and welding has commenced the deposition sequence will be carried out as shown in Figure 2.

![Figure 2: Deposition Weld Sequence](image)

The completed deposition weld is dressed/blended and allowed to cool to ambient temperature then inspected visually and by MPI. Costs to complete one deposition repair weld are in the region of £5k.
3.3.2 Welded Patch Repair:

Carrier pipe preparation and welding related controls are the same as described for Direct Deposition Weld Repair although Patch Repairs haven’t been widely used on OPA pipelines.

Patch material being API 5L X52 or equivalent. Patch dimensions are at least 1.5 times the thickness of the carrier pipe to which it is being welded and extends to at least 6 times the thickness of the carrier pipe either side of the defect being repaired.

3.3.3 Welded Sleeve Repair:

Welded sleeves present an opportunity to restore the MAOP back to its original value using two close fitting half steel shells which are made from compatible material to the carrier pipe. The results of work carried out by Battelle showed that steel sleeve repairs are capable of restoring the strength of a damaged pipeline to a pressure level in excess of a pressure that corresponds to 100 percent of the specified minimum yield strength (SMYS) of the line pipe steel [2].

There are two types of full encirclement split steel sleeves, Type A and Type B. The Type A has no end closure welds and it is used to reinforce a locally corroded area with no welding to an in-service pipeline and is not generally implemented by OPA.

Type B sleeves are pressure containing, with each end fillet welded to the carrier pipe and can be used for repair defects that are 80% deep or greater; they can also be used to repair circumferentially-oriented defects and leaking defects. Type B Welded Sleeves are generally used on GPSS pipelines.

A typical arrangement of these sleeves is shown in the Figure 3 below:

![Figure 3: Full encirclement welded sleeve repair of a pipeline](image-url)
Welding of these sleeves in the field is normally a challenging task requiring very skilled personnel (experienced Senior Pipeline Inspector (SPI), Welders, Welder’s mates and Inspection personnel) and equipment. The main essential concern is that of flow rate and controlling it. There will be sufficient welding rods to complete the welds required along with adequate backup equipment such that should any one item fail during the welding operations the replacement can be brought in to replace it immediately. A stand-by qualified welder will also be on hand.

The key elements that need to be considered when welding a type B sleeve onto an in-service pipeline are (and not restricted to): -

- Communications with local Emergency Authorities.
- Welding equipment and consumables.
- Approved welding procedures.
- Welder/welders qualifications & employment history.
- Inspectors' qualifications & employment history.
- Preparation of pipe and steel sleeve.
- Welding time (i.e. allow for cooling effect of product movement).
- Pre-heating and welding of longitudinal seams.
- Pre-heating and welding of circumferential seams.
- Prevention of hydrogen cracking (Low Hydrogen Electrodes).
- Inspection of welds (during and post installation).

As stated previously one essential variable that must be controlled is the flow rate. This needs to be strictly controlled in terms of time as well as flow rate reduction within the pipeline such that the welding time can be assessed and worked to. Communications with the Pipeline Control Centre will be essential so that the flow rate isn’t increased before welding activities have been completed. If the flow rate unexpectedly stops then the welding crew need to be informed by the control centre immediately and all welding activities halted.

### 3.3.4 Epoxy Resin Sleeve Repair:

Epoxy Resin Sleeves involve no welding to the live line and consists of 2 outer shells welded together along the length of the sleeve. The open ends are filled/blocked with a filler grout material to act as a barrier when the sleeve is being filled with epoxy resin.

Around the sleeve there are a number of bleed holes such that the air can be displaced when filling the annulus with epoxy resin. It should be noted that the pipeline pressure requires reducing while installing ESR Sleeves.

Inspection required is considerably less intensive when compared to a Type B Welded Sleeve. Typically, one inspector will use ultrasonic and magnetic particle inspection techniques to check the sleeves’ longitudinal welds. The remaining inspection and installation activities are carried out by the installation operator.
3.3.5 Observations/Thoughts: Epoxy Sleeve and Welded Type B Sleeve:

Activities associated with the Welded Sleeve Repair are that the client & contractor are in full control of all the parameters and welding activities as well as inspection of the welds can be carried out easily and continuously. Everything is visible and transparent and as long as the strict guidelines within the relevant standards and specifications are adhered to risks such as burn through should not become a problem, the only ‘concern’ actually being welding to a live line.

In comparison the client has no control over installation of the Epoxy Resin Sleeve Repair (apart from indicating where the repair sleeve is to be installed and paying the operators services), this relies solely on the installation operators skills. The advantage is that there is no welding directly to the live line hence removing the ‘concern’ aspect, although as previously stated, the Pipeline Pressure is required to be reduced while installation is in progress.

