Improving the Fatigue Performance of SCRs via a Special Touchdown Zone Pipe Section

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Abstract
A special section of seamless pipe machined on the inside and outside to have upset ends is used at the touchdown zone of a 20in oil export steel catenary riser (SCR) in order to improve the fatigue life. This paper covers the drivers for the choice of this special section, procurement, management of challenges, and lessons learned. The chain of supply (pipe, machining, coating, welding, and fatigue testing) involved several suppliers across several countries posing another challenge.

Introduction
Starting with the first SCRs installed in the Gulf of Mexico in 1994, SCRs have been an attractive solution to develop offshore oil and gas fields due to several factors including cost, relatively easy installation, relatively long track record, and reliability. However, fatigue life of the welds is a main issue for SCRs and can pose a significant challenge depending on many factors.

The 20.0in x 1.0in oil export SCR in consideration uses seam-welded X65 pipe and is tied back via a titanium tapered stress joint at an 18° hang-off angle to the host floater in approximately 5000ft water depth. Its weld fatigue life in the critical touchdown zone (TDZ) fell significantly short of the required 20 year design life. Vortex-induced vessel motion (VIM) was the main contributor to the fatigue damage. Increasing the SCR hang-off angle, refining the design, reducing design conservatism to reasonable levels, and making provisions to reduce the hi-lo and improve the stress concentration factor failed to achieve the required design life. Managing the location of the high fatigue damage at the TDZ by relocating the vessel was not an option. Consequently, improving locally the pipe section modulus at the TDZ welds over the required length by using upset ends was chosen as a good solution, i.e. inserting a special fatigue-resistant section at the TDZ. The length of this special TDZ section accounting for vessel movement due to future SCR tiebacks, installation tolerances, and including margin was calculated to be 360ft. The thickness of the upset ends was calculated to be 1.25in. The upset length was fixed at 14in to accommodate installation requirements vis-à-vis AUT (automatic ultrasonic testing) and field joint coating. A summary of the fatigue life at the TDZ is given in Table 1. Schematics of the SCR and the special section at the TDZ are shown in Figure 1 and Figure 2. It should be noted that the estimation of fatigue life improvement based on simple section modulus calculations was extremely close to detailed finite element analysis results of modeled upset ends.

Table 1 – Fatigue Life at the Touchdown Zone (TDZ)

<table>
<thead>
<tr>
<th>Upset Ends at the TDZ</th>
<th>Un-factored WIF Life (Years)</th>
<th>Un-factored VIM Fatigue Life (Years)</th>
<th>Un-factored VIV Fatigue Life (Years)</th>
<th>Combined Factored Fatigue Life (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Upset Ends</td>
<td>528.6</td>
<td>202.4</td>
<td>2.38 E+06</td>
<td>13.9</td>
</tr>
<tr>
<td>With Upset Ends</td>
<td>2,416</td>
<td>925</td>
<td>1.09 E+07</td>
<td>63.5</td>
</tr>
</tbody>
</table>

Note: The un-factored fatigue life does not include safety factors. The combined factored fatigue life includes safety factors of 10 for WIF (wave-induced fatigue) and VIM (vortex-induced vessel motion) fatigue, 20 for VIV (vortex-induced vibration) fatigue, and 5% allowance of the overall combined fatigue life for installation.
Achieving upset ends
Several options were considered to achieve the upset ends for this special TDZ section:

1. Short thick forgings welded to the seam-welded pipe ends with high-quality girth welds qualified to C-class fatigue performance. This was a very attractive option from cost and schedule perspective; however, concerns (absent project specific fatigue test data at the time) over the pipe seam weld failing before the forging-to-pipe high-quality girth weld rendered this option less desirable.
2. Forged pipe with upset ends. Very high cost and long schedule of this option rendered it unacceptable.
3. Seamless pipe machined down on the inside and outside to achieve the upset ends. This option was the preferred solution based on its cost and schedule benefits and elimination of concerns over the seam weld.

