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ASSESSMENT OF PIPELINE DEFECTS AND APPROPRIATE REPAIR METHODOLOGIES

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ABSTRACT

Oil and gas transmission pipelines have a good safety record. This is due to a combination of good design, materials and operating practices. However, like any engineering structure, pipelines do occasionally fail. The major causes of pipeline failures around the world are external interference and corrosion; therefore, assessment methods are needed to determine the severity of such defects when they are detected in pipelines.

Defects occurring during the fabrication of a pipeline are usually assessed against recognised and proven quality control (workmanship) limits. These workmanship limits are somewhat arbitrary, but they have been proven over time. However, a pipeline will invariably contain larger defects at some stage during its life, and these will require an assessment to determine whether or not to repair the pipeline. Consequently, the past 40 years has seen a large number of full scale tests of defects in pipelines, and the development of a number of methods for assessing the significance of defects. Some of these methods have been incorporated into industry guidance, while others are to be found in the published literature.

This paper presents a summary of the 'best practices' in pipeline defect assessment for a range of defects. Additionally, the paper presents the key elements of a pipeline repair methodology, as some defects will inevitably need repair.

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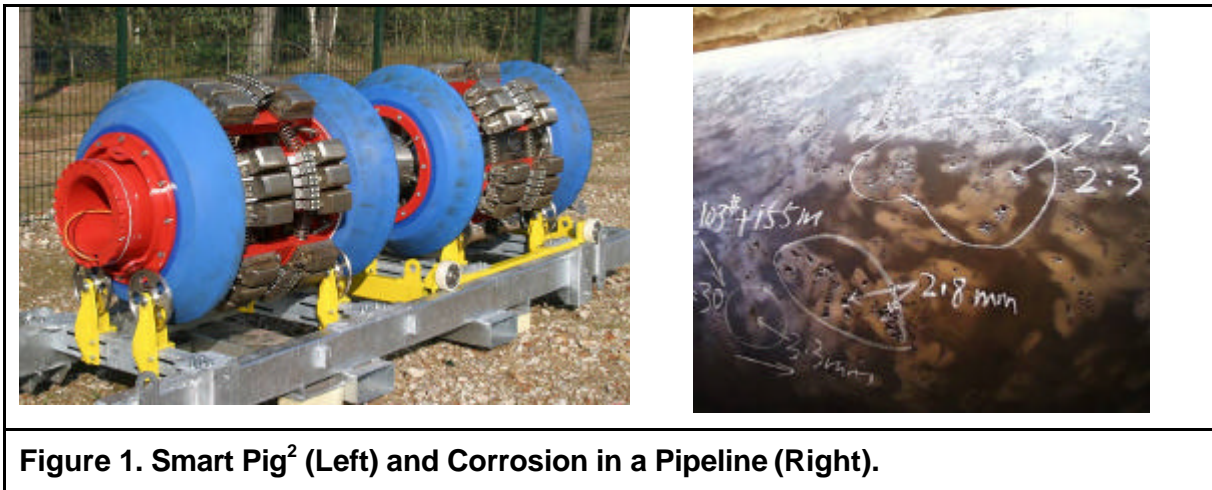
1. INTRODUCTION

Pipelines are a very safe method for transporting hydrocarbons, but like any engineering structure they will contain defects and these defect may lead to failure.

Consequently, it is important that these defects are:

- understood;
- predicted;
- prevented or mitigated;
- detected;
- assessed;
- repaired (when necessary); and
- documented.

We are detecting more defects in pipelines, mainly due to the increased use of 'smart pigs' that can now reliably detect and size a wide range of defects in pipelines, **Figure 1**. Additionally, most of our oil and gas pipelines around the world are 'middle aged' (over 40 years old) and inevitably will contain many defects. This combination of maturing pipeline systems, and closer and more regular inspections mean that every pipeline operator needs to be aware of the behaviour of defects, and how to assess and repair them.



This paper gives a summary of the accepted assessment methods of pipeline defects, presents some general repair methodologies, and ends with a view of the future.

1.1 What is a 'Defect'?

Pipelines can contain many differing types of defects such as corrosion, dents and gouges, but first we need to be careful with 'definitions'.

Modern standards (e.g. API 1163 [1]) now consider:

- an 'anomaly' is a deviation from sound pipe material or weld.
- a 'defect' is an anomaly for which an analysis indicates that the pipe is approaching failure as the nominal hoop stress approaches the specified minimum yield strength

² Smart pig image courtesy and copyright of Rosen.

of the pipe material. This means an anomaly with dimensions or characteristics that exceed acceptable limits.

- an 'imperfection' is an anomaly in the pipe that will not result in pipe failure at pressures below those that produce a nominal hoop stress equal to the specified minimum yield strength of the pipe material. That means an anomaly with characteristics that do not exceed acceptable limits.