Once the Epoxy Resin Sleeve has been filled with the resin the bleed holes are plugged and as such there is no visible indication as to whether the resin has cured fully within the annulus of the sleeve. There is also no real means of knowing if the annulus of the sleeve has had a perfect/good fill. This is in comparison with the Type B Welded Sleeve where the integrity of the welding is monitored continually and inspected throughout the entirety of the job.

As a repair method, age wise, the Epoxy Resin Sleeves are relatively new method of repair and as such their lifetime performance has not been fully proven in the field. Compare this to the Welded Sleeve (type B), which is a like for like repair and has been used for many years.

Welded Sleeve material is the same if not better quality than the carrier pipe steel and as such have a very similar elastic modulus (API 5L X52 in the case of the GPSS). Epoxy Resin Sleeves rely on the resin to transmit and loads to the outer steel case but with epoxy having a lower elastic modulus than steel, so the question arises that could this actually translate in the original defect (initially repaired by the ERS) to grow or even fail due to fatigue[4]. That said, the current performance of the ERS’s has been positive.

Approximate costs for installing these two systems to the GPSS:

- Epoxy Resin Sleeve = £10k-£12k.
- Welded Sleeve (Type B)) = £10k-£12k.

These costs are associated with the actual installation process and do not include costs associated with activities required to facilitate these installations such as scheduling meetings, land owner liaison, defect location surveys etc.
3.3.6 Bolted Clamp:

Temporary Bolted Clamps (photographs 1 & 2) are quick to install and temporary measures to contain defects and leaks until such time that a permanent repair method can be installed.

![Photograph 1: Plidco Bolted Clamp](image1)

![Photograph 2: Installed Plidco Bolted Clamp](image2)

As long as the defect area can be contained within the bolted clamp containment area they are extremely useful in as much as the defect can be contained fairly quickly and using installation personnel that do not need to be as skilled as say personnel involved with either Welded Sleeves (Type A or B) and Epoxy Resin Sleeves.

3.3.7 Relay Section of Pipeline:

Relaying a section of pipeline can be a time consuming and costly activity. An activity that is becoming more prevalent due to the age of the pipelines that guarantees restoring the relayed section of pipe to the original MAOP.

A pipeline relay is constructed in parallel with the original line still in service. The relay is hydrostatically pressure tested, cleaned, gauged and wrapped ready for a predetermined point in time where the in service pipeline is emptied of product such that ‘Tie-In’ works can be completed.

The final ‘Tie-In’ welds (Golden Welds) will undergo both Radiography and Ultrasonic Inspections as these welds will not be exposed to the hydrostatic pressure test.
4.0 GPSS Case Study:

Pipeline Characteristics:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline</td>
<td>Classified</td>
</tr>
<tr>
<td>Pipeline Location</td>
<td>Classified</td>
</tr>
<tr>
<td>Material</td>
<td>API 5L GRD B/X42</td>
</tr>
<tr>
<td>MAOP</td>
<td>65.0Bar</td>
</tr>
<tr>
<td>Product</td>
<td>JET A-1</td>
</tr>
<tr>
<td>Pipe Diameter</td>
<td>10&quot;</td>
</tr>
<tr>
<td>Pipe Wall Thickness</td>
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</tr>
</tbody>
</table>

GPSS pipelines generally suffer from external corrosion (see photographs 3 & 5) at field and tie-in joint locations where the welded joint was initially wrapped with hot or cold applied tapes.

The case study covered here is for an aging onshore pipeline in the southern part of England. Following On Line Inspection a number of validation digs were carried out and two of the locations identified are discussed regarding repair methods used, costs and philosophy behind the decisions for the repair methods implemented.

Based on the available data a study was carried out to determine the current condition of the line, evaluate the current corrosion prevention measures, and develop a strategy to rehabilitate the pipeline and to ensure its future integrity in relation to the MAOP of 65 bar. The pipeline could not be taken out of service very readily so the decision was made to undertake the repair while the pipeline was operational.

4.1 Repair and Rehabilitation Strategy

The corrosion features identified in the intelligent inspection were evaluated using the ASME B31G \[5\] to determine the failure pressure.

The analysis indicated that two external corrosion features required immediate repair the characteristic of each of these features and the considerations for the selection of the appropriate repair method as discussed in the following section.
5.0 Selection of Repair Method

A number of points need to be appreciated/assessed before selection of the repair method to be implemented such as:

- Defect size and criticality – To be assessed by OPA Engineers.
- Repair options open to you at that point in time: Is there time to prepare for a Type B Welded Sleeve?
- Defect repair site location: Sometimes it will be impossible to install any other repair method other than a relay section e.g. by horizontal directional drill. Open cutting areas that are Sites of Special Scientific Interest (SSSI) would not be tolerated so sometimes the options available only point to one conclusion.
- Temporary repair followed by permanent repair?
- Can the defect size be contained within the repair technique to be used? Type B Welded Sleeves can be welded to each other to increase the containment length.

