OIL & GAS

USE OF EPOXY SHELL TECHNOLOGY AS AN EFFECTIVE SOLUTION FOR PIPELINE PROTECTION

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SAFER, SMARTER, GREENER

Abstract

In the UK, National Grid high pressure gas transmission pipelines are designed and constructed in accordance with the Institution of Gas Engineers and Managers standard; IGEM/TD/1. This standard requires that pipelines which cross or which are in close proximity to a high-density traffic route are constructed using 'thick wall' pipe with a design factor of 0.3, or 0.5 if the wall thickness is not less than 19.1mm. The purpose of this requirement is to provide protection against damage to the pipeline during construction work and in future operation, and to minimize the potential for pipeline failure which may affect people using the road. In addition, the standard requires that where the addition of a new traffic route upgrade to an existing traffic route impacts on the pipeline design, the pipeline must be modified to comply with the design factor and wall thickness requirements. Compliance with this requirement involves diversion or lift and relay of existing pipelines, which in turn involves hot tap and stopple operations.

During construction of a 48" diameter, grade X80, gas transmission pipeline (design pressure of 94 Bar), 'thick wall' pipe was installed at a specified location to facilitate a proposed road diversion. Unfortunately, the location of the road diversion was subsequently moved, which meant that the thick wall section of pipe that was installed during construction would only extend partially under the new road.

Compliance with IGEM/TD/1 would require a diversion to be completed, however due to the location and timescales involved, alternative methods of pipeline protection had to be investigated.

The solution developed was to install a series of epoxy shells. Although not a recommended method for pipeline protection in IGEM/TD/1, the document does not prohibit the use of alternative methods.

This paper presents a detailed overview of the scale of the problem faced by National Grid and the support provided by DNV GL and PIE (UK) Ltd, focusing on the steps taken towards getting acceptance of the proposed solution through discussions with the Authority responsible for the road development, and challenge and review by Experts on the IGEM/TD/1 Panel, installation of the epoxy shells and reinstatement of the land in readiness for the road to be diverted.

Following the success of the specific pipeline project, there has been an update to IGEM/TD/1 to enable the use of alternative methods, such as epoxy shells, for changes to traffic (road and rail) routes. Furthermore, this technology has been used again by DNV GL to successfully reinforce a 12" pipeline to facilitate construction of a new road.

Introduction

In November 2007, National Grid commissioned Feeder 28, a 1200mm diameter, 94 Bar gas transmission pipeline. The pipeline was designed and constructed to IGEM/TD/1 Edition 4 [1], supplemented by National Grid established Procedures and Specifications.

Planning of the pipeline route took several years to complete as consideration had to be given to, for example, the impact on the environmental, human impact, infrastructure (high density traffic routes, railways, overhead electricity transmission lines, other buried plant) and other engineering constraints. Also, these factors require consultation and agreement with relevant outside organisations.

Consideration also needed to be given to future developments that may impact the pipeline during its design life (and beyond), for example, new (or an expansion of) commercial or housing developments, new (or modifications to) road and rail infrastructure.

During the planning phase, National Grid was aware of the Welsh Governments ongoing commitment to develop the A477, so included a thick wall pipe section, at the Red Roses location, as per the proposed routing of the road. The thick wall section was to protect the pipeline and to ensure compliance with the requirements of IGEM/TD/1 Edition 4 for the increased traffic density associated with the development.

Following commissioning of the pipeline, the Welsh Government proposed some changes to the route of the A477, which impacted on the provisions made at Red Roses. The road was re-positioned, some 60m away, which meant that the as laid, thick walled section, would no longer span the width of the road.

National Grid was faced with two options, at a minimum cost of £50M;

- Shut down the pipeline, and cut out and replace the thinner wall section with thick wall pipe, which would require a 56km recompression of the line or vent to atmosphere, and an extensive shut down period, or
- 4km diversion using a bifurcated stopple technique, which hadn't been done before on a 1200mm diameter, 94 Bar pipeline.

Another problem facing National Grid was the location of a 133kv electrical transmission tensioning tower, which could prove problematic for the site equipment that would be required to undertake either of the work activities.

To identify and mitigate any potential issues with the proposed methods to modify the pipeline and to ensure compliance with the requirements of current edition of IGEM/TD/1 (Edition 5) [2], National Grid consulted Dr Jane Haswell, then Chairperson of the TD/1 Panel. During those discussions, a third option was proposed, the potential use of epoxy shells.

This paper presents an overview of the innovative use of the epoxy shell solution (including the challenges posed by the TD/1 Panel of Experts) and the mechanical and geotechnical studies that were undertaken towards verification of the design, and to support site activities for the installation of the epoxy shells.

A result of the work undertaken was an update to IGEM/TD/1 Edition 5, to include a new subsection, 6.10.4, enabling the use of technologies, such as the epoxy shell, to support changes/modifications to traffic (road and rail) routes.

Since completion of the installation of epoxy shells for pipeline protection at the Red Roses location, and the amendments to IGEM/TD/1, a second design and installation has been undertaken on behalf of SGN and Transport of Scotland; shelling of a 324mm diameter gas pipeline to facilitate construction of a new road. An overview of this latest application is also provided.

The Epoxy Shell Pipeline Repair System

The epoxy shell was developed by British Gas during the 1980s as a method of repairing pipeline damage, such as corrosion, gouge, dent, cracking and combinations of damage (e.g., dent plus gouge). An epoxy shell repair comprises two 'oversized' half shells which are either welded or mechanically joined to fully encircle the damaged section of pipe. The shell is centralised, about the pipe cross section, to ensure a fully circumferential annular gap within specified limits. The annular gap is then sealed at both ends prior to injecting the specially formulated epoxy grout. The concept of the epoxy shell is shown in Figure 1.

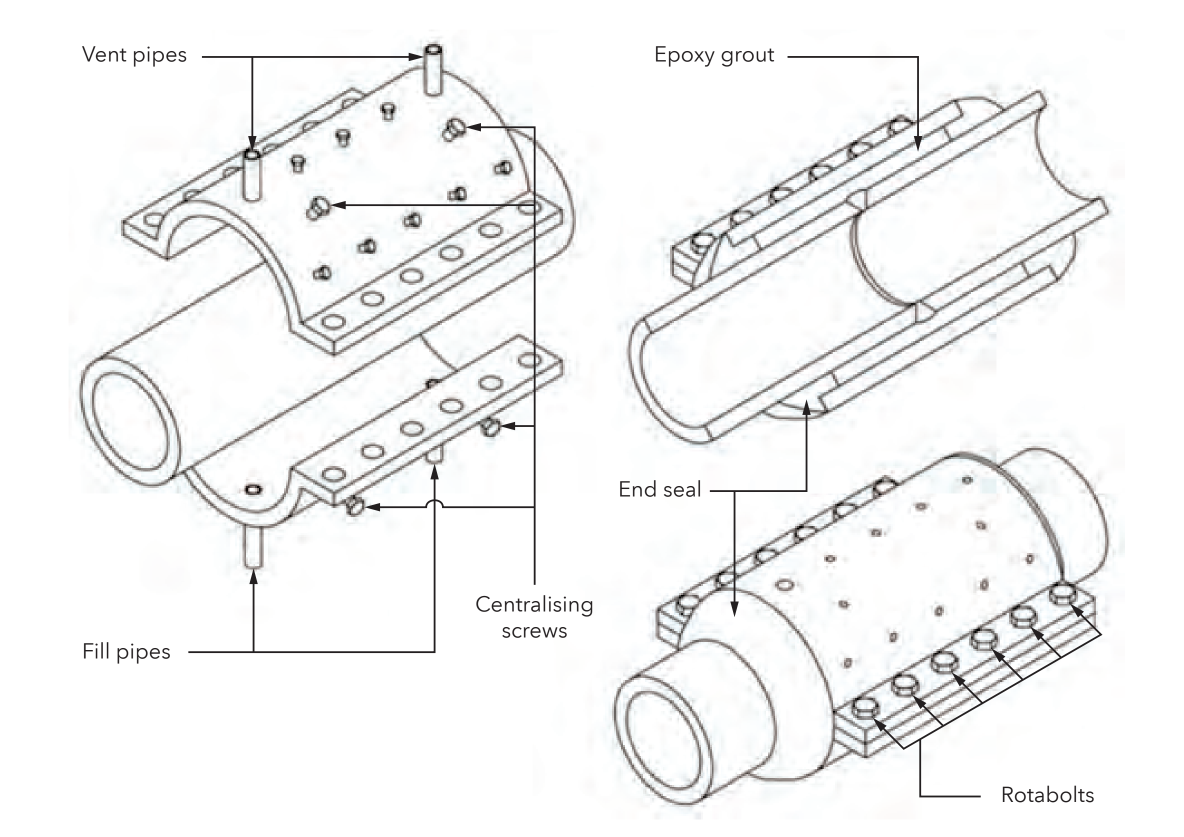


Figure 1: Epoxy shell system

Extensive testing and analysis was carried out to confirm its performance characteristics (static and fatigue strength) over the long term to provide assurance that the 'damaged' pipeline, once repaired, can continue to operate to its original design intent over its specified design life.

In the UK, the epoxy shell quickly became, and remains, the preferred method for the repair of external damage to both gas transmission and distribution pipelines, that are owned and operated by National Grid and the Gas Distribution Networks (Cadent, Northern Gas Networks, Scotia Gas Networks and Wales & West Utilities).