These definitions are consistent with API 5L [2], that describes a defect as '*An imperfection of a size and/or population density greater than the acceptance criteria specified in this International Standard*'. Defects considered acceptable to standards such as API 5L are often called 'workmanship' defects.

Not all defects are a threat to the pipeline: this is why pipeline standards such as API 5L allow certain anomalies to remain in the pipeline and can remain in the pipeline during construction and operation. Furthermore, some defects may exceed these workmanship standards, but are not a threat to the pipeline's safety throughout its life. These defects require some type of assessment to prevent unnecessary repairs. This means we will need to calculate their failure stress, and if this calculated failure stress is above the pipeline's maximum operating stress throughout the pipeline's life, then the defect will not fail the pipeline.

1.2 What is a 'Fitness-for-purpose' Assessment?

We often describe an assessment of a defect in a pipeline as an 'engineering critical assessment', or a 'fitness-for-purpose assessment'. 'Fitness-for-purpose' used in a defect assessment context means that a particular structure is considered to be adequate for its purpose, provided the conditions to reach failure are not reached [3]. It is based on a detailed technical assessment of the significance of the defect.

We need to be careful with this term as it has legal implications in different countries [4], and local and national legislation/regulations may not permit certain types of defects to be assessed by fitness-for-purpose methods or may mandate specific limits. Such issues should always be considered prior to an assessment.

It is better to refer to a fitness-for-purpose assessment of a defect simply as an 'assessment'.

1.3 How can we assess a Defect in a Pipeline?

The first thing we need to emphasise is that defect assessment is not a substitute for good design, construction or operation – it is complementary. All engineering structures should be designed, built and operated to a recognised standard.

A defect can be assessed using a variety of methods:

- previous relevant experience (including workmanship acceptance levels);
- model or full scale testing;
- generic defect assessment methods;
- pipeline-specific analytical methods; or
- full structural analysis.

This paper will focus on pipeline-specific methods, but will briefly outline both generic and pipeline-specific methods below.

1.3.1 Generic

Various technical procedures are available for assessing the significance of defects in a range of structures. These methods use a combination of fracture mechanics and limit state

(plastic collapse) methods. Both BS 7910 [3] and API RP 579 [5] contain detailed engineering critical assessment methods which can be applied to defects in pipelines (although the latter document is biased towards defects in process plant).

1.3.2 Pipeline-specific

Documents such as the above are generic; they can be conservative when applied to specific structures such as pipelines. Therefore, the pipeline industry has developed its own defect assessment methods over the past 45 years (and, indeed, documents such as BS 7910 recommend that such methods be used, and API 579 incorporates several). These pipeline-specific methods are usually based on experiments, sometimes with limited theoretical validation; they are 'semi-empirical' methods. Consequently, the methods may become invalid if they are applied outside their empirical limits.

Methods and guidelines developed by the pipeline industry range from the NG-18 equations [6] (which formed the basis of methods such as ASME B31G [7] and RSTRENG™ [7]) and the Ductile Flaw Growth Model (DFGM) (implemented as PAFFC (Pipe Axial Flaw Failure Criteria)) [9,10] developed by the Battelle Memorial Institute in the USA on behalf of the Pipeline Research Council International (PRCI), to the guidelines for the assessment of girth weld defects [11], mechanical damage [12], and ductile fracture propagation [13] produced by the European Pipeline Research Group (EPRG).

1.3.3 Pipeline-specific versus generic methods

The generic methods will usually produce conservative results when compared to pipeline-specific methods. This can largely be attributed to issues of 'constraint' and 'ductile tearing'.

Constraint is the restriction of plastic flow in the vicinity of the crack tip due to stress triaxiality. Stress triaxiality is induced by load and geometry. The standard test methods used to measure fracture toughness are designed to give conditions of high constraint at the crack tip to ensure conservative results. Pipelines have low constraint because they are thin walled (geometry) and are predominantly subject to membrane tensile loading (loading mode). Conventional (single parameter) fracture mechanics does not consider the elevation in fracture toughness due to a reduction in the level of constraint, and hence an inherent margin of safety is included when applied to low constraint structures.

The semi-empirical pipeline-specific methods consider constraint implicitly because they have been developed from full scale tests in which these effects manifest themselves directly. Similarly, the increase in toughness with ductile crack growth (a rising resistance curve) is also considered implicitly. The difference between pipeline-specific and generic methods diminishes when sophisticated fracture mechanics (two-parameter fracture mechanics, tearing analysis, etc.) and limit state methods are applied.

2. ASSESSMENT METHODS

2.1 What Assessment Methods are Available and which are the ‘Best’?

The various assessment methods that can be used on pipeline defects have been reviewed, and the best practices recommended [4,14,16] **Table 1**; consequently, they will not be covered in this paper. **Table 1** shows these preferred methods, with other useful methods in italics, for defects orientated in the longitudinal direction and circumferential direction.

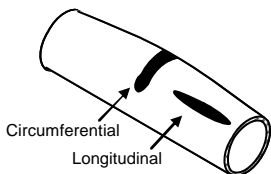
Defect	Longitudinally-orientated	Circumferentially-orientated
		
corrosion	DNV-RP-F101 [17] <i>modified B31G</i> [8], <i>RSTRENG</i> [8]	Kastner local collapse solution [19]
gouges	NG-18 equations [6] <i>PAFFC</i> [9,10], <i>BS 7910</i> [3] or <i>API 579</i> [5]	Kastner local collapse solution <i>BS 7910</i> or <i>API 579</i>
plain dents	empirical limits [4]	
kinked dents	no method ¹	
smooth dents on welds	no method	
smooth dents with other types of defect	dent-gouge fracture model [12]	no method
manufacturing defects in the pipe body ²	NG-18 equations <i>BS 7910</i> or <i>API 579</i>	Kastner local collapse solution <i>BS 7910</i> (or <i>API 579</i>)
girth weld defects		workmanship, <i>EPRG</i> [13] <i>BS 7910</i> or <i>API 579</i>
seam weld defects	workmanship, <i>BS 7910</i> or <i>API 579</i>	
cracking	<i>BS 7910</i> (or <i>API 579</i>), <i>PAFFC</i>	
environmental cracking ³	<i>BS 7910</i> (or <i>API 579</i>), <i>PAFFC</i>	
leak and rupture	NG-18 equations <i>PAFFC</i>	Schulze global collapse solution [20]

Table 1. Recommended Methods for Assessing the Burst Strength of Defects Subject to Static Internal Pressure [16].

Notes:

1. ‘No method’ indicates limitations in existing knowledge, and circumstances where the available methods are too complex for inclusion in a document such as ‘PDAM’ [4].
2. The term ‘manufacturing defect’ covers a wide range of pipe body defect (laminations, inclusions, seams, gouges, pits, rolled-in slugs, etc.). Consequently, it may not be possible to characterise a manufacturing defect in the pipe body as a metal-loss or crack-like defect. In these circumstances it is necessary to rely on workmanship limits and industry experience.

3. Environmental cracking (stress corrosion cracking, hydrogen blisters, hydrogen stress cracking, etc.) can be very difficult to measure and assess, and its growth rate unpredictable.

2.2 Limitations in Available Methods

Table 1 is limited to internal pressure loadings, but obviously pipelines are subjected to other types of loadings. Available assessments methods are limited when differing types of loadings are considered, **Table 2**.

	Internal pressure (static)	Internal pressure (cyclic)	External pressure	Axial force	Bending moment	Combined loading
defect-free pipe	Yes ¹	Yes	Yes	Yes	Yes	Yes
corrosion	Yes	Yes	No	Yes	Yes	Yes
gouges	Yes	Yes	No	Yes	Yes	Yes
plain dents	Yes	Yes	No	No	No	No
kinked dents	No	No	No	No	No	No
smooth dents on welds	No	Yes	No	No	No	No
smooth dents and gouges	Yes	Yes	No	No	No	No
smooth dents and other types of defect	Yes	Yes	No	No	No	No
manufacturing defects in the pipe body	Yes	Yes	No	Yes	Yes	Yes
girth weld defects	Yes	Yes	No	Yes	Yes	Yes
seam weld defects	Yes	Yes	No	Yes	Yes	Yes
cracking	Yes	Yes	No	Yes	Yes	Yes
environmental cracking	Yes	Yes	No	Yes	Yes	Yes

Table 2. Summary of Availability of Defect Assessment Methods in the Literature by Defect Type and Loading [15].

Notes:

- 1 'Yes' means methods published (with limitations). 'No' indicates no method is published or there are limitations in existing knowledge.

Additionally, the methods that are published have inherent limitations as they are usually based on experimental data: **Table 3** gives an example of the range of applicability of the method used to assess combined dents and gouges. The limitations of the experimental data should not be exceeded. Clearly, any user of the methods in **Table 2** must be aware of these limitations, and not apply the methods outside their range of applicability.