Special Section Pipe Manufacture
The X65 seamless pipe for this special section at the TDZ was manufactured at a pilger mill in Germany. In order to obtain the 1.25in upset end thickness after machining the inside and outside of the pipe and considering the manufacturing tolerances, the required pipe thickness was 2.2in. At this thickness, the maximum pipe length that could be produced was 26.25ft. In order to maintain the installation procedures of the standard 40ft-long seam-welded SCR pipe and observe installation limits, the produced pipe length with upset ends was chosen at 20ft. Drawings of the special section joints are shown in Figure 3 and Figure 4. Actual produced joints are shown in Figure 5.
Figure 3 – Special TDZ Section Joint with Upset Ends at Both End (Typical Joint)

Figure 4 - Special TDZ Section Joint with Upset End at One End (Transition Joint)

Figure 5 – Special TDZ Section Joints in Germany Prior to Machining
Special Section Pipe Machining
Following fabrication, the pipe was transported to Italy for machining on the inside and outside as per the agreed machining tolerances (on the inside diameter and wall thickness) and surface finish. Machined joints are shown in Figure 6.

![Figure 6 – Special TDZ Section Joints During and after Machining in Italy](image)

Special Section Fabrication
The special section was fabricated by the installation contractor as follows:

1. The 20ft-long joints with upset ends at both ends were double-jointed onshore in Croatia making 40ft-long joints.
2. The 40ft-long joints with upset ends at both ends (and in the middle after double jointing) were triple-jointed in the pre-fabrication area onboard the installation vessel in order to make 120ft-long triple joints to be fed into the firing line similar to the rest of the SCR pipe.
3. The 20ft-long joints with upset ends at one end were welded to 20ft-long seam-welded joints onshore in Croatia in order to make 40ft-long transition joints between the special TDZ section and the rest of the SCR pipe.
4. The 40ft-long transition joints with upset end at one end were welded to two 40ft-long seam-welded pipe (at the non-upset end) in the pre-fabrication area onboard the installation vessel in order to make 120ft-long triple joints to be fed into the firing line similar to the rest of the SCR pipe.
5. The 120ft-long triple joints were welded together in the firing line to make the SCR.

The welding procedures for the upset ends onshore (double-jointing) and offshore (triple-jointing and in the firing line) were made the same in order to reduce the number of weld procedure qualifications (WPQs), the number of fatigue tests, the complexity of fabrication and installation, and cost.

A duplicate set of the double joints of this special TDZ section was fabricated for a spare as a contingency against pipe collapse during installation. Double-jointing is shown in Figure 7. Double joints packed and ready for shipping are shown in Figure 8.

![Figure 7 – Double-jointing 20ft-long Joints in Croatia to make 40ft-long Joints](image)
Special Section Pipe Coating
The standard SCR pipe was coated in Louisiana in a typical coating run with a three-layer polypropylene coating (3LPP). However, due to the impact of the upset ends on the pipe run speed vis-à-vis the coating line rollers and therefore coating thickness and more importantly heating temperature, it was not possible to coat this special section like the rest of the pipe joints. Consequently, the 40ft-long double-jointed pipe was transported to Conroe, Texas and coated with a single-layer 100% solids epoxy coating. Typical coated joints are shown in Figure 9.

Special Section Test Pipe
Eleven 20.5in x 1.25in x 26.25ft pipe joints and two 20.0in x 1.0in x 26.25ft pipe joints were procured for weld procedure qualification (WPQ), AUT validation, fatigue testing, and coating testing.

Special Section Installation
The special section triple joints were welded together in the firing line with due diligence applied in welding the joints in the correct location/section of the SCR. The field joints were coated with fusion bonded epoxy (FBE) and covered with heat-shrink sleeves over epoxy primer.