DNV GL's range of application of epoxy technology has evolved over the years to include;

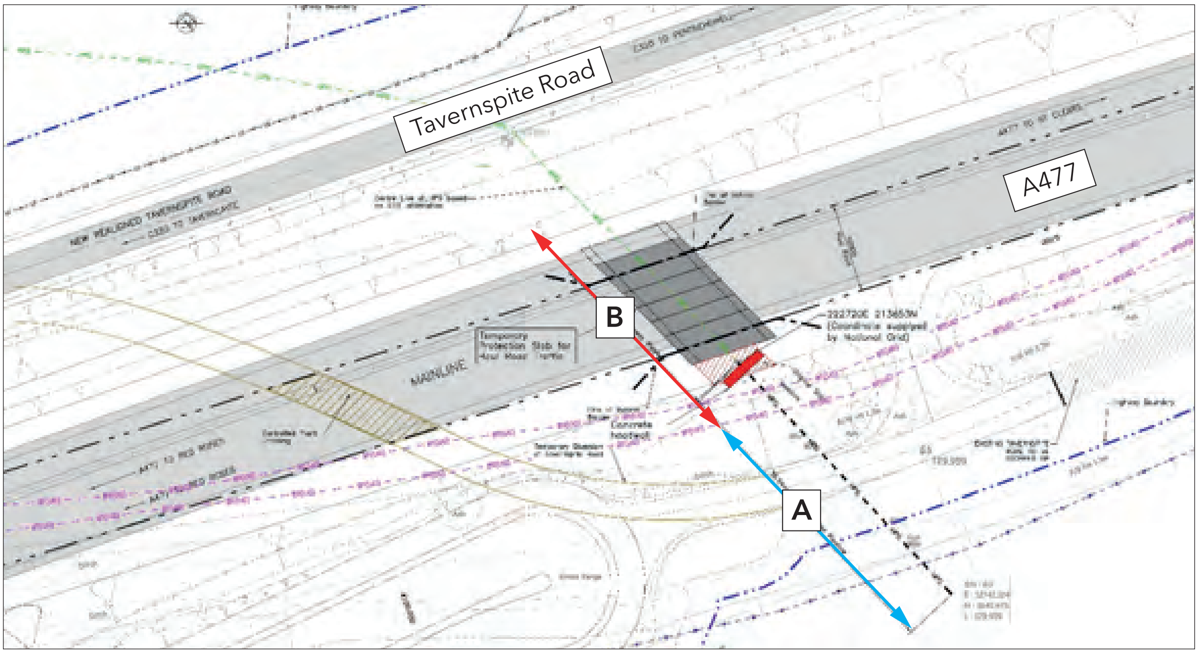
- a lobster-back version of the epoxy shell (for repair of bends),
- the Grouted Tee (an innovative method for installing branch connections),
- pipeline end seals (concentric and eccentric),
- domed repair to encapsulate damaged fittings (a variant of the epoxy Tee, but the branch has a welded domed end), and
- the epoxy pipe clamp (a small version of the epoxy shell, but designed for high pressure piping, up to 690 Bar)

Refer to appendix A for further details on the range of technologies, and the epoxy grout system.

Red Roses

The 'Problem'

As can be seen in Figure 2, 'normal' thickness pipe is laid at the location of the re-positioned A477 and the re-aligned Tavernspite Road. The as-laid, 'thick' walled section transitions to normal thickness at the southern boundary of the A477.



A As-laid 'thick' wall pipeline **B** As-laid 'normal' thickness pipeline
Figure 2: Pipeline route and new road layout

To facilitate the revised road layout, the thick wall section needed to extend approximately 80m, as shown in Figure 3.

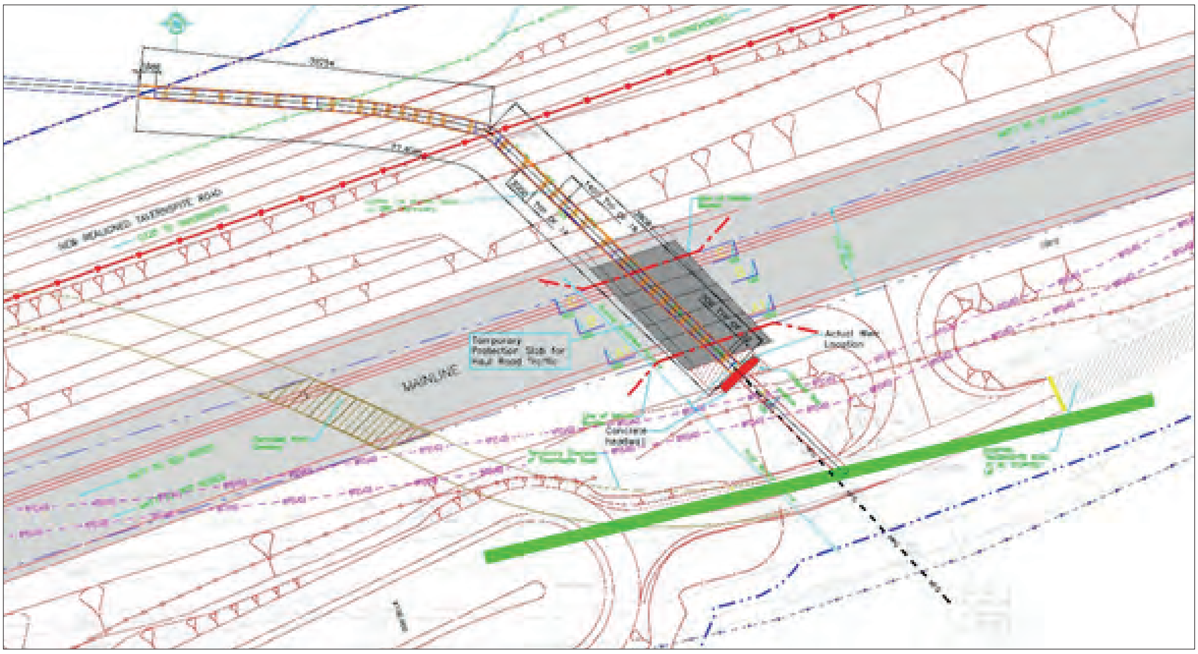


Figure 3: Length of required 'thick' walled pipeline

Figure 1 and Figure 2, show only the plan view of the pipeline. The topographic elevation of the section to be shelled varies; lowest at the Southern end, with sag-bends and over-bends along its length.

Design of the Red Roses Epoxy Shells

A Working Group, represented by National Grid, DNV GL and PIE Ltd, discussed possible solutions, and identified potential implications regarding compliance with the requirements of IGEM/TD/1. PIE Ltd subsequently produced a technical note, summarising the problem, giving a high-level overview of the proposed solution, the Working Groups interpretations towards achieving the requirements of IGEM/TD/1, and supporting evidence for the proposed solution from development work undertaken by National Grid and DNV GL. The document was then presented to the IGEM/TD/1 Panel of Experts.

The Panel of Experts gave no objections to the proposed use of epoxy technology, although caution was cited with using 'appropriate' wording in a future update of IGEM/TD/1 to ensure that use of such technology in the future is justified, and the solution is appropriately designed for the specific application.

The technical note was drafted as a 'design concept'. However, the Panel of Experts responded with technical suggestions to consider while undertaking the detailed designs. These were all noted and considered while designing the shells, developing the excavation and installation plans, and pipeline protection.

The suggestions included;

- Consideration of the 'stress reduction' requirements, as stated in IGEM/TD/1, for road crossings
- Attention be given to the 'gap' between adjacent shells, for
  - Localised stress concentrations, and potentially high stresses due to traffic density
  - Continuity of CP connection for pipeline protection
  - Avoidance of preferential corrosion
  - Identification of any degradation during future ILI surveys
- Provision for reinforcement of the pipeline, of length not less than that specified in IGEM/TD/1, beyond the new road boundaries

The shells were designed in accordance with the principals and concepts outlined in National Grid specification, T/SP/F/15, with the following considerations;

- Wall thickness of shell to be equivalent to that of the pipe
- Shell to be of equivalent strength to that of the pipe
- Application over cold field bends
- Application over forged/induction bend
- Continuation of shell assembly
- Longitudinal flange design, including the effects of a pressure 'increase' following completion of the installation when the pipeline was returned to normal service
- Effects of a pressure 'reduction' following completion of the installations
- Continuity of CP

A brief overview is given below of the shell designs for the bends (cold field, and forged/induction) and straight pipe sections, considerations for excavation during installation (including pipeline support), pipeline protection and reinstatement.

Shell design

Although the purpose of the installation was not to repair pipeline damage, but to reinforce the pipeline, the shells were conservatively designed in accordance with T/SP/F/15 [3], adopting the same design criteria as specified for load transfer and external interference for repair of pipeline damage.

The wall thickness of the pipeline is 15.9mm, and the line pipe is grade X80 steel; T/SP/F/15 recommends plate material, P460 NL1 [4] is used to fabricate the shells. However, P460 NL1 has a lower yield strength than grade X80. Hence an equivalent thickness for the shells was calculated based on the lower strength. A minimum thickness requirement of 19.7mm was calculated, hence all shells were fabricated from P460 plate that was nominally 20mm thick.

T/SP/F/15 permits an epoxy grout thickness tolerance of between 6 and 40mm for shell diameters up to 1200mm. All shells were designed with an annular gap between the pipe surface and internal surface of the shell of 25mm, which provides an adequate spacing to maintain the epoxy grout thickness tolerance, and keeps the volume of epoxy grout required to a manageable level. In addition to the standard, straight shell design, it was necessary to design shells for field cold bends and a forged/induction bend, details of which are given below (see also Figure 4);

- **Shells over field cold bends:** there were four 18m lengths that contained varying degrees of field cold bends (bend radius of 40D). The as-built drawings provided by National Grid gave the length and angle of each, which dictated the length of shell required to ensure the required annular gap, and tolerance, was maintained.
- **Shell over forged/induction bend:** there is one 30° forged/induction bend. T/SP/F/15 does not permit straight shells over forged bends due to large variations in epoxy grout thickness. For such applications, lobster back type fabricated shells are widely accepted. The flanges were not fabricated, they were profiled from a single bar stock, of length equivalent to the total length of the fabricated shell. This was to maintain strength around the bend, reduce deformation of the shell during fabrication and to eliminate large fillet welds (see Figure 4c).
- **Continuity shells:** these shells were designed to cover the 'gaps' between adjacent shells, to provide protection against corrosion, provide continuity of CP, and to stiffen the assembly at the 'joints', significantly reducing the potential localised stress due to traffic loading. Each shell was 500mm long, designed to provide an overlap onto the ends of each shell of 200mm (approximately) and cover the gap between the shells of 120mm (note, the gap was required to enable application of the end seal putty, prior to injection of the epoxy grout). To enable this, the flange length of each main long shell was reduced by 200mm. On assembly, the ends of each continuity shell are sealed and the annulus injected with epoxy grout to provide a continuous shell assembly (see Figure 4a).

Figure 4 provides an overview of the design of the straight shells, the forged/induction bend and the continuity shells.

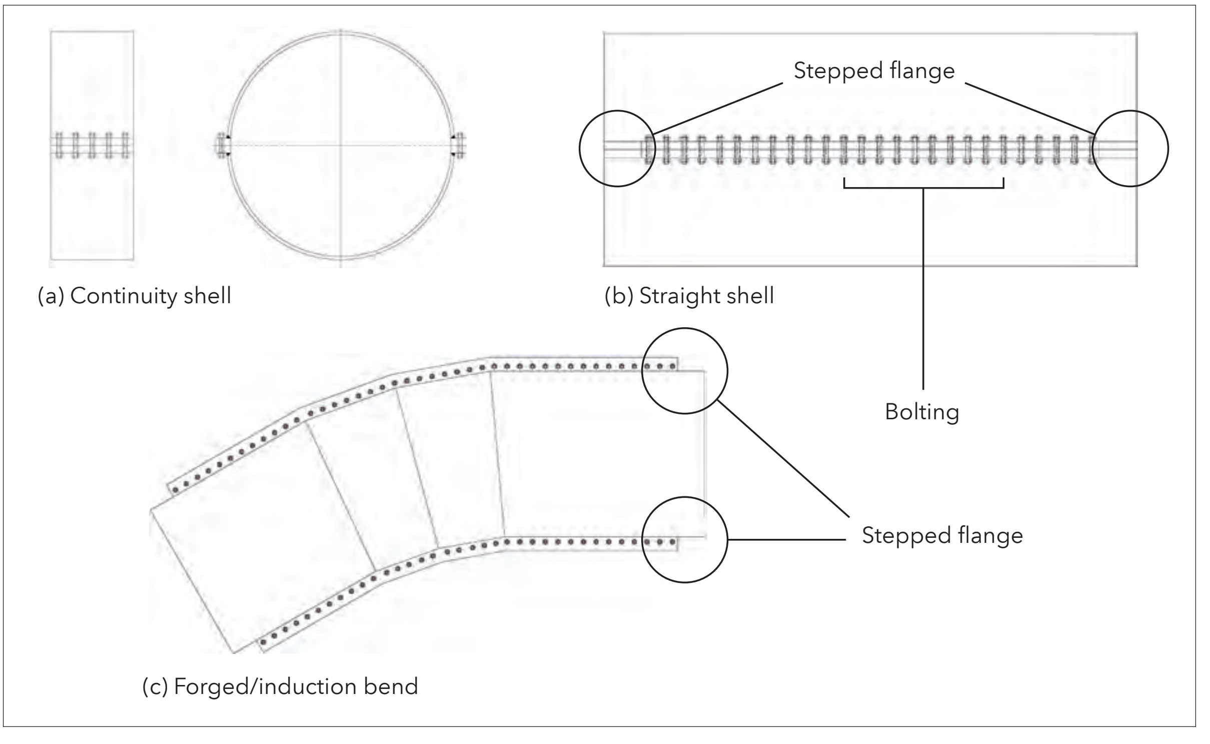
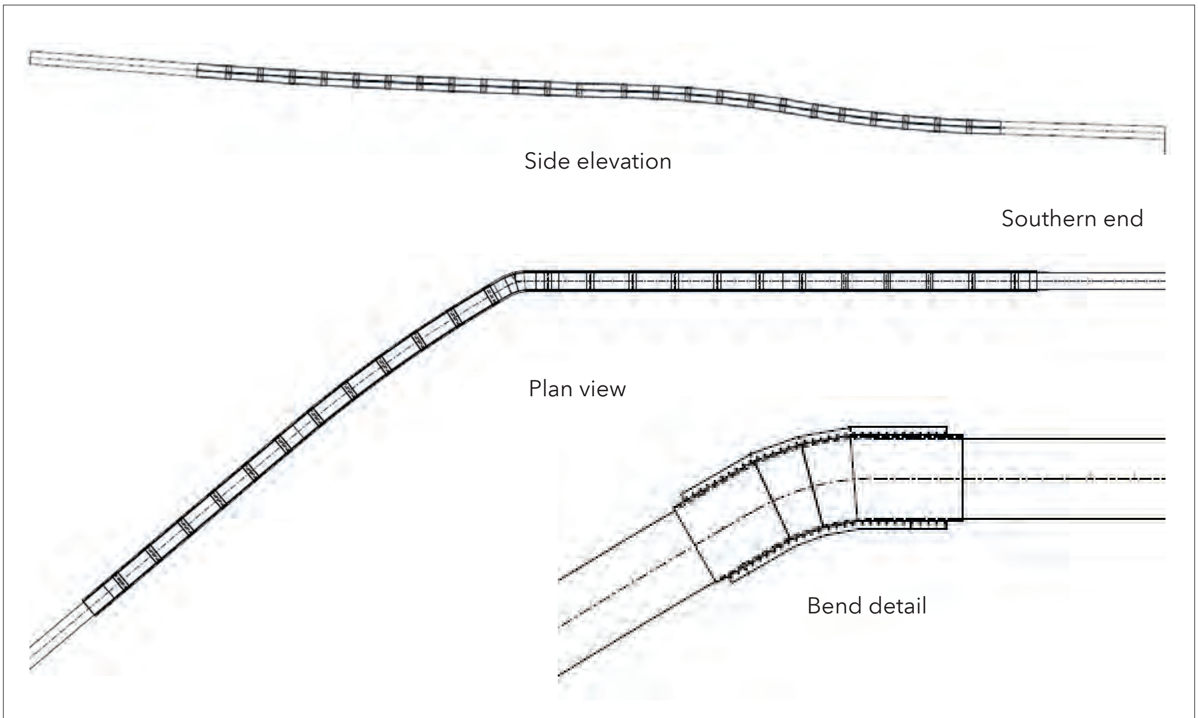


Figure 4: Epoxy shell designs

Rotabolts were used to bolt the flanges together, to a specified torque setting, ensuring an even load distribution along the flange. The Rotabolts provide a positive indication of 'correct' bolt tension, with an accuracy to ±5%; the performance characteristics of the system have been certified by GL (Hamburg).

Figure 5 provides an overview of the complete shell assembly along the length of pipeline to be reinforced, as well as an inventory list of the number and type of shell required. A plan and side elevation is provided to show the position of the 30° bend, as well as the field cold bends.



Quantity	Shell Design
1	30° bend
14	3m long shell with stepped flange at both ends
16	1.45m long shell with stepped flange at both ends
1	3m long end shell with stepped flange at one end (field boundary)
1	1.6m long end shell with stepped flange at one end (thick wall end)
32	0.5m long continuity shell
Note: Designed so that all girth welds are located centrally within a 3m long shell	

Figure 5: Layout and requirements of optimum shell design

The design pressure of the pipeline is 94 Bar, but during installation of the shells, the pressure was to be approximately 70 Bar. T/SP/F/15 requires that the design be based on a 100 Bar design pressure, hence the shell and flange are required to be design for a pressure increase of 30 Bar (i.e., 70 to 100 Bar). However, for an increased margin of safety, the Working Group agreed that the shells should be designed to withstand a maximum pressure increase of 70 Bar following installation.

Having considered strength requirements of the steel shell for an increase in pressure, consideration also had to be given to the bond strength of the epoxy grout, should the pipeline be depressurised during its service life. During development of the epoxy shell repair system, it was concluded from the testing undertaken that a minimum tensile bond strength of 12 N/mm² was required. Good bond strength is usually achieved by removing the existing pipeline coating prior to installation and grit blasting the pipe surface and inner surfaces of the shell, to facilitate good adhesion between the pipe, the epoxy grout and the repair shell.

The pipeline has a fusion bonded epoxy (FBE) coating, which is an extremely difficult coating type to remove, and is a very time consuming process. The need to remove the FBE coating was questioned, given the purpose of the installation, and the quality of coating adhesion. Hence a detailed experimental programme was undertaken to see if the shells could be installed over the pipeline FBE coating, while maintaining the minimum bond strength between the epoxy grout and FBE coating, as required in T/SP/F/15.
The experiments demonstrated that this was an acceptable deviation, but it was recommended that the coating be 'sweep blasted' prior to installation of the shells. More details on the experimental program are given later in this paper. The next section provides a summary of the analyses undertaken to support excavation of the pipeline, and reinstatement, ensuring compliance with the requirements of IGEM/TD/1 for the design traffic loading.

Supporting analyses for pipeline reinstatement and excavation to facilitate installation

Analyses were required to confirm pipeline reinstatement requirements, and to advise an appropriate excavation length (and requirement for pipe supports) to facilitate installation of the shells.

National Grid commissioned site specific ground investigations to confirm soil conditions. To compliment this, DNV GL obtained additional soil condition reports from other, publicly available boreholes, and inferred site geology from the British Geological Survey (BGS) Geological Map of Carmarthen, and BGS digital maps.

DNV GLs in-house, commercially available software, SURFLOAD version 3.1 was used to undertake the analyses, to confirm pipeline reinstatement requirements. An overview of the analyses and summary of key findings is given below.

DNV GLs in-house software, PIPELINE version 6.3.1 was used to evaluate excavation and pipeline support requirements. An overview of the analyses and summary of key findings is also given below, after the pipeline reinstatement analyses.

Soil properties input into the software, were based on the site ground investigation reports, albeit with additional conservatism included.

■ **Pipeline reinstatement**

The road, and hence the reinforced pipeline section, was designed for HB45 traffic load, as described in BS 5400-2:2006 [5]. In addition to this, the analyses also considered;

- Longitudinal bending stress within the pipeline due to a maximum post-construction settlement of 50mm
- Pipeline internal pressure of 94 Bar
- Temperature change from -15°C to +15°C
- Construction induced bending stresses, as given in NEN3650 [6].

The pipeline soil cover depth varied; 1.7m at its shallowest depth, with a 0.32m road structure for the A477, to 2.0m cover with 0.12m road structure for the adjacent Tavernspite Road.

For each load case considered in the analysis, an HB45 loading was applied. An initial analysis was undertaken for reference, followed by analyses specific to the reinforcement project as summarised below;

- **Load case 1.** The existing pipeline, with 2.0m depth of cover, 0.32m road structure, no shelling
- **Load case 2.** Pipeline with shelling, 1.7m depth of cover with 0.32m road structure
- **Load case 3.** Pipeline with shelling, 2.0m depth of cover with 0.12m road structure

Each analysis was undertaken using the pressurised and de-pressurised cases to account for worst case conditions.

National Grid specification, T/SP/GM/1 [7] specifies performance acceptance limits for high pressure pipelines, which include a requirement for the following parameters;

I. von Mises equivalent stress not to exceed 90% SMYS
II. Membrane stress not to exceed 80% SMYS
III. Ovality not to exceed 5% of the pipe diameter
IV. Buckling compressive wall stress not to exceed 13 N/mm² (pipeline only) else 18.3 N/mm² (pipeline plus shelling)
V. Stress range in the pipe wall from transient loads not to exceed 35 N/mm² (both pipeline only case, and pipeline plus shelling)
VI. Vertical transient pressure in the soil at the crown of the pipe not to exceed 0.0101 N/mm² (pipeline only) else 0.0495 N/mm² (pipeline plus shelling)

For **Load Case 1**, the analysis demonstrated that the acceptance limits, I to IV were satisfied, but the stress range (case V) and transient pressure (case VI) limits were **exceeded**.

For **Load Case 2**, the analysis demonstrated that the acceptance limits, I to V were satisfied, while the transient pressure (case VI) limit was **on the limit**.

For **Load Case 3**, the analysis demonstrated that each acceptance limit was **satisfied**.

The initial analysis (Load Case 1) clearly demonstrated a need for pipeline reinforcement. Although the stresses within the pipeline were assessed as acceptable for static loading conditions, they were unacceptable for the design cyclic loading conditions. Installation of the shells reduced the stresses significantly, but for the A477 section additional analyses were required to reduce the transient pressure loading. The subsequent assessments demonstrated that increasing the road structure had a negligible effect, but an increase in cover depth would ensure that all performance requirements were satisfied. Following discussions between National Grid and the Road Developer, agreement was reached to increase the depth of cover from 1.7m to 1.96m, with 0.32m of road structure. This was greater than the minimum depth of cover (1.91m) required to achieve the performance acceptance limits.

It should be noted that the analyses were undertaken based on nominal pipe dimensions, which, for the pipe wall thickness included a 5% under-tolerance (nominal wall thickness was 15.9mm). The pipe inspection certificates, at time of construction, were reviewed and it was found that the minimum wall thickness measured for all pipe joints at the Red Roses site, was 15.9mm. Hence, the actual stresses in the pipe sections would be lower than predicted from the analysis, and the margin of safety would therefore increase.

■ Pipeline excavation

Following discussions with National Grid, two excavation schemes were considered to facilitate installation of the shells;

Option A. Excavate the whole 80m length of the pipeline and use temporary structural supports,

Option B. Expose 80m length of pipeline to the crown, sequentially excavate five overlapping 20m sections of the pipeline, at a time, and backfilling to provide support to the shelled section of pipeline.

The following considerations had to be given for each option;

- Shelling to commence from the 30° forged/induction bend, then work towards the thick wall section (this was due to alignment complexities of the shells)
- Due to depth of cover, the shelling operations would require 3m temporary access either side of the pipeline, and 1.2m underneath
- Local geology and soil conditions
- Prediction of stresses within the pipeline
- Prediction of settlement stresses

The following loads were modelled on the pipeline, for each option;

- Pipeline internal pressure of 94 Bar
- Self-weight of the pipeline (475 kg/m)
- Weight of gas in the pipeline (90kg/m)
- Weight of shell and epoxy grout (975kg/m)
- Temperature change from -15°C to +15°C
- Construction induced bending stresses, as given NEN3650

For both options, analyses were undertaken of the pipeline with and without the shells.

The results of the analyses were compared to the performance acceptance criteria specified in T/SP/GM/1 (for von Mises stress and membrane stress) and ASME B31.4 [8] (for maximum allowable shear stress);

I. von Mises equivalent stress not to exceed 90% SMYS
II. Membrane stress not to exceed 80% SMYS
III. Maximum shear stress not to exceed 45% SMYS

For **Option A**, several supported spans were analysed; no support, one support (40m spans), three supports (20m spans), five supports (15m spans) and seven supports (10m spans). To summarise, the results of the analyses are presented in Table 1 for excavation of the pipeline with no supports, and excavation of the pipeline with supports placed every 20m (note the analyses suggested that a span of 40m would be acceptable, although the results of the analysis was close to the performance acceptance limit, hence 20m spacing was considered optimum for Option A).

Parameter	Acceptance limit	Result (no shell)		Result (with shell)	
	[N/mm²]	[N/mm²]	[% SMYS]	[N/mm²]	[% SMYS]
Analysis: full 80m excavated, with no pipe supports					
Max. deflection mid-span$	-	314mm	-	856mm	-
Von Mises equivalent stress	495.9	428.4	77.7	684.0	124.1
Membrane stress	440.8	428.4	77.7	684.0	124.1
Max. shear stress	248.4	6.5	1.2	17.9	3.2
Analysis: full 80m excavated, with supports every 20m					
Max. deflection mid-span$	-	2.6mm	-	6.8m	-
Von Mises equivalent stress	495.9	333.7	60.6	342.8	62.2
Membrane stress	440.8	333.7	60.6	342.8	62.2
Max. shear stress	248.4	1.1	0.2	2.9	0.5
Notes:	*$ Max. deflection at mid-span is an absolute displacement value given in 'mm' Greyed out cells – acceptance limit exceeded (not acceptable)*				

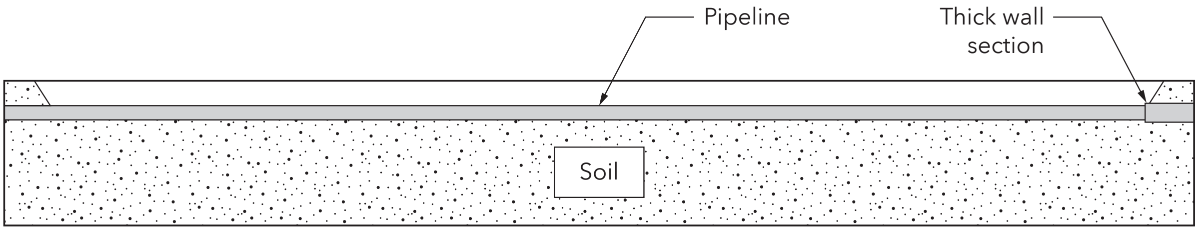
Table 1: Pipeline support – full length excavation

For **Option B**, individual analyses were undertaken for each excavated section in the sequence of operations to confirm that the stresses within each were not greater than the acceptance limits. Each section was assessed as acceptable. The results are presented in Table 2. As can be seen, the results are comparable to those for a full 80m excavation with temporary supports every 20m. However, the results are dependent on the strength of the soil backfill being adequate to support the pipeline.

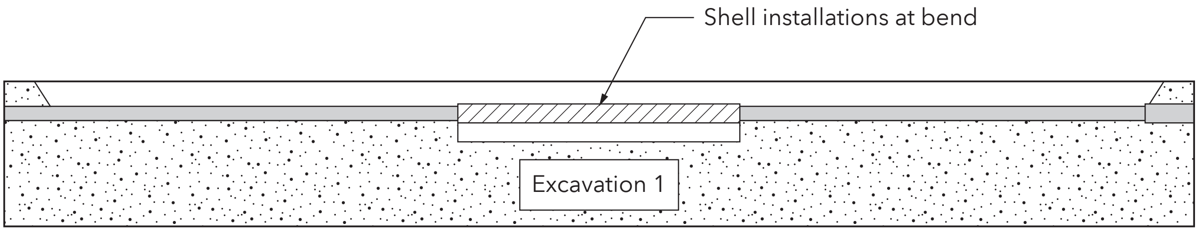
Parameter	Acceptance limit	Result (no shell)		Result (with shell)	
	[N/mm²]	[N/mm²]	[% SMYS]	[N/mm²]	[% SMYS]
Analysis: full 80m excavated, with supports every 20m					
Max. deflection mid-span$	-	2.6mm	-	6.8m	-
Von Mises equivalent stress	495.9	333.7	60.6	342.8	62.2
Membrane stress	440.8	333.7	60.6	342.8	62.2
Max. shear stress	248.4	1.1	0.2	2.9	0.5
Analysis: full 80m crowned, sequentially excavate 20m spans					
Max. deflection mid-span$	-	-	-	6.0m	-
Von Mises equivalent stress	495.9	-	-	345.4	62.7
Membrane stress	440.8	-	-	345.4	62.7
Max. shear stress	248.4	-	-	2.9	0.5
Notes:	*$ Max. deflection at mid-span is an absolute displacement value given in 'mm'*				

Table 2: Comparison of stress concentrations

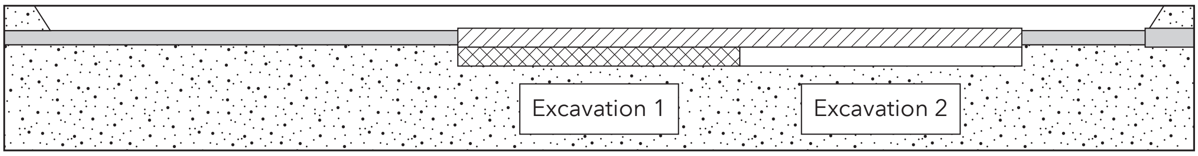
The excavation scheme, adopted by National Grid was Option B. A summary of the procedure is given below;



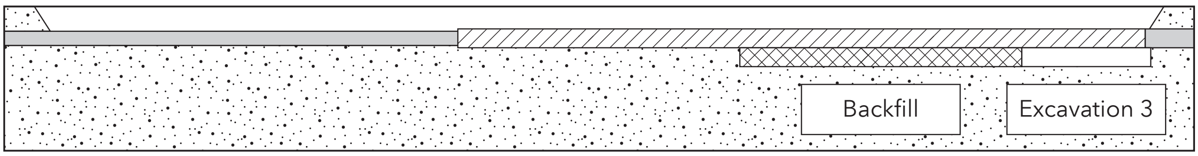
Expose the pipeline to reveal its crown, for a length of 83m.



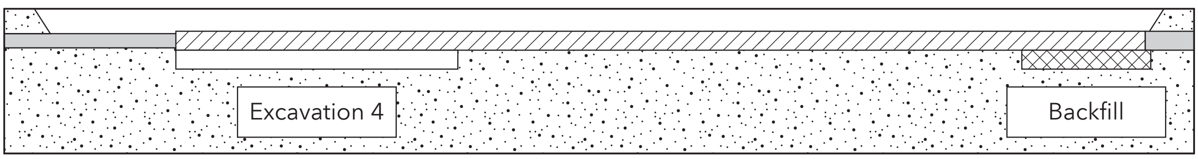
Excavation 1: To extend 10m either side of the 30° forged/induction bend.
Install shells per plan, backfill to the crown of the pipe.



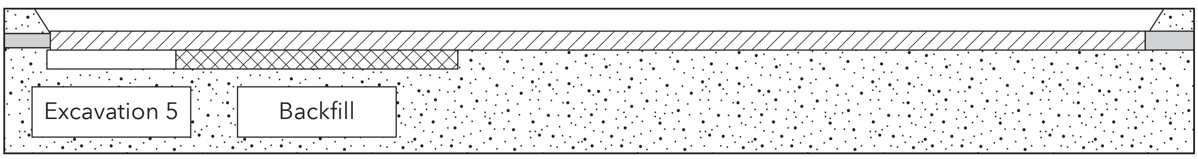
Excavation 2: Excavate pipeline for 20m, towards the head wall (South-East, Figure 3).
Install shells per plan, backfill to the crown of the pipe.



Excavation 3: Excavate pipeline for 10m, from Excavation 2, up to the head wall. Install shells per plan, backfill to crown of pipe.



Excavation 4: Excavate pipeline for 20m, from the 30° bend, towards the field boundary (North-North West, Figure 3).
Install shells per plan, backfill to crown of pipe.



Excavation 5: Excavate pipeline for 13m, from Excavation 4, to the field boundary.
Install shells per plan, backfill to crown of pipe.

Although National Grid and the Works Contractor aimed to achieve zero settlement after backfilling of the pipeline, a small amount of settlement after completion of works was considered inevitable. Excessive settlements can lead to unacceptable service conditions for pipelines and so an appreciation of potential settlement was deemed important.

A maximum settlement of 20mm displacement along the length of the shelled pipeline was considered most likely, based on historical works undertaken by the Contractor, for National Grid. However, additional analyses were undertaken assuming a hypothetical worst-case maximum settlement of 50mm displacement across the span of the pipeline. The results of both analyses confirmed that the stresses were not greater than the acceptance limits. Consideration was then given to future road usage (HB45 loading was applied), as well as the potential for impact on the pipeline during its service life (a 20t load, simulating impact from a digger bucket was applied at a series of positions along the length of the pipeline, to confirm the highest stress along the section). The results assuming 'worst case' settlement of 50mm displacement, and a 20t impact load, are presented in Table 3.

Parameter	Acceptance limit	Result	
	[N/mm²]	[N/mm²]	[% SMYS]
Von Mises equivalent stress	495.9	449.8	81.6
Membrane stress	440.8	419.2	76.1
Max. shear stress	248.4	10.2	1.9

Table 3: Post work settlement stresses (worst case, 50mm displacement, with 20t impact load)

■ Key observations

The following are key points taken from the above analyses that consider pipeline excavation and reinstatement;

- Installation of the shells should be undertaken using Option B; expose the length of the pipeline to the crown, and undertake five off sequential excavations, shelling and backfilling the excavation before proceeding with the next excavation.
- For pipeline reinstatement, the depth of cover would need to increase to 1.91m (from 1.7m) with 0.32m of road structure; following discussions between National Grid and the Road Developer, the depth of cover on reinstatement of the pipeline was increased to 1.96m, with 0.32m of road structure.
- Assuming a 'worst case' settlement of 50mm displacement, and a chance impact from a digger (20t impact load), the stresses are within the performance acceptance limits.

Evaluation of Inter-Coat Adhesion and Shear Strength

Traditionally, prior to fitting an epoxy shell to a damaged section of a pipeline, the pipeline coating is required to be removed and the substrate blast cleaned to facilitate adhesion between the pipe, the epoxy grout and the repair shell. Most epoxy shells have been applied to pipe that has been coated with coal tar enamel (CTE), poly-ethylene (PE) or tape coatings, which are relatively easy to remove. Feeder 28 has an FBE coating applied to provide corrosion protection. FBE coatings are extremely difficult and time consuming to remove and there is general consensus that they are sufficiently well bonded to the pipe not to compromise the adhesion of the epoxy grout. Prior to application of the epoxy shells, sweep blasting of the FBE coating was proposed to provide a mechanical key for adhesion of the epoxy grout. To quantify this, a series of laboratory experiments were undertaken to assess the adhesion of the epoxy grout when applied directly to the FBE coating, and when applied after sweep coating of the FBE.

FBE coatings absorb water during service, which can compromise their adhesion to the pipe surface. In addition, water permeation into the FBE may also compromise its inter-coat adhesion with the epoxy grout. However, although the adhesion of the FBE coating is compromised by water ingress, the process is reversible and a period of drying (e.g., following excavation of the pipeline to facilitate installation of the shells) can result in a significant recovery in adhesion. The effect of absorption and desorption of water was also evaluated experimentally.

Adhesion testing

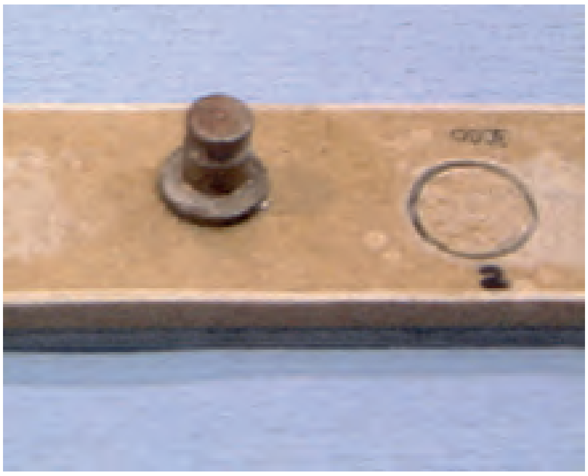
For evaluating the cohesive strength and inter-coat adhesion to the FBE, steel plates (300x50x6mm, length, width, thickness) were coated with FBE (350-450µm thickness) at a temperature of 240°C and allowed to cure for 3 minutes prior to water quenching. The test plates were conditioned as follows;

I. No conditioning
II. Water immersion for 7 days at 50°C
III. Water immersion for 14 days at 50°C
IV. Water immersion for 7 days at 50°C, followed by drying for 24 hours at 20°C
V. Water immersion for 14 days at 50°C, followed by drying for 24 hours at 20°C

The epoxy grout was cast at a thickness of 6mm over the surface of the FBE, which was prepared by one of two methods;

I. No surface preparation
II. Sweep blasted with a 50:50 mixture of G12 and G24 steel grit

The adhesion test involved gluing dollies to the surface of the epoxy grout using a cyanoacrylate adhesive. A hole saw was used to score around the adhesion dolly to ensure that the pull-off force applied to the dolly was always acting over the same test area. The pull-off force was applied perpendicular to the coating's surface using a hydraulic unit. The test procedure is shown in Figure 6.



(a) Glue dolly to surface

(b) Trepan (around dolly) using hole-saw

(c) Test
Figure 6: Adhesion test procedure

Pull-off values, which are representative of the tensile strength of the material, or adhesion to the substrate, were determined at 20°C. The results of the testing for the different conditions and surface preparation are shown in Figure 7.

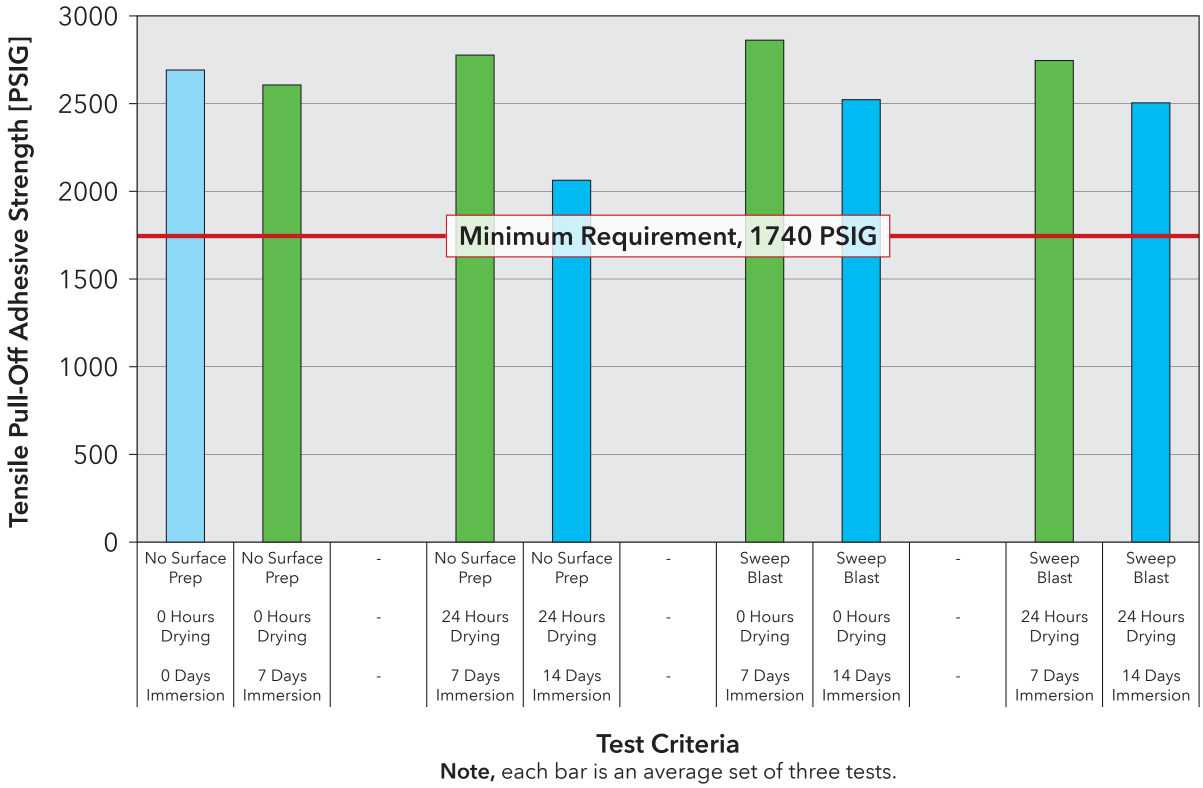


Figure 7: Adhesion test results

Shear Testing

Steel plates (150x25x6mm, length, width, thickness) were coated with FBE (350-450µm thickness) at a temperature of 240°C and allowed to cure for 3 minutes prior to water quenching. The test plates were conditioned as follows;

I. No conditioning
II. Water immersion for 7 days at 50°C
III. Water immersion for 14 days at 50°C
IV. Water immersion for 14 days at 50°C, followed by drying for 24 hours at 20°C

After conditioning, shear test specimens were prepared by creating a 25x25x6mm wide mould at the ends of two of the FBE coated test plates, which had been prepared by one of two methods;

I. No surface preparation
II. Sweep blasted with a 50:50 mixture of G12 and G24 steel grit

The epoxy grout was poured into the mould and excess material removed. Preparation of the test specimen is shown in Figure 8.

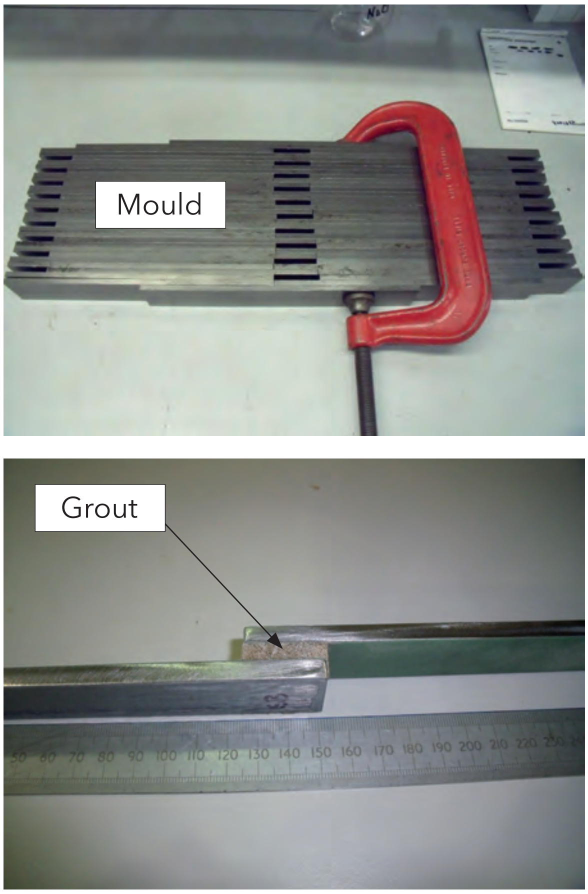


Figure 8: Lap shear test specimen

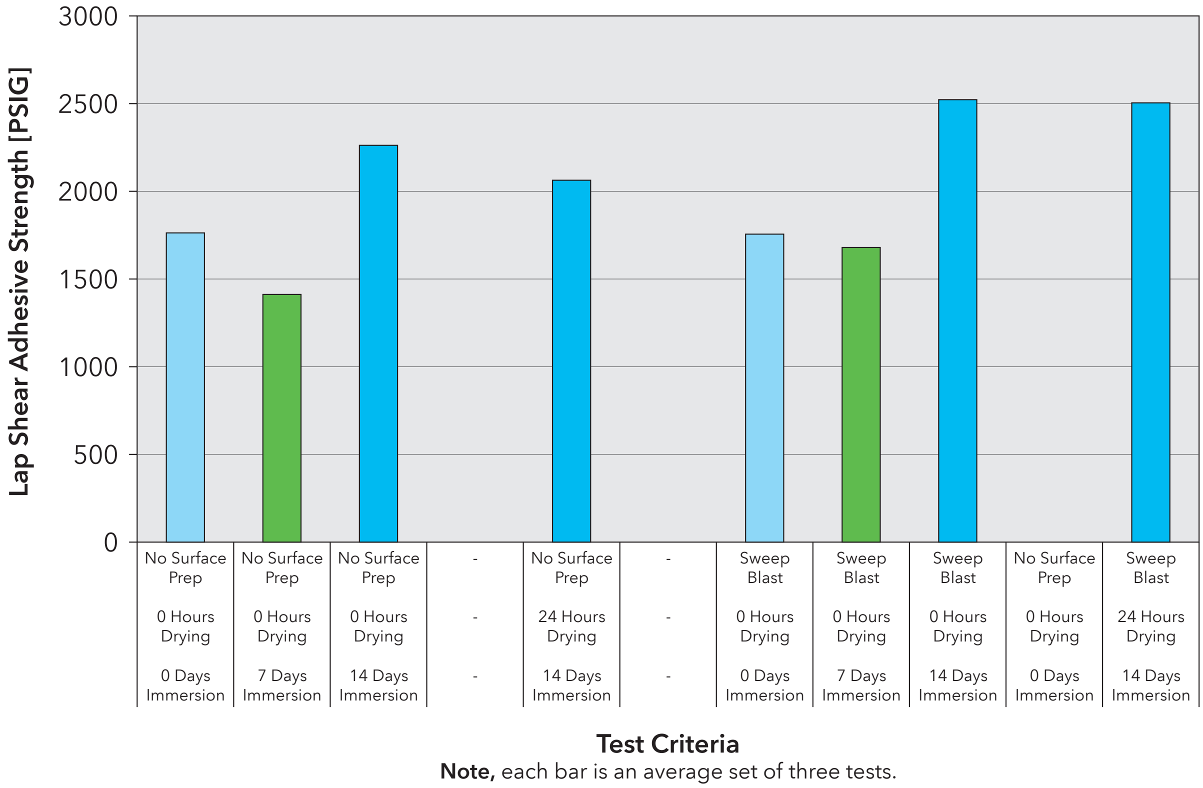


Figure 9: Lap shear test results

Lap shear tests were performed against ASTM D1002 [9] to determine the tensile strength at 'break' and the mode of failure of the epoxy grout. A summary of the results is given in Figure 9.

■ **Key observations**

The following are key points taken from the above analyses that consider inter-coat adhesion and shear strength;

- When applied to a dry FBE coating the pull-off adhesion strength of the epoxy grout exceeded the minimum tensile bond strength (1740 PSIG) required from an epoxy grout intended for use in pipeline repair shells
- When applied to an FBE coating that had been subjected to water immersion at 50°C for 7 and 14 days, the pull-off adhesion strength still exceeded this minimum tensile bond strength
- Lap shear specimens, which had been sweep blasted, gave high tensile values, albeit lower than those achieved from pull-off adhesion tests. Although reduced tensile values were recorded when tests were conducted on FBE that had been immersed in water for 14 days, drying out of the FBE for 24 hours resulted in values that were comparable to those achieved on dry FBE surfaces
- The adhesion of the FBE to the steel substrate was greater than the cohesive strength of the epoxy grout even after 14 days' water immersion at 50°C
- Based on the results of the tests undertaken, the surface of the existing FBE mainline coating on Feeder 28 should be sweep blasted prior to application of the epoxy shells

Site Installation

The following are a series of pictures that show various stages during the installation of the epoxy shells at the Red Roses location;

(a) Installation of fabricated shell at 30° bend

(b) Continuation of shells, towards head wall

(c) Installation of continuity shell

(d) Installations continue

(e) Finish installation of continuity shells
(note CP connection points)

(f) Assuring electrical continuity for CP system

Update of IGEM/TD/1

On successful completion of Red Roses the TD/1 Panel of Experts proposed an amendment to IGEM/TD/1 Edition 5 to include an option to use alternative methods, such as epoxy shells, to provide protection to a pipeline where there has been a change to traffic routes. The clause is written as follows;

6.10.4 Changes to traffic routes (roads and railways)

Additional traffic routes or modifications to existing routes on a pipeline represent a significant increased risk of third party damage throughout the construction and over the remaining life of the pipeline. The additional traffic also increases the population exposure to risk from the pipeline. The pipeline design and integrity shall be reviewed in order to manage the additional risks over the life of the pipeline.

Where the addition of a new traffic route or construction work to upgrade an existing traffic route impacts upon the design of a pipeline, the pipeline shall be modified to meet the requirements of clauses 6.10.2 to 6.10.3.

If it is not reasonable or practicable to modify the pipeline to meet the requirements of clauses 6.10.2 to 6.10.3, appropriately designed and specified protection agreed by the operator may be installed.