Pipe Diameter, mm	216.3	to	1066.8
Wall Thickness, mm	4.8	to	20.0
2R/t ratio	33.6	to	107.7
Grade (API 5L)	X42	to	X65
Yield strength, Nmm⁻²	279.2	to	543.3
Tensile strength, Nmm⁻²	475.0	to	701.2
yield to tensile ratio	0.61	to	0.87
2/3 Charpy Impact Energy, J	16.3	to	130.7
Dent Depth, mm	1.5	to	146.5
H/2R	0.42	to	18.0
Notch Depth (d), mm	0.18	to	6.1
d/t	0.014	to	0.51
Notch Length (2c), mm	50.8	to	810.0
2c(Rt)^{0.5}	0.84	to	8.98
Burst Pressure, Nmm⁻²	0.972	to	25.24
Burst Stress, Nmm⁻²	29.2	to	626.8
Burst Stress (% Specified Minimum Yield Strength)	7.05	to	151.5

Table 3. Range of Applicability of the Dent-Gouge Fracture Model [4].

Indeed Reference 5 emphasises that considering these limitations is a key step in defect assessment:

- Step 1. Flaw and damage mechanism identification (cause?);
- Step 2. *Applicability and limitations of assessment procedures (can I assess it?);*
- Step 3. Data requirements (have I the data?);
- Step 4. Assessment techniques and acceptance criteria (what method will I use?);
- Step 5. Remaining life evaluation (how long can the defect survive?);
- Step 6. Remediation;
- Step 7. In-service monitoring.

3. DEFECT REPAIR METHODOLOGIES

On many occasions a defect assessment will allow a defect to remain in the pipeline without repair. Inevitably, some defects will require a repair, and some defects may require pipeline modification. There is guidance on pipeline repair [21, 22, 23], but any repair or modification of a pipeline should be treated as an engineering project. Consideration must be given to:

- Location;
- Resources;
- Feasibility;
- Safety;
- Schedule;
- Detailed design and analysis;
- Procurement;
- Construction/Installation;
- Working practices/procedures;
- Planning.

For example, for an onshore pipeline, not only must it be repaired properly, but the work must be carried out safely and with the minimum of damage to the environment. Some of the issues that may have to be considered are:

- Parts of the excavation may have to be done by hand (to prevent damage to the pipeline). This will require more workmen and take longer than mechanised digging.
- The sides of the excavation may need to be piled to prevent collapse.
- Pumps may be needed to keep the excavation free of excess water.
- For major projects it may be necessary to create a sound working base within the excavation.
- The time of year when work can be done may be restricted by environmental considerations such as the nesting season of rare birds.

An offshore project is likely to be an even larger operation. It will require a ship, divers and/or remotely operated vehicles (ROVs), and a habitat may be required. The environment (weather conditions and currents) may affect the ability to work. For some circumstances, large specially-designed machines will be required, the operation of which will need to be proven.

Additionally, most repair methods were developed and proven on onshore pipelines, where internal pressure is the major loading. Subsea pipelines can have high external tensile and compressive loadings, and extra care is needed when assessing defects in these pipelines, and choosing the subsequent repair.

3.1 Safety First

Safety is always our first consideration. Recognised, proven procedures, relevant standards, and qualified personnel should be used.

Pressure reductions [24], excavation safety, trench safety, welding safety, pipe movement safety, fire prevention, emergency procedures, etc., will be primary concerns.

Pressure reductions alone may not be sufficient to demonstrate safety prior to working on a pipeline. Some pipelines may have 'locked-in' stresses; for example, from ground movement (onshore) or a buckle (offshore). These locked-in stresses need to be considered prior to pressure reductions and work on the line.

3.2 Repair Philosophy

A good repair approach/philosophy is [25]:

- Replace 'like-for-like';
- Apply a 'temporary' (see later) repair, until replacement can be carried out;
- Apply a 'permanent' (see later) repair, only where replacement is not practical.

3.3 Some Words of Caution

Repairs can often require a quick response, and may require significant engineering. Reference 26 gives some wise words on repairs:

- 'Do no harm': a bad repair can make matters worse, and repairs need careful engineering, at least as much as a new construction, so it is best not to act in haste.
- A repair is often not a good time to try something new: there is less experience with a new procedure, compared to tried and tested designs. 'Surprises' may occur with uncertainty and incompletely planned engineering.
- Preparedness pays off: repairs may need additional pipe, so a prudent operator buys more pipe than the project needs.

3.4 Structural or Containment?

We will repair defective pipe for differing reasons, but the two major reasons will be:

- Pressure containment: this is where we are ensuring that the product will not escape from the pipeline. For example, we may have a leaking defect, and we place a 'clamp' over the leak to contain the product leakages.
- Structural repair: this is where we are restoring the structural strength of a pipeline. For example, if we have a cracked girth weld, and the pipeline is subjected to high axial stresses, we know that this cracked weld will have poor load bearing capacity in the axial direction, and hence will need strengthening in this direction.