Special Section WPQ Program
Two full WPQ programs were conducted at the installation contractor’s facility in Croatia; one covering the upset end welds (procedures A, B, and C below) and one covering the transition welds (procedure D below). Making the onshore and offshore welding procedures the same for the special TDZ section was decided upon for schedule and cost efficiency and reduction of complexity. Thus, the WPQ covered the following procedures:

A. Upset end-to-upset end seamless pipe—firing line procedure: 1.25in- to 1.25in-thick pipe for offshore welding of 120ft-long triple joints in the firing line onboard the installation vessel.
B. Upset end-to-upset end seamless pipe—triple jointing procedure: 1.25in- to 1.25in-thick pipe for offshore welding of 40ft-long (double) joints into 120ft-long triple joints in the pre-fabrication area onboard the installation vessel—this procedure was identical to the firing line procedure; hence, covered by the same WPQ program above.
C. Upset end-to-upset end seamless pipe—double jointing procedure: 1.25in- to 1.25in-thick pipe for onshore welding of 20ft-long joints into 40ft-long double joints—this procedure was also identical to the firing line procedure; hence, covered by the same WPQ program above.
D. Seamless pipe to seam-welded pipe, firing line procedure: 1.0in-thick seamless pipe to 1.0in-thick seam-welded pipe for onshore welding of 20ft-long joints into 40ft-long joints for the transition welds from the special TDZ section to the standard seam-welded pipe section.
**Special Section Fatigue Test Program**

A full-scale fatigue test program with 4 welds at each of three stress ranges was performed in the UK for the following welds:

A. 1.25in-thick seamless pipe to 1.25in-thick seamless pipe covering the upset ends (firing line procedure, onshore and offshore).

B. 1.0in-thick seamless pipe to 1.0in-thick seam-welded pipe covering the special section-to-standard pipe transition welds (firing line procedure, onshore).

Schematics of the fatigue test samples (each with two welds) are shown in Figure 10 and Figure 11. A typical fatigue test setup is shown in Figure 12. While all the welds passed successfully, important lessons were learned regarding the seam welds and the pipe parent material.

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**Figure 10** – Schematic of a Fatigue Test Sample of a Typical Joint with Upset Ends (20.5in X 1.25in Pipe)

**Figure 11** – Schematic of a Fatigue Test Sample of a Transition Joint (20.0in X 1.0in Pipe)

**Figure 12** – Typical Fatigue Test Setup

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Challenges
Several challenges were faced in procuring this special TDZ section:

1. Manufacturing: Limited number of suppliers of pipe joints of this diameter and thickness.
2. Machining: Machining was initially in the pipe supplier’s scope; however, it had to be performed in Italy after the pipe supplier decided not to take it on.
3. Welding, AUT validation, and fatigue Testing: Development of two additional WPQ programs, AUT programs, and two full-scale fatigue test programs in an already tight schedule.
4. Coating: Concerned with “burning” these expensive joints and based on experience of another project, the coating contractor concluded that its 3LPP coating process could not accommodate upset ends. This required a full qualification and test program of a single layer, 100% solids epoxy coating.
5. Transportation and logistics: Transporting pipe across several countries faced hurdles in terms of customs and taxes.
6. Installation: Special consideration had to be taken into account onboard the installation vessel to maintain the location of the special TDZ joints and TDZ transition joints.

Lessons Learned
The following lessons were learned from the procurement and fabrication of this special TDZ section:

1. Sufficient float should be included in the procurement and fabrication schedule to allow for recovery when tasks do not go as planned such as encountered in the machining, coating, and shipping scopes.
2. Only formal quotes (in writing) from suppliers should be relied upon for cost, schedule, and especially for scope of work in order to avoid having to make alternative plans in a tight schedule.
3. It is best to use suppliers that have a successful track record of supplying similar specialty items where possible.
4. Code criteria of a B2-fatigue curve for seam welds and a B1-fatigue curve for pipe parent material should not be taken at face value—failures in the seam welds and pipe parent material were observed before meeting the code criteria.
5. The effort and interfaces required for the design, procurement, fabrication, and installation of specialty items should not be underestimated.
6. The effort and logistics required to transport the pipe between different countries vis-à-vis customs and taxes (origin, final destination, number of joints at each stop, currency conversion, etc.) should not be underestimated.
7. It is best to use local expeditors and shipping companies in every country where possible.
8. The effort and cost required for inspection should not be underestimated.
9. Plans and schedule should account for the month of August in Europe (summer vacation).

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