Note: *Appropriate protection includes the use of specially designed epoxy shells.*

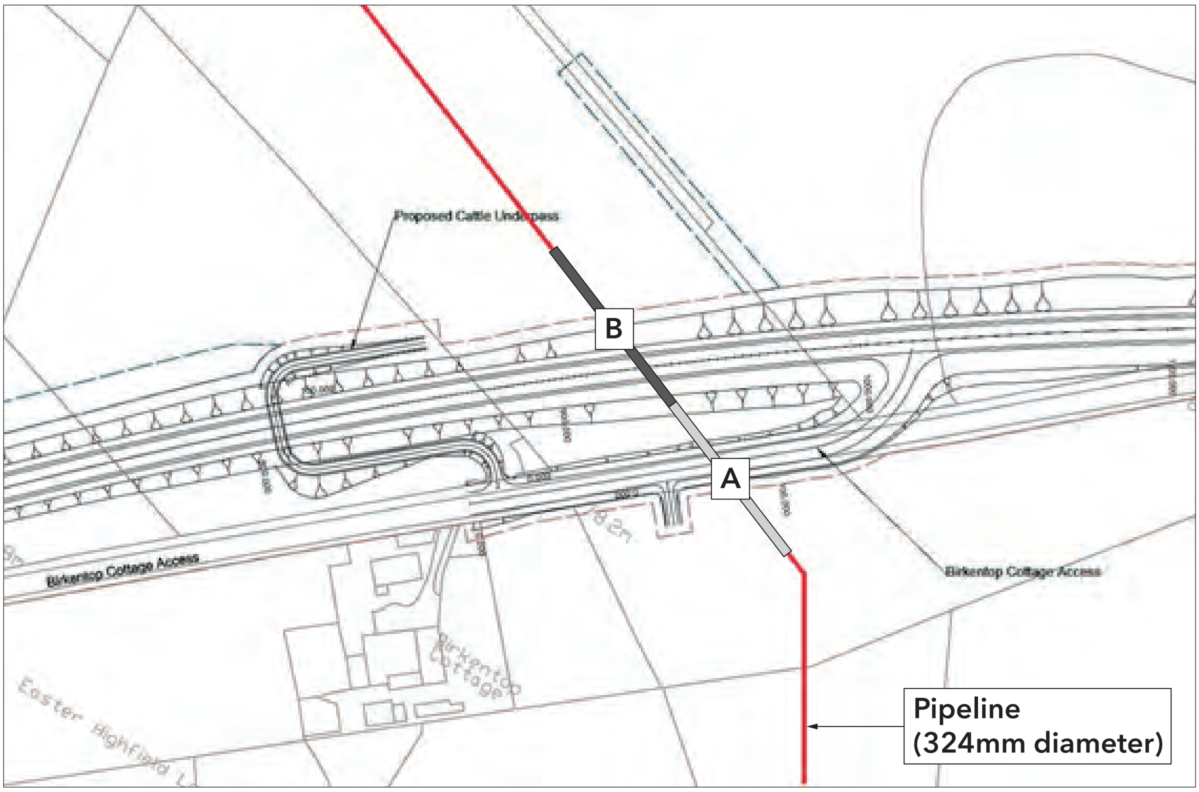
If it is not reasonable or practicable to carry out the required modifications to the pipeline or the installation of appropriately designed and specified protection, a documented safety evaluation, including a quantified risk analysis, may be carried out in accordance with Section 6.8.

A Second Installation - Dalry, Scotland

Following the success of the pipeline reinforcement at Red Roses, DNV GL has carried out a second installation. This was for SGN, to facilitate construction of a new bypass on the A737, at Dalry, by Transport Scotland.

The pipeline was constructed in 1978, to the requirements of IGEM/TD/1, Edition 1 [10] and has a diameter and nominal wall thickness of 324 x 7.1mm. The pipeline is constructed from seamless, grade X46 line pipe. The maximum operating pressure of the pipeline is 39.3 Bar.

As can be seen in Figure 10, a nitrogen sleeve (marked 'A') was laid for the original road construction, but it does not extend far enough to facilitate construction of the new bypass. Only standard wall thickness pipe is laid where the new bypass will be constructed, hence the pipeline will be non-compliant with IGEM/TD/1 for the density of traffic that will pass over. The pipeline needs to be reinforced a further 48m, from the end of the nitrogen sleeve. Aware of the Red Roses reinforcement project, SGN enquired about the potential use of epoxy technology, as an alternative to the solution that they were considering; a diversion utilising standard and thick walled pipe, HDD (horizontal directional drilling) for routing under the road, connection to the existing pipeline by a double stopple and by-pass operation.



A Existing sleeve (nitrogen filled) B Length of pipeline to reinforce

Figure 10: Pipeline route and road layout, showing length of pipeline for reinforcement

Design of the Dalry Epoxy Shells

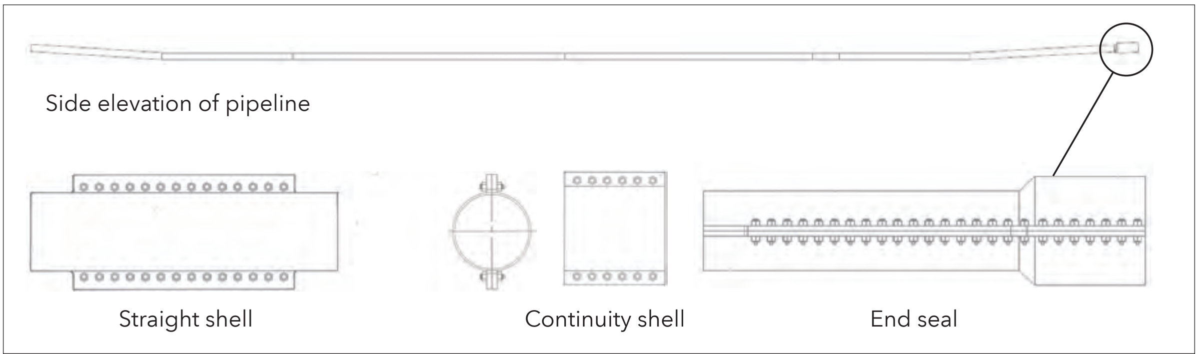
The shells were designed in accordance with T/SP/F/15, with the following considerations;

- Wall thickness of shell to be equivalent to that of the pipe
- Shell to be of equivalent strength to that of the pipe
- Continuation of shell assembly
- Point load stress concentrations from centralising bolts
- Longitudinal flange design
- Continuity of CP

For grade X46 line pipe, T/SP/F/15 recommends that the shell is fabricated from P460 NL1 steel. As this has a higher yield strength than the line pipe, a plate thickness of 10mm was used.

Despite two off 3° sag bends, only straight epoxy shells of length 1.5m and 2.0m were required. In addition, an end sleeve was required to connect to the existing nitrogen sleeve end seal. As with Red Roses, 500mm length continuity shells were also designed, to bridge the gap between adjacent pipeline shells (approximately 100mm), overlapping the end of each pipeline shell by 200mm. A detailed stress analysis was undertaken to confirm suitability of the designs. The analyses considered the pipeline maximum operating pressure (39.3 Bar) which is equivalent to a nominal hoop stress in the pipeline of approximately 28% SMYS, and an internal pressure equivalent to a nominal hoop stress of 100% SMYS.

An overview of the shell designs and requirements for Dalry is given in Figure 11.



Quantity	Shell Design
19	2.0m long straight shell with stepped flange at both ends
3	1.5m long straight shell with stepped flange at both ends
23	0.5m long continuity shell
1	End seal to connect to existing nitrogen sleeve end seal
1	2.0m long shell with stepped flange at one end
Note: Designed so that all girth welds are located centrally within a 1.5m or 2.0m long sleeve	

Figure 11: Layout and requirements for Dalry epoxy shells

Unlike Red Roses, prior to installation of the shells, the pipeline was grit blasted to surface cleanliness SA-2½, which is the standard method for surface preparation when installing an epoxy shell for the repair of pipeline damage. The inside surfaces of each shell were also grit blasted to ensure good adhesion between the pipe, the epoxy grout and the shell.

Pipeline Excavation

The same method that was used for Red Roses, to assess different excavation lengths and support scenarios, was used for Dalry. As there was only a requirement to reinforce 48m of pipeline, two options were considered;

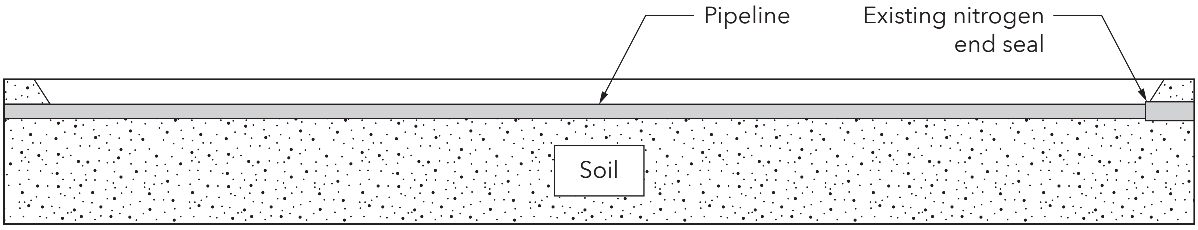
Option A. Excavate the whole 48m length of the pipeline and use temporary structural supports,
Option B. Expose 48m length of pipeline to the crown, sequentially excavating two overlapping 24m sections of the pipeline, at a time, and backfilling to provide support to the shelled section of pipeline.

SGN had commissioned site specific ground investigations for the A737 Dalry bypass scheme; these were undertaken by White Young Green Ltd and Ian Farmers Associates. This information, together with BGS geological maps, was used by DNV GL to assess the different excavation options.

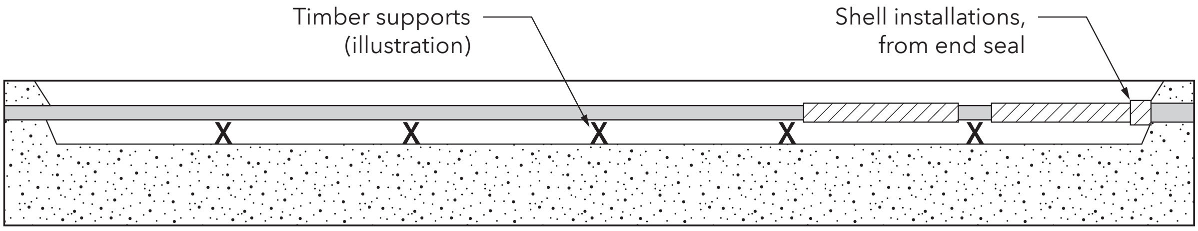
For both options, analyses were undertaken of the pipeline with and without the shells, and the results of the analyses were compared to the performance acceptance limits specified in T/SP/GM/1 (note, the limits are different to those for Red Roses due to differences in line pipe material grade).

The excavation scheme, adopted by SGN, was Option A, with five supports positioned at increments along the pipeline of between 6 and 10m; the shorter increments were for the positioning of the first support from the nitrogen sleeve, and between support 3 (at mid span) and support 4.