Some repair methods and equipment, such as a leak clamp, are for containment, and will not normally be able to provide any structural support for the defective pipeline.

We need to fully assess the conditions (e.g. loadings and ongoing degradation) in which any repair is being used, and if we are using a structural repair we will need to know all the loads on the pipeline.

3.5 Temporary or Permanent?

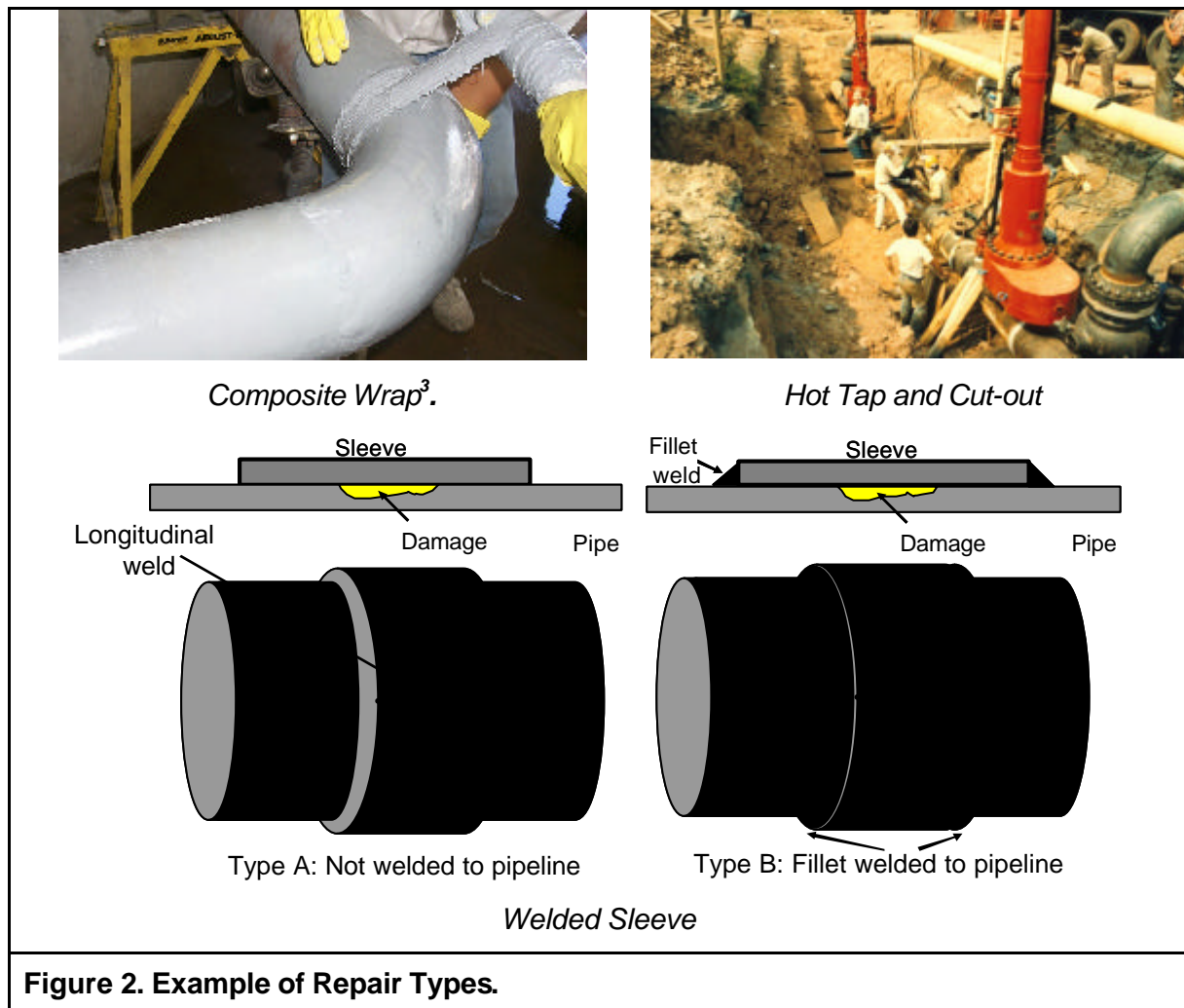
Pipeline repairs are termed 'permanent' or 'temporary'. What do 'permanent' and 'temporary' mean? First, for all pipe repairs, the operator needs to perform a structured risk assessment that includes the consideration of all of the potential future damage or deterioration mechanisms over the life-cycle of the repaired pipe system [27]. Second, operators need to consider the life of the defect and repair; for example for a clamp repair:

- will internal metal loss of the pipe underneath the clamp continue?
- will degradation of the elastomeric seal material occur?