Feature Location 1:

Feature Location 1 (see photograph 3) was in a wooded area. The defect was approximately 500mm in length centred on a girth weld and mainly between 4 & 8 O'clock circumferential positions.

External corrosion feature area was multiple pitting with depths ranging from 1mm to 3.5mm (Pipeline wall thickness of 9.5mm, i.e. 36% wall thickness loss).

The wall thickness was assessed using Ultrasonic equipment with the corrosion depth mapping being carried out using the Conformable Array equipment. There was slight ovality associated with the area to be repaired so along with the presence of the girth weld it was OPA’s decision to install an Epoxy Resin Sleeve.

Photograph 3:
External Corrosion (Feature Location 1)
The Epoxy Resin Sleeve is capable of encompassing slight ovality along with the girth weld as well as filling in the pitting as seen in photograph 5.

The Type B Welded Sleeve was ruled out due the fact that no contractor could be brought in within the required repair period (i.e. obtaining the employment of skilled and qualified welders in time for the repair works).

The repair site took 3 days to prepare (excavation, access works and pipe preparation) with the actual sleeve installation taking one full day. A further 1 day was required to wrap (Serviwrap R30A with Denso tape used at the existing flood coating/Serviwrap interfaces) and backfill the repair site taking a total of 5 working days and at a cost of approximately £8k.

Advantages associated with the Epoxy Resin Sleeve include installation with no welding to the live line, no real need for skilled operators for the installation of the sleeve apart from the Inspector and Installation Operator.

Disadvantages from an observer’s perspective are that there is no real way to ensure a complete/perfect fill is obtained only when you see epoxy resin emerging from the bleed holes. Plus there could be a potential for the epoxy to not cure properly (faulty batch etc).

Photograph 4:
PII Epoxy Resin Sleeve Installed to GPSS Pipeline (Feature Location 1)

Feature Location 2:

Feature Location 2 (see photograph 5) was located next to a stream and therefore a site of environmental concern hence OPA resorting to the option of a Type B Welded Sleeve. This was decided upon due to limited experience with the Epoxy Resin Sleeves (to date) plus the contractor, materials and skilled personnel were available to carry out the proposed repair technique.
Photograph 5:  
*External Corrosion (Feature Location 2)*

The repair period was similar to that of the Epoxy Resin Sleeve as previously covered i.e. 5 working days. The equipment and personnel levels were higher due to the nature of welding to a live line i.e. constant inspection/heating/welding. Preparatory works such as arranging with the Pipeline Scheduling Department to ensure an envelope of time where the flow rate and pressure could be reduced to known levels for the duration of the works had to be organised. Also ensuring that there were back up equipment for all welding, heating and inspection activities was a priority.

The welded sleeve was completed (see photograph 7) in one day and the pipe subsequently cleaned, wrapped and backfilled the following day.

Photograph 6:  
*Type B Welded Sleeve Installation to GPSS Pipeline (Feature Location 2)*
5.1 Future Rehabilitation Strategy:

In addition to the repairs carried out as discussed in the previous section, a re-inspection interval and programme of future repairs and actions were put in place:

- A review of the Cathodic Protection System performance, based on close interval potential surveys to determine any areas of inadequate protection, this review would define potential upgrade on the CP system.

- Similarly a coating defect location survey will be carried out to detect areas with critical levels of coating damage.

6.0 Applicable Standards and Codes:

API Spec 5L: -
Specification for line pipe
BS4515:2009: -
Specification for welding of steel pipelines on land and offshore. Carbon and carbon manganese steel pipelines
Swedish Standard SIS 05 59 00:1967: -
Pictorial Surface Preparation Standards for Painting Steel Surface
OPA Internal Specifications: -
The Welding of Fittings and Repairs to the GPSS Pipelines Under Pressure (For Actual Pipeline Wall Thickness of not Less Than 5mm)
BS 5996:1993: -
Specification for Acceptance Levels for Internal Imperfections in Steel Plate, Strip and Wide Flats, Based on Ultrasonic Testing
BS 6072:1981: -
Method for magnetic particle flaw detection
BS EN 499:1995: -
Welding consumables. Covered electrodes for manual metal arc welding of non alloy and fine grain steels. Classification
BS 89:1990: -
Specification for direct acting electrical measuring instruments and their accessories.
BS 638:1996: -
Arc welding power sources equipment and accessories
BS 970:1996: -
Wrought steel in the form of blooms, billets, bars and forgings.
BS 4069:1982: -
Specification for magnetic flaw detection inks and powders.
BS 5044:1973: -
Contrast aid paints used in magnetic particle flaw detection
BS 6990:1989: -
Welding on steel pipes containing process fluids or their residuals.
BS 7570:2000: -
Code of Practice for validation of arc-welding equipment.
ASME B31G – 2009: -
Manual for Determining the Remaining Strength of Corroded Pipelines
7.0 References:


