EPRG Guidelines on the Assessment of Defects in Transmission Pipeline Girth Welds – Revision 2014

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The 1996 edition of the EPRG guidelines on the assessment of defects in transmission pipeline girth welds has been reviewed to extend their range of application. The revised 2014 guidelines replace and retain the three Tier structure of the old guidelines. The 2014 guidelines can be used for pipe grades up to X80 and defect heights greater than 3 mm. A novel defect interaction criterion is given for co-planar defects in girth welds which comply with the EPRG material and performance requirements. Additionally, guidance on the pipe material and weld metal testing requirements is given. The new guidelines provide conservative allowable defect sizes as they are fully validated by Curved Wide Plate (CWP) test data. The guidelines are simple, transparent and can be applied by users without requiring extensive experience in fracture mechanics

INTRODUCTION

The European Pipeline Research Group (EPRG) published the first edition of their guidelines on the assessment of defects in transmission pipeline girth welds in 1996 [1][1]. They were based on existing standards and codes of practice, the analysis of extensive test data, in particular curved wide plate (CWP) and full scale tests, and the experience of EPRG member companies. These guidelines were structured in three assessment levels or Tiers and specified defect acceptance levels in Tier 1 (defined as *good workmanship*), and defect limits in Tiers 2 and 3 (based on *fitness-for-purpose*). The Tiers progressively allowed larger defects but at the expense of requiring more extensive mechanical property data, so that at the highest Tier CTOD testing was required. This multi-level approach was also adopted in Annex A of API 1104 [2] in 2007 and other pipeline welding codes.

The Tier 1 defect acceptance levels of the EPRG guidelines were essentially based on the workmanship requirements of existing codes such as API 1104 [2]. The Tier 2 defect limits were mainly derived from curved wide plate (CWP) test data and have been adopted by standards such as EN 12732 [3] and AS 2885.2 [4]. Tier 2 has been used by various EPRG member companies on major projects for both cross-country and offshore pipeline installations [5] and [6]. Tier 3 has not been widely used. The technical background to the 1996 guidelines is given in the original paper [1], which should be consulted for the background to their development.

Application of the 1996 guidelines assumes that the performance and material requirements summarized in Table 1 are satisfied. These are considered appropriate for conventional onshore and offshore transmission pipelines where the expected axial (combined tensile and bending) strain is less than or equal to 0.5 % and provide safe defect limits for stress-based designs.

Tier 1 provides the minimum standard of workmanship and provides safe girth welds when the axial stresses are within the limits of the standard loading conditions. The Tier 1 defect acceptance levels reflect the capability of radiography as the NDE technique for detecting and quantifying weld discontinuities Provided the above pipe material and weld metal properties requirements are satisfied, the Tier 2 defect length limit was seven times the thickness for a 3 mm high defect per 300 mm length of weld. This limit normally gives a substantial increase in the allowable defect size compared with workmanship standards which usually limit the defect length to either 25 mm or 50 mm depending on the defect type and location. It should also be noted that the allowable length varies with the thickness in the Tier 2 approach, whilst at Tier 1 the allowable lengths are fixed irrespective of the pipe wall

[1] As these guidelines will be referred to very frequently throughout this paper, for brevity they will be simply referred to as "the 1996 guidelines" and the bibliographic reference omitted.

thickness. Finally, comparison of large diameter full-scale pipe bend tests and tension loaded CWP tests has shown that the Tier 2 defect limit is conservative if the arc length of the CWP specimen is 300 mm (12 inches), which equates to approximately 10% of the circumference of a large diameter pipe.

MOTIVATION FOR A REVISION OF THE 1996 GUIDELINES

The 1996 guidelines were restricted to a maximum grade of X70 (L485) at Tiers 2 and 3, as this was the limit of the underlying test data available at that time. Since then, grade X80 (L555) material has become widely used with the construction of major projects in the UK, the USA, Canada and China while research programmes have generated a large amount of CWP tensile test data on X80 girth welds. Further, pipeline welding and construction technology has also evolved, most notably with the widespread use of mechanized GMAW systems for girth welds and the use of automated ultrasonic systems (AUT) for inspection. Additionally, EPRG member companies have had practical experience in using the guidelines on projects [5], [6]. However, their application to girth welds inspected using AUT involved the use of project specific testing to allow for sizing errors. All of these factors encouraged EPRG's Design Committee to initiate a project to revise the guidelines, concentrating on Tier 2.

The revisions do not include any requirements for defect sizing accuracy, as this is a function of the inspection system and the interpretation of the output. However, the user of the guidelines should be fully aware that the accuracy with which the defect can be sized is an essential input variable for the safe application of the guidelines. Further, it should be noted that use of the guidelines does not consider the effect of cyclic stresses due to pressure variations or external loads on the fatigue performance of the girth weld.

This paper presents the 2014 guidelines and an overview of the changes and the rationale for the revised version of the guidelines. Most of the proposed changes have been presented at industry conferences. The references to these presentations are given as they contain the evidence supporting the changes. For users who are familiar with the 1996 edition, it should be noted that the figures and tables required to use the 2014 guidelines are similar to the form in the 1996 guidelines so that they are suitable for use in project specifications.

EPRG WELD DEFECT GUIDELINES – REVISION 2014

As with the 1996 version, the EPRG guidelines – Revision 2014 are based on literature reviews, an extensive laboratory test programme, published experimental data and accepted fitness for purpose methods. The guidelines are structured in three tiers and specify defect acceptance levels in Tier 1 (good workmanship) and defect limits for Tiers 2 and 3 (fitness-for-purpose). The application of current welding standards can lead to quite different defect limits, but the EPRG guidelines provide uniform acceptance levels and defect limits, with a comprehensive technical justification.

The requirements for the application of Tiers 1, 2 and 3 are given in Table 1. Note that for the revised Tier 2 the defect height can vary, as detailed in Table 2, instead of being fixed at 3 mm. Detailed commentary and explanations of the requirements are given in the next section. The revised guidelines have been developed for application to new pipelines, where all the required testing can be carried out. If they are used to assess features found in an existing pipeline where only limited data are available, expert advice should be obtained.

The revised defect size limits are summarized in Tables 3 to 5. Table 3 summarizes acceptance levels for the weld geometry, covering weld cap and root profile, concavity and undercut defects. In Table 4 the acceptance levels for both planar and non-planar defects are listed. Care should be taken in using the limits for non-planar defects, to ensure that the presence of any non-planar defect does not mask the presence of other, more severe, defects. In any event the presence of large numbers of non-planar defects is an indication that the welding process is out of control and remedial action is required.

Interaction and accumulation criteria are given in Table 5. Root concavity is not included in accumulation calculations, unless it causes the weld thickness to be less than that of the pipe.

DETAILED COMMENTS, EXPLANATIONS AND FURTHER GUIDANCE NOTES

The following sections give detailed comments and explanations of the changes, concentrating on Tier 2 where the changes have been most extensive. These are provided to aid the user in applying and interpreting the guidelines. They would normally be required when applying the guidelines in project specifications; indeed it is expected that a specification could be generated by selecting the required Tier from Tables 2 to 5.

2014 GUIDELINES - TIER 1

A comparison of the Tier 1 requirements of the 1996 guidelines with those of current national and international codes for pipeline girth welding showed that there were no major differences. Thus the Tier 1 requirements for the 2014 guidelines are unchanged. Beyond the standard transverse tensile test, no specific testing is required to ensure weld- metal yield strength matching or overmatching. However, a criterion based on the weld- metal yield strength requirements of Appendix C, paragraph F303 of DNV OS-F101 [7] has been included:

> *All weld metal tensile tests may be carried out by special agreement to ensure that YS(weld metal) ≥ YS(pipe material). If such tests are carried out the weld metal yield strength should be at least 80 N/mm^2 greater than the specified minimum yield strength of the pipe in the transverse (hoop) direction*.

This requirement can be applied at the discretion of the user. Note that it is considered prudent to apply it for pipelines in high strength steels or pipelines which might be loaded axially up to the pipe material's yield strength,

2014 GUIDELINES - TIER 2

Pipe Grade Extended to X80 (Grade L555)

Analysis of the CWP data on X80 girth welds [8], [9] showed that the guidelines could be extended to include Grade X80 at Tiers 1 and 2, provided the 1996 material property requirements are satisfied. This change does not extend to Tier 3 as this is based on full scale pipe test results, and there is insufficient new data available to justify an extension. Whilst some curved wide plate testing has been carried out on girth welds in materials stronger than X80, notably on X100 materials, the results are inconclusive and the EPRG working group considered that it would be premature to extend the grade limit beyond X80. Project specific CWP or full scale tests will be required to set defect acceptance criteria for pipelines using very high strength grades above X80; alternatively fitness for purpose assessments using well tried fracture mechanics analysis methods such as BS 7910 [10] or API 579 [11] could be conducted.

Pipe Wall Thickness

In the 1996 guidelines the nominal wall thickness for Tier 2 was restricted to a range of 7 mm to 25.4 mm, as this was the range covered by the underlying CWP test data. A new lower limit of 5 mm has been introduced, based on the welding section of the Australian pipeline standard, AS 2885.2 [4]. Note that the lower limit of 5 mm was also validated by CWP and full scale testing [12]. A new upper thickness limit of 30 mm has been set, based on unpublished testing carried out for projects at the University of Gent.

Pipe Material and Weld Metal Yield Strength Requirements

The 1996 guidelines required that the yield strength of the weld metal at Tier 2 and 3 should be equal to, or greater than, the yield strength of the pipe material, or that the weld metal is overmatching. However, no guidance was given on:

- The pipe material specimen geometry (round bar or a full thickness strip) to be used.
- The type, location and number of pipe and weld metal specimens to be tested.
- The actual pipe material strength value that the weld metal yield strength should have to exceed. This could be the specified minimum yield strength (SMYS), or a higher value to take account of the distribution of strength in the pipe supply and the weld metal. Beyond that, detailed mechanical testing over the last years showed that the scatter in the yield strength of both the parent pipe and the weld metal should be considered. By definition, the yield strength of production pipes should exceed the specified minimum value, so requiring the weld metal strength to exceed the pipe SMYS would not ensure that the actual weld metal overmatches the actual strength of all pipes installed in the pipeline.
- The orientation of the test specimen, as the usual measurement of pipe strength is in the transverse or hoop direction, whilst the yield strength required for assessing a girth weld defect is the pipe strength measured in the longitudinal direction. That is, the pipe material tensile properties measured in the transverse direction may not be representative of the longitudinal properties.

Research has shown that these factors can affect the use of the guidelines, [8] and [9]. In particular, the type, location and number of pipe and weld metal specimens can have a significant effect on the results [13]. To ensure that girth welds along the pipeline spread do not undermatch the actual yield strength in the axial direction of either adjacent pipe length, EPRG's requirement at Tier 2 for the weld metal yield strength is now:

- *The yield strength of the weld metal should be measured using a round bar all-weld-metal specimen. The positioning of this specimen in the weld should ensure that only weld metal is included in the cross section.*
- *The pipe material yield strength should be measured in the longitudinal direction using full thickness strip specimens.*
- *Minimum YS (weld metal) should be greater than the minimum pipe metal yield strength in the longitudinal direction plus five standard deviations .*
    - *If possible the longitudinal yield strength and the size of the standard deviation should be obtained from tests on the pipe supply using specimens oriented in the longitudinal direction.*
    - *If test data from the longitudinal direction are not available, established correlations between longitudinal and transverse strengths may be used to estimate the minimum longitudinal yield strength from the production testing data for the pipe supply.*
    - *The standard deviation of yield strength can be assumed as 20 N/mm^2 if a value cannot be obtained from production test data.*

- *For seamless and SAWL pipe that has been cold expanded, it can be assumed that the yield strength measured in the transverse direction will give a conservative estimate of the strength in the longitudinal direction.*
- *For SAWH pipe, the relation between transverse and longitudinal strengths will depend on the anisotropy of the strip and the helix angle of the weld, so test data or correlations should be used to estimate the longitudinal yield strength.*
- *For EW[2] (either LFW or HFW) pipe the yield strength in the longitudinal direction is likely to be above that measured in the transverse direction and test data or correlations should be used to estimate the longitudinal yield strength.*

It is considered that this recommendation can be applied in practice for new construction and will ensure that the weld metal yield strength will always overmatch the longitudinal yield strength of the linepipe if the scatter in yield strength distribution is smaller than 120 N/mm^2. If this scatter is smaller (low standard deviation) then it may be possible to reduce the required level of weld metal yield strength. Further, testing a full-thickness strip specimen of the linepipe will automatically ensure that through-thickness variations in strength do not give misleading results, particularly for thicker materials. A larger increase above the minimum pipe yield strength has been imposed at Tier 2 than at Tier 1 to reflect the larger defect sizes allowed at Tier 2, where it is more important to guarantee overmatching. It is accepted that this change will result in additional testing, but this should be offset by the greater defect tolerance given by Tier 2.

EPRG recognises that there are still some outstanding concerns in this area: in particular the effects of thermal cycles during coating on mechanical properties, the limit on the pipe metal Y/T ratio in the longitudinal direction, and the sampling position of the weld-metal specimen in the circumferential and through-thickness direction require due consideration. These are discussed below.

Parent pipe yield/tensile ratio

A limitation of the 1996 guidelines was that the parent pipe Y/T ratio was restricted to a maximum value of 0.90 at Tier 2. This could be of concern for practical application, as the harmonized API/ISO linepipe specification [14] allows Y/T values up to 0.93 in the circumferential direction for all the pipe grades to which the revised guidelines apply. In critical cases it may also be necessary to take account of the effects of the thermal cycle during coating of the linepipe, as this can cause strain aging which increases the yield strength and Y/T ratio.

During the revision of the weld-defect guidelines, EPRG considered whether it was safe to increase the Y/T limit in the guidelines to 0.93 for consistency with the ISO standard and the former European linepipe specification [15]. Also, the linepipe specifications only specify the Y/T ratio in the circumferential direction, whilst the longitudinal orientation is more relevant to the performance of girth welds. There was only limited CWP data available to support such an extension because the CWP test results suggested that the safety margins were becoming small for matching welds. Thus it was judged that a further change which would increase the Y/T limit could not be justified.

However, as weld yield strength overmatch is a favourable factor for defect tolerance, it is recommended that project specific validation tests in the longitudinal direction are performed for Y/T ratios over 0.90 to determine whether the Tier 2 guidelines can be used in specific cases [17]. Alternatively, applying the plastic collapse model used to derive the defect limits [8], the allowable defect lengths shown in Table 2 could be reduced at high Y/T. However, validation testing and further

[2] This is the generic description in ISO 3183 for this type of pipe.

analysis would be required to define the reduced defect lengths, and introducing a variation in the allowable lengths would complicate the criteria.

Weld-metal strength mismatch

The measured weld-metal tensile properties are sensitive to the through-thickness position and circumferential sampling location. The measured differences are due to the variation in weld bead shape around the circumference. In other words, when the testing is limited to one single all-weld-metal and one single pipe material test, significant errors in establishing the level of strength mismatch can be made. Therefore, it is recommended that sufficient statistical data are produced on the tensile properties of both pipe material (longitudinal direction) and weld metal to obtain a reliable (lower bound) estimate of the actual level of strength mismatch. The location and number of specimens shall be specified by agreement. Further, the pipe material tensile properties should be derived from test coupons which have undergone a thermal cycle representative of plant and field coating.

In cases where it is difficult to obtain the required level of strength overmatching, it may be possible to take advantage of the “geometric overmatch” provided by the reinforcement of the weld cap. Although this advantage can be significant for girth welds in thin wall pipe, this is difficult to specify and quantify for a general set of guidelines, and so would require testing for a specific case. Using the geometric overmatch may also require additional inspection to ensure that sufficient reinforcement is actually present at all points around the weld. Besides this, CWP tests on field welds often reveal that the failure characteristics and strain capacity are also affected by geometric factors (weld reinforcement, shape of the weld bevel, etc.) and by differences in wall thickness. Variation also occurs in the tensile properties of the pipes at either side of the girth weld and in the girth weld region. To date, the individual effects and the interaction of these variables on defect acceptance are not incorporated in the recommended ECA methods. However, the combined effects of pipe material yield strength and wall thickness differences of the pipes adjacent to the girth weld can be accommodated by ensuring that the girth weld is overmatching with respect to the thinnest or weakest pipe. A related concern arises when a project uses multiple suppliers, as the pipes can have widely different characteristics, although many users would treat the pipe supplier as an essential variable and qualify each pipe source.

Tier 2 defect size limits

In the 1996 guidelines it was assumed that the defect height would not exceed 3 mm. This assumption was based on the practical observation that, typically, the defects in manual welds are confined to a single weld pass. At the time the guidelines were being developed, radiography was the most common inspection method for onshore transmission pipelines, and so a through-wall height requirement was of little practical value. Defect height information is, however, available when AUT is used, and so it was decided to set explicit limits on the defect height. As the allowable height limit increases, the allowable length limit is reduced. This development also allows for the impact of sizing errors on the reported heights. For example, if a typical AUT system sizing error of 1 mm is used, a defect reported as 3 mm high could be 4 mm high and so would have to be rejected using the 1996 guidelines.

The background to the new defect size limits is given in [8] and [9]. The limits are based on a simple plastic collapse model combined with an analysis of curved wide-plate test data. The experimental data required some adjustments to the collapse model, particularly for heights in the range 4 mm to 5 mm. The resulting limits are shown as multiples of the wall thickness in Table 2. The defect limits are conservative for irregularly shaped defects, provided the maximum measured height is used in the assessment.

For defects less than 3 mm high, the length limit is the same as in the 1996 Tier 2 rules. The revision now allows defects up to 5 mm high, but with a reduction in the length limit. As in the 1996 guidelines, the defect length limit is simply expressed as a multiple of the thickness. To avoid accepting large defects in thin walled pipelines, an additional limit on the defect height of 50% of the thickness has been added. As before, the 2014 Tier 2 defect limits are based on the worst-case loading situation of 0.5 % axial strain. This gives a margin of conservatism for lower axial stresses.

Tier 2 defect interaction criteria

Where there are multiple defects close together, they may interact and behave as a larger defect. The Tier 1 criteria (and other similar workmanship-based approaches) do not explicitly assess interaction between defects, but just control the total length of defects in a specified length, the "accumulation length". The accumulation length is usually 300 mm or a proportion of the pipe circumference. This is effectively just controlling the loss of cross sectional area from the defects without considering if the multiple defects interact and increase the driving force for fracture. Interaction is specifically assessed in engineering critical assessment codes such as BS 7910 [10] or API 579 [11] by considering the spacing between the defects. If this spacing is less than a critical value the defects are assumed to interact. The critical value is a function of the defect dimensions: for example, the shorter of two adjacent defects was used as the critical value in the previous (2005) edition of BS 7910 [10].

At Tiers 2 and 3 the 1996 guidelines recommended the use of the defect recategorisation and defect interaction rules of the former PD 6493:1991 [16]. Co-planar neighbouring defects were assumed to interact if the spacing between them was less than the length of the shorter defect. Research has shown that this rule is over-conservative for tough materials such as pipeline girth welds where failure is controlled by plastic collapse rather than fracture. Based on an extensive program of CWP tensile tests on specimens with multiple defects, a new interaction criterion for co-planar defects was developed for use at Tier 2, full details of the derivation are given in [18] and [19]. The new approach is based on a plastic collapse analysis similar to that used to derive the original Tier 2 defect lengths. The collapse analysis is modified to take account of the experimental results which show that the ligament between adjacent defects can carry a greater load than would be expected from a simple yield strength analysis. This is believed to be due to constraint effects elevating the load carrying capacity of the ligament above the uniaxial yield strength of the material.

The interaction criterion proposed is a two-level approach which compares the sum of the individual defect lengths (Σl_i) with one of two characteristic defect length limits, l (Option A) or L (Option B), with $l < L$. Option A is the safer criterion. If the defects interact according to the Option A criterion, defect interaction can then be assessed by the less restrictive Option B.

The Option A defect length limit l is obtained from Table 2 and allows accumulation without considering interaction up to the maximum allowable length of a single defect. The height used in Table 2 to determine this length is the greatest height of any of the group of co-planar adjacent defects under consideration. The application of the Option A criterion does not require the determination of the spacing, s, between the defects. Option A limits the total length of the defects to the maximum length allowed for an isolated defect of the same height, as shown in Table 2.

The Option B defect length limit L is obtained from assuming that all defects have the same height as that of the highest defect, h_{max}. Here Σs_i is the (sum of the) spacing(s) between the defects, t the wall thickness and W the arc length. For the revised Tier 2 guidelines, W is assumed to be 300 mm. The factor M is a correction factor, which depends on the defect height.

Table 6 shows the proposed values assuming W = 300 mm; L has the units of mm in this case. The correction factor M ensures that the multiple defect limit L reduces to the length limit of an isolated (single) defect of length l when the defects touch and $s = 0$.

If the total length of the defects under consideration is less than L then interaction does not occur and they can be considered acceptable. If interaction is predicted to occur, then the interacted defect is assumed to have a length equal to the total length of the defects and the separations. The Option B length L is greater than l due to the load carrying capacity of the ligament between the defects. Using Option B should reduce the number of repairs, as fewer groups of defects will be considered to interact and hence require repair, but this advantage comes at the expense of more calculation and the need to measure the spacing(s) between the defects.

Example of new Tier 2 interaction criteria

An illustration of the application of the new interaction criteria is shown in Figure 2. The pipe nominal wall thickness is 12.7 mm, and it is assumed that defect dimensions have been determined by AUT and sizing errors have been included in the lengths and heights.

In Figure 2A two co-planar defects are spaced 15 mm apart. Under the 1996 guidance, one of these defects is unacceptable as its height of 4 mm is greater than the assumed limit of 3 mm. The defects are also considered to interact under the 1996 guidance as the separation of 15 mm is less than the length of the shorter defect, 30 mm. The interacted defect length would be 30 + 15 + 25 = 70 mm. Applying the revised guidelines, the 4 mm high defect is acceptable in isolation as the allowable length for this height (Table 2) is 64 mm. Using the Option A interaction criterion, the allowable total length of the defects is based on that for the higher (4 mm) defect and is 64 mm. The total length of the two defects is 30 + 25 = 55 mm which is less than the allowable length l. Hence the two defects do not interact and are considered acceptable. As the Option A criterion has been satisfied, there is no need to check the more complicated Option B.

In Figure 2B the higher defect is now measured at 40 mm long. Both defects are acceptable in isolation under the revised 2014 guidelines, but applying the Option A criterion the total length is now 30 + 40 = 70 mm. This exceeds the allowable length from Table 2 for an isolated 4 mm high defect, and so this pair of defects is not acceptable using Option A. A single interacted defect of total length 85 mm (30 + 15 + 40) and height 4 mm is produced by the recategorization. This defect is unacceptable. The user can elect to use Option B (Table 2) to determine a less restrictive criterion. Setting W = 300 mm, Σs_i = 15 mm, h_{max} = 4 mm and the correction factor M = 0.933 for defects up to 4 mm high gives the allowable total length as 78 mm. This is greater than the sum of the lengths of the two defects, 70 mm, and so the two defects do not interact and can be considered acceptable. Note that if the 3 mm high defect also had an increased length of 40 mm, but maintaining the same separation, the two defects would also fail the Option B assessment as the total length of the defects, 80 mm, would exceed the maximum allowable of 78 mm. In this case the recategorized defect has a length of 95 mm and so is unacceptable.

2014 GUIDELINES - TIER 3

The Tier 3 defect limits are given in Figure 1, in which defect lengths are given as a percentage of the pipe circumference as a function of the wall thickness. Three lines are given for planar defects, limiting the length of an individual defect, interacting planar defects, and the total length of all planar defects. There is a general limit of 25 % of the circumference for all types of planar defects in a weld. A separate limit is applied to the total length of all types of defect, both planar and non-planar.

As noted in the Introduction, there has been little use of the Tier 3 limits and so no revisions have been made. In particular, the extension of the allowable pipe grade to L555 introduced at Tier 2 has *not* been included at Tier 3 as this Tier is based on full scale pipe tests rather than curved wide-plate test data. Whilst there is a small amount of published full scale test data on girth welds in L555 or X80 material such as [20], this was not considered sufficient to support changes to Tier 3. A small change will be made to the weld-metal strength requirements following the changes described above for Tier 2. The intention is to ensure that the weld-metal yield strength is always above that of the parent pipe. Although ECA procedures such as BS 7910 [10] can analyse undermatched welds, the analysis is complicated and requires knowledge of the amount of undermatching. This level of analysis is not appropriate for the guidelines, and so a requirement for overmatching has been retained.

As an alternative to the Tier 3 defect limits, other recognized fitness for-purpose methods can be used.

2014 GUIDELINES - OTHER REVISIONS

Practical application of the 1996 guidelines to construction projects produced some minor changes which are incorporated in the 2014 guidelines, including:

Porosity and hollow bead

The layout of the 1996 guidelines grouped porosity and hollow bead together for wall thicknesses over 10 mm. This has been interpreted by some users as setting limits on a defect “Porosity, Hollow Bead”. These are different types of defect and the layout has been changed to reflect this. This grouping also resulted in a limiting length of 6 mm for these defects in thick pipe (t > 10 mm), which is not consistent with the length allowed in thin pipe of 50 mm. This presentation has been revised to separate the two defects and provide consistent size limits (Table 3).

Cap and root undercut

The 1996 guidelines allowed cap and root undercut up to 3 mm deep with a length up to 7t. This appears to allow both root and cap undercut of this depth to occur at the same location, which would allow an effective loss of cross section of 6 mm. Whilst it is very unlikely that, in practice, undercut of 3 mm depth would occur, the total defect height of 3 mm has been split between root and cap, so that the depth limit for coincident cap and root undercut is 1.5 mm (see Table 3). This is also the limit on depth for root concavity, although there is no limit on the allowable length of root concavity whilst undercut has a limit of 7t. BS 7910 [10] limits the depth of undercut to the smaller of 10% of the wall thickness or 1 mm in steels with a yield strength below 450 N/mm2, and AS 2885.2 [4] has a limit on undercut of 0.8 mm depth for all steel grades, so the revised Tier 2 requirements are closer to other standards.

Length of slag and inclusions

For yield strengths below 450 N/mm2 and wall thicknesses above 10 mm, the allowable length of slag and inclusions in the 1996 guidelines was 40% of the pipe circumference. It is understood that this limit was derived from the original (1980) edition of BS PD6493 [16] although it does not appear to be explicitly stated in the PD. Comments have been made that this limit allows excessive porosity for large diameter pipelines and so the limit of 15% of the circumference which had been used in the 1996 guidelines for thicknesses below 10 mm has been adopted for all wall thicknesses (Table 4).

Allowable porosity

Porosity is limited to 5% of the projected area over a length of 300 mm on a radiograph at Tier 2 in the 1996 guidelines. When the welds are inspected by AUT, the projected area cannot be measured, and an alternative acceptance criterion is required. Porosity is not generally considered a serious defect, and the projected area limit is understood to be partly intended to ensure that porosity does not mask more serious defects. The limit on length has been set at 7t for consistency with other defect types.

Cracking

Copper-induced cracking (CIC) can occur either as isolated clusters anywhere in the weld due to break-up of the contact tip in GMAW welding systems, or more extensively in the root pass where mechanized systems use copper backing shoes on the internal line up clamp and the welding parameters are out of control. CIC can be difficult to detect and to size once found, and it is possible for copper contamination to spread beyond the cracked area. Although copper can be deliberately added to steel as a strengthening element, the effects of uncontrolled copper additions on the weld metal and HAZ toughness are likely to be adverse, and so CIC is not allowed.

A general prohibition on other forms of cracks has been retained. This is to ensure that defects such as weld-metal or HAZ hydrogen cracking are not accepted. In principle, such defects could be assessed using ECA methods or CWP testing, but the occurrence of cracking is generally an indication of poor-quality welding.

2014 GUIDELINES - DEFECT CHARACTERISATION

Defect dimensions

For Tiers 2 and 3 the defect is assumed to be characterised by its bounding rectangle perpendicular to the pipe axis. The defect characterisation parameters used in these guidelines are h (defect height) and l (defect length)[3], where h is the through-thickness extent and l the length of the containment rectangle. The dimensions are obtained from NDT and should include the effect of sizing errors.

Inspection Techniques

The use of the revised Tier 2 defect limits assumes that the inspection technique used is capable of sizing the defect dimensions in both the length and the through-wall directions. The accuracy with which the defect can be sized is a critical input to the use of the revised guidelines. Defect sizing accuracy is a function of the inspection technique and equipment and, in some cases, the skill of the technician. Consequently, the user of the defect size limits should determine the accuracy of the inspection technique, if necessary by qualification trials on project material and weldments. Beyond the determination of the height sizing accuracy, length sizing accuracy requires due consideration. Obviously, length sizing is a critical factor when multiple defects are detected [21] and interaction is being assessed.

REPAIR WELDS

Repair welds can be assessed to the same Tier as the original weld, provided the repair procedures have been qualified by mechanical testing to the same level. Particular attention should be paid to ensuring that testing covers all the possible combinations of parent pipe, original weld metal and repair weld metal. This may require testing of the fusion line and HAZ of both the repair and parent pipe and the repair and original weld metal. Specific inspection procedures should be developed for repair welds to ensure that the entire repair area is examined. The inspection must ensure that the original defects have been removed and that any new defects in the repair are located and sized.

APPLICATION TO PIPELINES IN SERVICE

It was noted earlier that the guidelines are mainly intended for application to new construction, where all the necessary testing can be carried out. In principle they can also be used to assess features discovered in an existing pipeline. Care is required if, as will often be the case, only limited materials' data are available. Depending on the specific case, there may be sufficient data to decide that the guidelines can be used. Expert advice should be obtained where the data are limited to determine if either the 1996 or 2014 versions of the guidelines can be used.

CONCLUDING REMARKS

This paper has presented the revisions to the 1996 version of the EPRG guidelines for the assessment of girth-weld defects in transmission pipeline girth welds. These changes have concentrated on Tier 2 with some minor amendments to Tiers 1 and 3. For users who are familiar with the 1996 edition, the figures and tables required to use the 2014 guidelines are similar to the form in the 1996 guidelines so that they are suitable for use in project specifications.

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[3] ECA codes using fracture mechanics methods conventionally denote the length of a surface crack as 2c due to symmetry conditions in many mathematical derivations.

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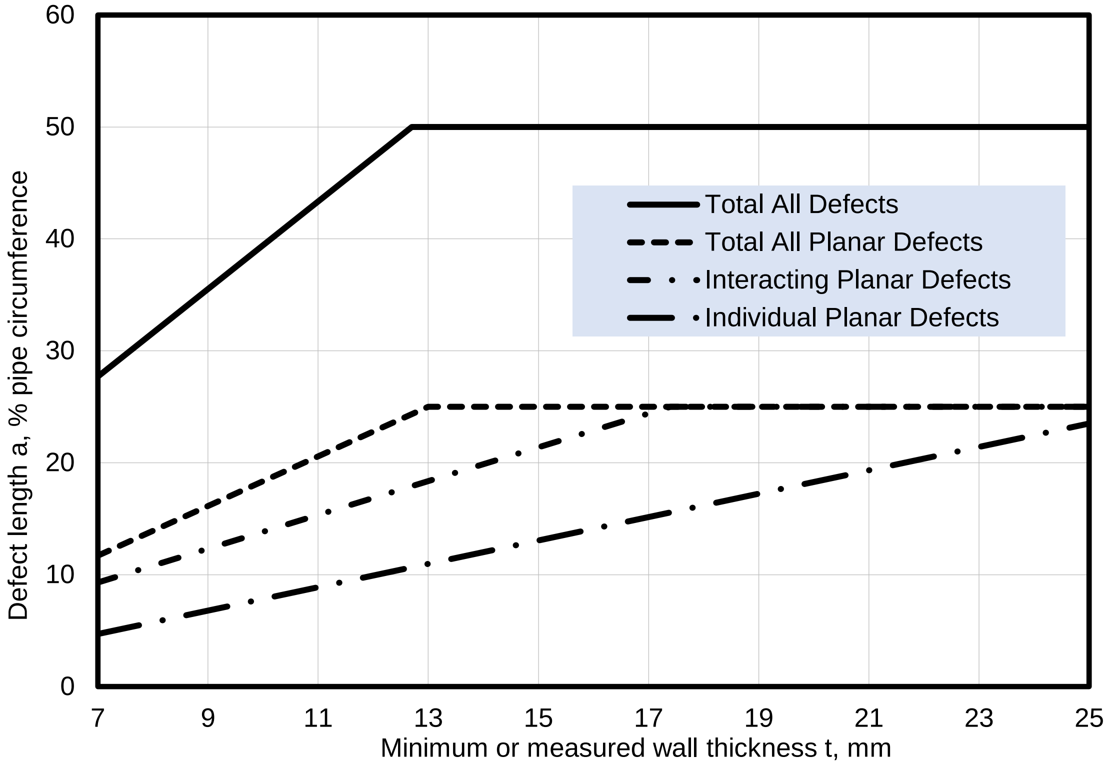
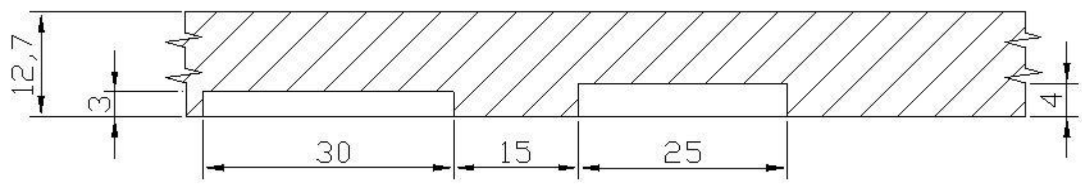


Figure 1 Tier 3 maximum defect length limits.



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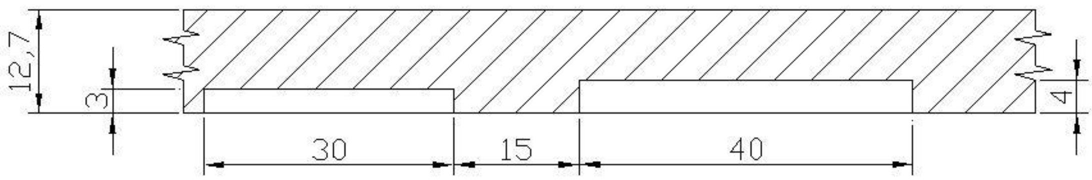

B

Figure 2 Example application of new Tier 2 interaction criteria; the length of the 4 mm high defect is increased in case B .

Table 1 Requirements and limits for defect acceptance levels (Tier 1), and defect limits (Tiers 2 and 3)

<table>
<tr><th colspan="2">Type of requirement</th><th>Tier 1(A)</th><th>Tier 2</th><th>Tier 3(B)</th></tr>
<tr><td rowspan="4">Geometry</td><td>Wall thickness (t)</td><td>7 ≤ t ≤ 25.4 mm
wall thickness outside this range by agreement</td><td>5 ≤ t ≤ 30 mm</td><td>7 ≤ t ≤ 25.4 mm</td></tr>
<tr><td>Defect height</td><td>No requirement</td><td>Table 2</td><td>≤ 3 mm (single weld run)</td></tr>
<tr><td rowspan="2">Additional remarks</td><td colspan="3">Surface breaking non planar defects should be treated as planar defects</td></tr>
<tr><td></td><td colspan="2">Only girth welds between pipes of equal thickness</td></tr>
<tr><td rowspan="2">Toughness</td><td rowspan="2">Charpy and CTOD values for the weld at minimum design temperature</td><td>CVN - Average energy ≥ 40 J
CVN - Minimum ≥ 30 J</td><td colspan="2">Sub-size specimen have the required impact reduced pro rata with their dimensions</td></tr>
<tr><td colspan="2"></td><td>CTOD – Average ≥ 0.15mm
CTOD – Minimum ≥ 0.10mm</td></tr>
<tr><td rowspan="5">Strength</td><td>Cross weld tensile tests with weld reinforcement removed</td><td colspan="3">Acceptable if the specimen breaks in the base material or when it breaks in the weld metal with a tensile strength ≥ the specified minimum tensile strength (SMTS)</td></tr>
<tr><td>Pipe yield strength Specified minimum yield strength in transverse direction (SMYS)</td><td>No limit specified</td><td>≤ 555 N/mm²</td><td>≤ 485 N/mm²</td></tr>
<tr><td>Yield strength matching</td><td>Tests can be carried out by special agreement to ensure that YS(weld) ≥ SMYS(pipe)+80 N/mm²</td><td>YS(weld) ≥ minimum YS (pipe) + 100 N/mm² in longitudinal direction (C)</td><td>Measurement of the yield strengths, location, type, and number of specimens by agreement. These measurements and the specific acceptance criterion should ensure that the weld metal strength overmatches the pipe strength in all cases. The Tier 2 strength requirements should be satisfied together with the requirements from any alternative fitness-for-purpose method.</td></tr>
<tr><td>Yield to tensile strength ratio (Y/T)</td><td>No requirement</td><td>Y/T (pipe) ≤ 0.90 in longitudinal direction</td><td>Y/T (pipe) ≤ 0.85</td></tr>
<tr><td>Additional requirement</td><td></td><td colspan="2">Only girth welds between pipes of equal grade</td></tr>
<tr><td rowspan="2">Loading</td><td>Applied strain/stress</td><td>Not specified</td><td>Strain ≤ 0.5 %</td><td>Stress ≤ YS(pipe)</td></tr>
<tr><td>Additional remark</td><td colspan="3">Onerous fatigue duty, or severe environmental effects are not included</td></tr>
</table>

NDT	Non-destructive testing	Not specified	100 % non-destructive testing of girth welds

(A) Alternatively, existing company standards, CEN standards, API 1104, or BSI 4515 may be used within their known and their defined limitations.
(B) The user can specify other Engineering Critical Assessment (ECA) methods based on documented fitness-for-purpose calculation or appropriate tests.
(C) The yield strength of the weld metal should be measured using a round bar all weld metal specimen. The positioning of this specimen in the weld should ensure that only weld metal is included in the cross section. The pipe material yield strength should be measured in the longitudinal direction using full thickness strip specimens.

Table 2 Allowable defect length limits for single planar defects at Tier 2

Defect height, h (mm) (with h ≤ 0.5t)	≤ 3	3 < h ≤ 4	4 < h ≤ 5
Allowable defect length limit, l (mm)	≤ 7 t	≤ 5 t	≤ 3 t

Table 3 Defect acceptance levels (Tier 1), and defect limits (Tiers 2 and 3); profile, concavity and undercut

Type of defect	Tier 1 Acceptance criteria	Tier 2 Limit criteria	Tier 3 Limit criteria
External Profile	Excess weld metal should be uniform and not more than 3 mm in height. It should merge smoothly with the parent metal and not extend beyond the original joint preparation by more than 3 mm on each side. No area should have the weld face lower than the adjacent pipe surface.		
Internal profile	The root bead or any concavity should merge smoothly into the adjacent surface but at no point should the weld be thinner than the pipe thickness.		
Root Concavity Length	25 % weld circumference		
Depth	1.5 mm or 0.1 t (lesser)		
Undercut (cap) Length	50 mm	7 x t	Figure 1
Total	50 mm in 300 mm or 15 % circumference (lesser)	7 x t in any 300 mm	
Undercut (root) Length	25 mm	7 x t	Figure 1
Total	25 mm in 300 mm or 8 % circumference (lesser)	7 x t in any 300 mm	
Undercut (coincident cap and root) Depth	1 mm or 0.1 t (lesser)	Each 1.5 mm or 0.1 t (lesser)	Assume to be < 1 mm

Table 4 Defect acceptance levels (Tier 1), and defect limits (Tiers 2 and 3); planar and non-planar defects

<table>
<tr><th colspan="3">Type of defect</th><th>Tier 1
Acceptance criteria</th><th>Tier 2
Limit criteria</th><th>Tier 3
Limit criteria</th></tr>
<tr><td colspan="3" rowspan="2">Inadequate root penetration
Length
Incomplete (lack of) fusion root
Total
and/or cap</td><td>25 mm</td><td>Table 1</td><td rowspan="2">Figure 1</td></tr>
<tr><td>25 mm in 300 mm or
8 % circumference (lesser)</td><td>Table 1 limit for highest indication in any 300 mm</td></tr>
<tr><td colspan="3" rowspan="2">Incomplete fusion, cold lap
Length
Lack of sidewall fusion
Total
Lack of inter-run fusion</td><td>50 mm</td><td>Table 1</td><td rowspan="2">Figure 1</td></tr>
<tr><td>50 mm in 300 mm or
15 % circumference (lesser)</td><td>Table 1 limit for highest indication in any 300 mm</td></tr>
<tr><td colspan="3">Cracks</td><td colspan="3">Not allowed</td></tr>
<tr><td colspan="3">Copper induced cracking</td><td colspan="3">Not allowed</td></tr>
<tr><td colspan="3">Crater cracks</td><td colspan="3">4 mm</td></tr>
<tr><td colspan="3" rowspan="2">Burn through
Individual

Total</td><td colspan="3">4 mm</td></tr>
<tr><td colspan="3">2 per 300 mm</td></tr>
<tr><td rowspan="6">t < 10 mm</td><td colspan="2" rowspan="2">Porosity
Individual

Total</td><td colspan="2">3 mm or 0.25 t (lesser)</td><td rowspan="5">Figure 1</td></tr>
<tr><td colspan="2">Not to exceed a total area when projected radially through the weld of 2 % projected weld area in radiograph consisting of the length of the weld affected by the porosity, with a minimum length of 150 mm, multiplied by the maximum width of the weld.</td></tr>
<tr><td rowspan="2">Hollow bead

Slag</td><td>Length</td><td colspan="2">50 mm</td></tr>
<tr><td>Total</td><td colspan="2">50 mm in 300 mm, or 15 % circumference (lesser)</td></tr>
<tr><td colspan="2" rowspan="2">Inclusions
Total

Width</td><td colspan="2">12 mm in 300 mm, and 4 per 300 mm</td></tr>
<tr><td colspan="3">3 mm or 0.5 t (lesser)</td></tr>
<tr><td rowspan="4">t ≥ 10 mm</td><td rowspan="2">Porosity

Hollow bead</td><td>Individual</td><td rowspan="2">As for t < 10 mm</td><td>6 mm or 0.25 t (lesser)(A)</td><td rowspan="3">Figure 1</td></tr>
<tr><td>Total</td><td>5 % projected area on radiograph</td></tr>
<tr><td rowspan="2">Slag
Inclusions</td><td>Total</td><td rowspan="2">As for t < 10 mm</td><td>15 % circumference(A)</td></tr>
<tr><td>Width</td><td colspan="2">3 mm</td></tr>
<tr><td colspan="6">(A) If the pipe yield strength is above 450 N/mm^2, limits for t < 10 mm should be used</td></tr>
</table>

Table 5 Defect acceptance levels (Tier 1), and defect limits (Tiers 2 and 3); accumulation and interaction criteria

Type of defect	Tier 1 Acceptance criteria	Tier 2 Limit criteria	Tier 3 Limit criteria
Defect accumulation t < 10 mm	100 mm in 300 mm, or 15 % circumference (lesser), excepting porosity and root concavity		Figure 1
Defect interaction t < 10 mm	Inherent in defect accumulation criteria	OPTION A – If total length of defects is greater than the Table 2 limit for the highest defect then recategorise as a single planar defect of length equal to the two individual lengths plus separation OPTION B - If total length of defects is greater than length from then recategorise as a single planar defect of length equal to the two individual lengths plus separation	Limits are given in Figure 1. If a planar, slag or porosity defect is separated from a planar defect by a distance smaller than the length of the shorter of the two defects, then recategorise as a single planar defect of length equal to the two individual lengths and separation.
Defect accumulation t ≥ 10 mm	As for t < 10 mm	Table 2 limit for highest indication in any 300 mm, excepting porosity and root concavity. Slag is exempt from accumulation, providing the yield strength of the pipe YS(pipe) ≤ 450 N/mm^2. Accumulation of planar and non-planar defects ≤ 40 % circumference.	Figure 1
	Root concavity is not included in accumulation calculations, unless it causes the weld thickness to be less than that of the pipe.		
Defect interaction t ≥ 10 mm	Inherent in defect accumulation criteria	OPTION A – If total length of defects is greater than limit for highest defect then recategorise as a single planar defect of length equal to the two individual lengths plus separation OPTION B - If total length of defects is greater than length from then recategorise as a single planar defect of length equal to the two individual lengths plus separation	If a planar, slag or porosity defect is separated from a planar defect by a distance smaller than the length of the shorter of the two defects, then recategorise as a single planar defect of length equal to the two individual lengths plus separation.

		Recategorised planar defect should have the same identity as the planar defect	Figure 1

Table 6 Option B Defect Interaction Criteria for Tier 2

<table>
<tr><td colspan="4">$$L = \frac{t\,W}{h_{max}}\left[1 - M\left(1 - \frac{h_{max}\sum s_i}{t\,W}\right)\right]$$</td></tr>
<tr><td>h_{max}</td><td>≤ 3 mm</td><td>3 < t ≤ 4</td><td>4 < t ≤ 5</td></tr>
<tr><td>M</td><td>0.930</td><td>0.933</td><td>0.950</td></tr>
</table>

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