These considerations will dictate the need for periodic inspection and/or testing to the repair component, and determine if the repair can be a 'fit and forget'.

This leads to a definition of 'permanent' as [27]... 'a repair component that is intended to remain in place for the remaining life of the piping system'. The repair component itself may well be regarded as being a 'permanent' repair but may require periodic examination [27].

In the USA, 'permanent' means [28] a repair that is equivalent to replacing the damaged pipe, or installing a 'full-encirclement split sleeve', **Figure 2**. This is because repair guidelines in the USA Regulations (cut outs, or full encirclement sleeve repair) were traditionally based on recommended industry practices from the 1960s. This was based on the 1968 edition of ASME B31.8 Code, the 1966 edition of the ASME B31.4 Code, and the 1969 edition of the National Association of Corrosion Engineers Standard RP-01-69. In 1999 the USA's Department of Transportation proposed a change, to allow operators to use repair methods that met a 'performance standard'. The proposed standard was that the method must be able to "permanently restore the serviceability of the pipe". This wording was used to describe the result expected from replacing damaged pipe or installing a full-encirclement split sleeve over the damage to pipe. Any repair needs to be as effective as these repairs.



In the USA, their Office of Pipeline Safety also puts a time limit on 'permanent' and specifies the requirements for the repair [29]:

³ Image from: C Alexander, 'Pipeline Integrity Remediation and Repair', SES, SGA Presentation, USA.

- ‘As to the permanency of repair, we are not suggesting that the repair should last indefinitely. It need last only as long as the pipe is expected to last under normal operating and maintenance conditions.’...
- ‘... a qualified repair method must have undergone “reliable engineering tests and analyses” to confirm that the method meets the performance standard....’.

3.6 Types of Repairs

The types of repair methods available for pipeline defects include:

- Grinding;
- Weld deposition repair;
- Full circumferential sleeves (both Types A and B);
- Patch/Part sleeve repairs
- Composite wraps (including ‘Clockspring™’);
- Mechanical clamps;
- Cut-outs.

Full descriptions of these repair methods can be found elsewhere [21, 22, 23, 30, 31, 32].

	Weld Repair¹	Sleeve: Type A²	Sleeve: Type B	Composite²	Hot tap
External Defect ² (=80%wt)	Yes	Y	Y	Y	Y ⁶
Internal Defect ² (=80%wt)	No	N	Y	N	Y ⁶
External Defect ² (>80%wt)	Y ¹	N	Y	N	Y ⁶
Internal Defect ² (>80%wt)	N	N	Y	N	Y ⁶
Leaks	N	N	Y	N	N
Cracks	N	N	Y	N	N ⁶
Girth Weld Defects	N	N	Y	N	N
Dents	N	Y ⁴	Y	N ⁷	Y ⁸
Dents with defects ³	N	Y ^{4,3}	Y ³	N	Y ⁸

Notes:

1. You always need a minimum wall to weld onto – check with expert. API 1160 limits application to wt>0.181”, and this will generally limit method to <80% wt defect depths. ‘wt’ is wall thickness.
2. Industry practice in North America is to limit Type A sleeves and composite repairs to defects not exceeding 80% wt.
3. Any damage in the dent must have been removed, e.g. by grinding. Care must be taken when grinding onto live pipelines. Depressurisation may be necessary.
4. Sleeve must be filled with incompressible material.
5. But not on a weld.
6. Cracks that are not leaking can be hot tapped to remove crack.
7. Some composite repairs can be used on straight pipe with dents, if they are filled with incompressible material, and proven by tests to be permanent.
8. If dent can be removed completely.

Table 4. Repair Guidelines from API 1160.

3.7 Which Methods for which Defects?

Various standards give guidance on which methods to apply to which defects. API 1160 [31] and ASME B31.8S [32] gives general guidance for liquid and gas pipelines respectively, **Table 4**. Additionally, there is guidance on repairing specific types of damage, **Table 5**.

Defect	Grinding	Type sleeve A	Type sleeve B	Composite sleeve	Clamp
Dent (=6%D) containing a seam/girth weld	N	Limited ¹	Y	Limited ¹	Y
Dent (=6%D) containing a gouge/groove/crack	Limited ²	Limited ^{1,3}	Y	Limited ^{1,3}	Y
Dent (=6%D) containing external corrosion (>12.5%t)	N	Limited ¹	Y	Limited ¹	Y
Dent (>6%D)	N	Limited ¹	Y	Limited ^{1,3}	Y
Buckle/ripple/wrinkle	N	Limited ¹	Y	N	Y

Notes:

1. Hardenable material is used to fill the defect.
2. All defects in dent must be removed, and remaining wall must be =87.5% wall thickness, t.
3. Gouge/groove/crack must be fully removed.
4. Other conditions apply – see ASME B31.4-2006. Replacement of all the above defects by cut-out and replacement pipe is acceptable. D = pipe diameter.