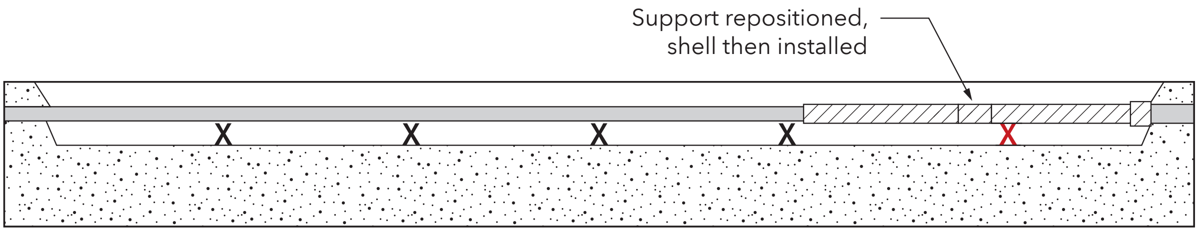
Additional analyses were undertaken to support re-positioning of the supports, under installed shells, to facilitate installation of the shells at the original support locations. A summary of the procedure is given below;



Expose the pipeline to reveal its crown, for a length of 48m.



Excavate full length of pipeline to be reinforced, positioning temporary timber supports as excavation progresses. Shell installation commences from existing nitrogen end seal



New support installed under shell, adjacent to existing support. Support then removed to facilitate installation of shell at original support location

Pipeline Reinstatement

A detailed assessment was undertaken, using the methods described for Red Roses, to identify the 'worst case' pipeline displacement and stresses on reinstatement of the backfill and siting of a concrete protection slab on top, which was to provide added protection.

For Red Roses, stresses were predicted along the pipeline for a maximum anticipated displacement, and these were then compared against performance acceptance limits in T/SP/GM/1. In contrast, for Dalry, the model was used to predict worst-case displacements (vertical and longitudinal) along the pipeline length and stresses within the pipeline, which were then compared with the performance limits to confirm acceptance of the reinstatement scheme. The model considered the following assumptions;

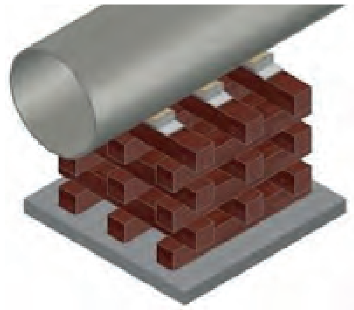
- The soils are homogenous and isotropic
- The backfill material for the excavation comprised in-situ re-worked cohesive soil (weight; 196 kg/m)
- The embankment fill comprised engineered granular fill (weight; 206 kg/m)
- The soils exhibit Mohr-Coulomb behaviour, except for the bedrock and embankment fill which were modelled as linear-elastic
- The concrete slab was modelled as linear-elastic non-porous material (weight: 235 kg/m)

The worst-case displacements were predicted to be 45mm vertical and 4mm longitudinal. Furthermore, the corresponding stresses within the pipeline did not exceed the performance acceptance limits in T/SP/GM/1.

Site Installation

The following are a series of picture that show various stages during installation of the epoxy sleeves at the Dalry location;

(a) Shells installed in excavation



(b) Timber support

(c) Continuity shell (prior to sealing the ends and epoxy grout injection)

(d) End seal connection to existing pipeline nitrogen sleeve

Industry Recognition

As a result of the Red Roses project, DNV GL was awarded the 2016, Landbased/Onshore Pipeline Technology Award from The Pipeline Industries Guild.

Acknowledgements

The authors would like to acknowledge the support of the IGEM/TD/I Panel of Experts.

This paper was first published and presented at the Technology for Future and Ageing Pipelines conference (TFAP), held 10-12 April 2018, in Gent, Belgium. Permission from the event organiser to re-publish is much appreciated

Conclusions

The following relate to the pipeline reinforcement works at the Red Roses location;

1. The modifications to the pipeline were compliant with the requirements of IGEM/TD/1 Edition 5. All works were undertaken in a safe, controlled manner, to budget and time, and the pipeline continued to operate and meet the demands of Industry and consumers during the work.
2. The innovative use of epoxy shell technology and the challenges from the TD/1 Panel of Experts has resulted in an update of IGEM/TD/1, to support the future use, by the Gas Industry, of technologies such as the epoxy shell, for modifications to existing traffic (road and rail) routes.
3. The project resulted in significant cost savings to the Welsh Government, and hence consumers. Furthermore, the project was completed to budget, and within the timescales imposed by the Welsh Government, and did not impact on the schedule for the road construction works.

The following relate to the pipeline reinforcement works at the Dalry location;

1. The modifications to the pipeline were compliant with the requirements of IGEM/TD/1 Edition 5. All works were undertaken in a safe, controlled manner, to budget and time, and the pipeline continued to operate and meet the demands of Industry and consumers during the work.
2. The project resulted in cost savings to Transport Scotland, and hence customers. Furthermore, the project was completed to budget, and within the timescales imposed by SGN to meet the requirements of Transport Scotland.

References

[1] IGEM/TD/1 Edition 4, 'Steel pipelines for high pressure gas transmission', Institution of Gas Engineers and Managers, Communication 1670, 2001

[2] IGEM/TD/1 Edition 5, 'Steel pipelines and associated installations for high pressure gas transmission', Institution of Gas Engineers and Managers, Communication 1789, 2016

[3] T/SP/F/15, 'Design, manufacture and selection of epoxy grouted shells (for operating pressures 7 bar to 100 bar inclusive)', National Grid, September 2012

[4] BS EN 10028-3, 'Flat products made of steels for pressure purposes. Weldable fine grain steels, normalised', BSI, 2009

[5] BS 5400-2, 'Steel, concrete and composite bridges – Part 2. Specification for loads', BSI, 2006

[6] NEN3650-1 (+A1), 'Requirements for pipeline systems – Part 1. General – Quire 1 to 6', Nederlands Normalisatie Instituut. Delft (official English translation, August 2006)

[7] T/SP/GM/1, 'The protection of pipelines from ground movement and external loading. External loading on steel pipelines and buried piping at installations', National Grid, October 2005

[8] ASME B31. 4, 'Pipeline transportation systems for liquids and slurries. ASME code for pressure piping, B31', American Society of Mechanical Engineers, 2012

[9] ASTM D1002-10, 'Standard test method for apparent shear strength of single shear-lap-joint adhesively bonded metal specimens by tension loading (metal-to-metal)', American Society for Testing and Materials, 2010

[10] IGEM/TD/1 Edition 1, 'Steel pipelines for high pressure gas transmission', Institution of Gas Engineers and Managers, Communication 674 ABCD, 1977

Appendix A: Further Developments of the Epoxy Shell Technology

Contact: Anthony Wood (Head of Repair and Intervention: Anthony.wood@dnvgl.com, +44(0)7786 703701) for more information on the epoxy technologies and to discuss potential applications.

The epoxy grout: is a three-component pourable grout based on a Bisphenol A/F epoxy resin, blended aliphatic polyamine hardeners, blended silica sands and inert fillers containing very small quantities of respirable silica. The epoxy system has been the subject of much development to ensure that it has high stiffness, high strength, good moisture tolerance, is rapid curing (achieving 90% if its specified properties within 24 hours), has minimal shrinkage and good flow characteristics (ensuring a reliable fill of the annular gap between the shell and pipeline). There are three epoxy systems, for application temperatures ranging from 5 up to 50°C. Following installation, the operating temperature range of the system is -50 up to +125°C.

The epoxy grout is an integral part of the repair system and is a DNV GL licensed product.

Lobster-back epoxy shell: developed for the repair of damage to pipeline bends and elbow fittings.

An oversize, fabricated steel sleeve for the repair of bends and elbows of different bend radius and angle, where the annular gap between the sleeve and bend/elbow is filled with epoxy.

Benefits include:
- Can be designed for any bend radius and angle
- No welding to the pipeline required
- No disruption to the pipeline product supply
- A minimum design life of 40 years.

Grouted Tee: developed for installing a branch connection to a live pipeline without interrupting or adjusting the pipeline product supply.

Since its initial development, the technology has been developed further for thin wall pipelines, cast iron pipelines and subsea (to depths of 200m).

Benefits include:
- No requirement for onsite welding
- Can accommodate larger pipe ovality than traditional welded Tees
- No disruption to the pipeline product supply
- A minimum design life of 40 years.

Copy/paste the link (below) into your internet browser for an overview of the grouted Tee technology (duration 4:20):

https://fast.wistia.com/embed/iframe/449dvx2ewc?controlsVisibleOnLoad=true&playerColor=00618c&version=v1&videoHeight=321&videoWidth=570&volumeControl=true



Epoxy End seal: developed to enable reinstatement of steel sleeves at road and river crossings.

Older pipelines at road and river crossings were often sleeved. The ends of the sleeve were sealed to prevent the ingress of soil and water, and the annular gap between the pipe and sleeve was filled with an inert gas (e.g., Nitrogen) to prevent corrosion. Over time, the effectiveness of the end seal to contain the nitrogen can reduce. Installation of an epoxy end seal enables retrospective nitrogen filling of sleeves already installed.

Benefits include:
- No requirement for pipeline intervention
- No disruption to the pipeline product supply
- Concentric and eccentric fit ups
- A minimum design life of 40 years


Domed epoxy repair: developed to enable encapsulation of damaged or corroded fittings.

There may be occasion when, for example, a pipeline fitting is accidentally damaged, corrosion is active either on the fitting or the carrier pipe itself, or cracking has initiated due to vibration and is propagating. The domed repair is an effective repair system; the annular gap between the domed repair and pipe/fitting is filled with epoxy, fully encapsulating the fitting.

Benefits include:
- No requirement for pipeline intervention
- No disruption to the pipeline product supply
- Elimination of vibration related stresses
- A minimum design life of 40 years.



Epoxy pipe clamp: developed to enable the repair of small diameter, high pressure pipework.

Initially developed for the repair of sealant injection pipework attached to ball valves. The design pressure rating of the pipework is 10,000 psi. The epoxy technology was adapted due to there being no repair system commercially available.

Benefits include:
- Designed to withstand pressure up to 20,000 psi
- Repair of pipe diameters from ½ to 2" (sealant and vent pipework)
- Snug fit to valve body
- A minimum design life of 40 years.



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