Table 5. Guidance on the Repair of Dents in ASME B31.4-2006 [33].

It should be emphasised again that the above repair methods are primarily for onshore pipelines. Some onshore repairs, and many offshore repairs require specialist methods and significant planning. This is particularly true of offshore pipelines: these pipelines can be damaged by anchors or fishing equipment that can cause extensive deformation (e.g. bending) with the damage (e.g. denting and gouging) [34] which collectively is difficult to model and assess.

3.8 Time to Complete Repairs

API 1160 (for liquid lines) and ASME B31.8 (for gas lines) and the USA Department of Transportation Pipeline Regulations all give guidelines for 'speed' of repair. For example, API 1160 gives the following times to repair:

1. Defects that require 'immediate repair':
 - Defect has predicted burst pressure > maximum allowable operating pressure (MAOP);
 - Metal loss >80% wall thickness (t);
 - Dents on top of line (4-8 o'clock) containing any defect;
 - Any other defect considered serious.
2. Defects that must be evaluated and repaired within 60 days of discovery:
 - All dents on top of pipeline.
3. Defects that must be evaluated and repaired within 6 months:
 - Defect has predicted safe operating pressure > MAOP;

- Dents with metal loss or dents with welds;
- Dents > 6% pipe diameter;
- Corrosion > 50% t, weld anomalies > 50% t;
- Metal loss > 50% t at pipeline crossings.
- Cracks
- Weld corrosion
- Gouges > 12.5% t

The above are only examples - the reader should perform their own assessments on speed of repair and consult their local regulations and codes.

4. LOOKING TO THE FUTURE

4.1 Competence

We have a number of pipeline defect assessment methods and repair types. As pipelines age, and are increasingly inspected using smart pigs, there will be a similar increase in the need for engineers to assess defects and repair some of them. This will require engineers, with a certain level of competence. Pipeline engineering competence has been discussed in the literature [37] and this applies to pipeline defect assessment: **Table 6** gives an example of the required competencies. An investment in training will be needed to meet these requirements.

Assessment Level	Reference Documents	Data Needed	Expertise of Assessor
1. Workmanship	Using general pipeline standards (e.g. API 5L)	Defect Size and Type	Competent Engineer
2. Quantitative	Using prescriptive pipeline integrity standards (e.g. API 1160)	Defect Size and Type Pipe Dimensions, Material and Pressure	Competent Engineer
3. Quantitative	Using 'best practice' publications in the literature	Defect Size and Type Pipe Dimensions, Material and Pressure	Engineer Experienced in Defect Assessment
4. Expert	Not explicitly covered by 'best practice' publications	As above plus Detailed Material Data, Samples etc.	Expert in Defect Assessment

Table 6. Competence Levels required for Defect Assessment.

4.2 Exceeding Technology Limits

The pipeline industry is changing; for example, we are moving to constructing onshore pipelines from higher grade (strength) materials, and our quest for oil from deepwater reservoirs is leading us to thicker wall pipe. These changes will also cause changes to our defect assessment methods and our repair methods.

The industry has developed its defect assessment methods and repair methods using relatively low grade, thin wall pipelines, and many of the methods are based on experiments. These experiments do not cover higher grade line pipe, or thicker wall pipe, for example **Table 3**, and this will mean that the methods are not proven on these 'new' pipeline parameters, and we will move into 'grey areas', **Figure 3**. This is of concern; our methods are limited, and in some cases dated, and as we change our pipeline materials and design we will make these methods invalid.

Accordingly, there is an urgent need to invest in defect assessment methods [34], otherwise we will be repairing many of the defects, rather than assessing them, and hopefully avoiding a repair.

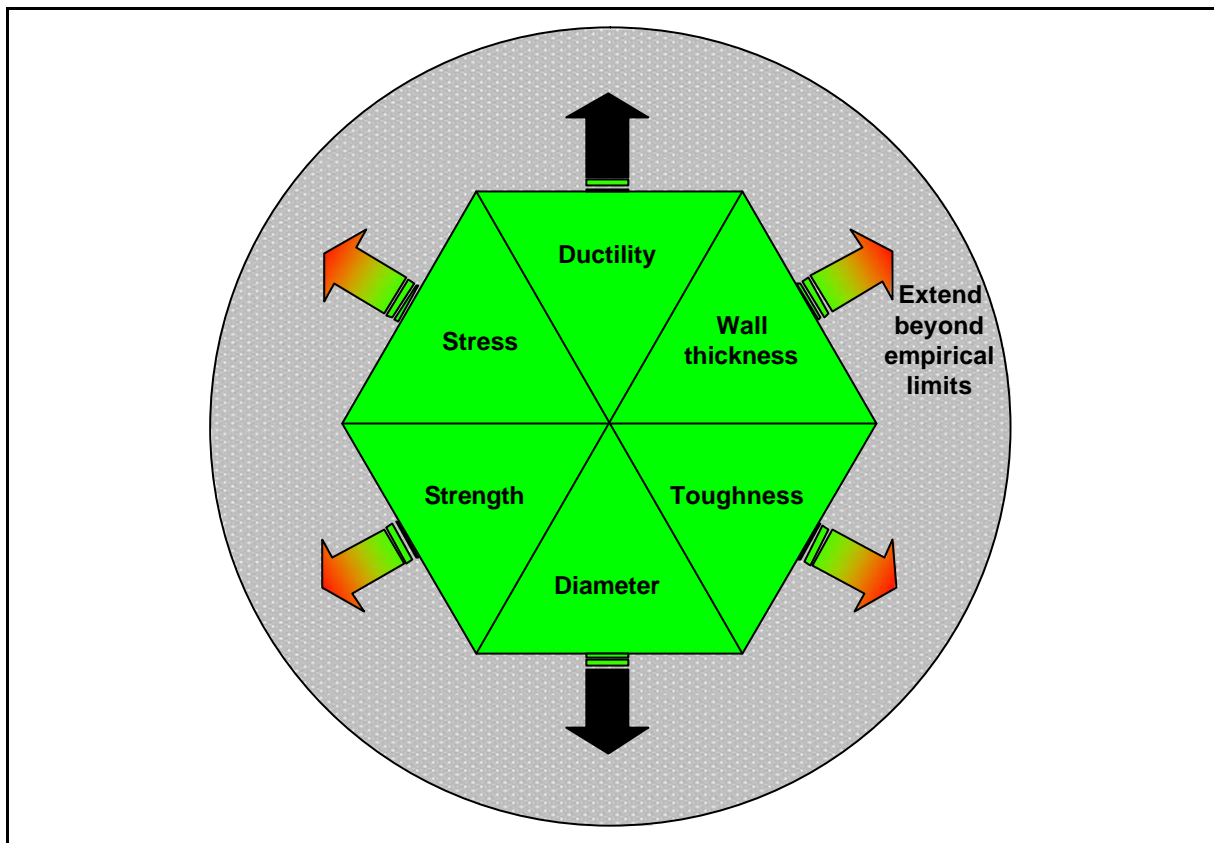


Figure 3. Exceeding Technology Boundaries in Pipelines.

4.3 The Role of Standards

We need to recognise the role of standards and industry guidelines. Some operators may well consider the available guidance on defects and repair in the current generation of standards as sufficient, and consequently no need for further changes or investment.

Standards are essential but they are not a panacea – they will need to be changed and updated as the industry changes, and this is particularly true of defect assessment and repair. But what exactly are ‘standards’ and what do they satisfy?

4.3.1 Standards are ‘good practice’

It is interesting to note that when ASME B31.8 was produced in 1955 one of the key contributors (F Hough) said:

“... a code is not a law... it is... written by engineers, operators and managers... as a result of their experience and their knowledge of the engineering and scientific principles involved, state what they agree is good practice from the standpoint of public safety... a code is merely a statement of what is generally considered good practice...”

In the UK ‘good practice’ refers to practices that have been acknowledged by the government regulator (the Health and Safety Executive (HSE)) or local authorities as representing standards of compliance with the law. It does not mean ‘custom and practice’ necessarily – that can be poor practice.

4.3.2 Satisfying standards may not be enough...

Good practice satisfies a law/requirement [35] (e.g. ASME B31.8 will satisfy this requirement), and satisfying 'good practice' can be viewed as meeting a minimum requirement. Recognising standards as a minimum requirement may come as a surprise to many operators – the law may well expect more.

Additionally, depending on the level of risk and complexity involved, it is possible the adoption of good practice alone may not be sufficient to comply with the law [36]. In these situations we need to adopt 'best practice', which is a practice that goes beyond good practice.

Consequently, satisfying standards may not be sufficient for pipeline design and operation; this is not surprising, as we cannot expect our standards to present all the solutions. We need to invest in our standards, and be aware of when the limits of standards are exceeded. When we exceed these limits, as we change our designs and materials, we need to produce new or alternative guidelines. The questions are: 'are we aware we are exceeding limits?' and 'are we investing in producing these guidelines?'. Clearly, research continues into pipeline engineering: the large numbers of papers presented at the biennial International Pipeline Conference in Calgary, Canada demonstrates this. But are we doing enough?

A few years ago, the author attended a seminar in Sydney, and the engineers at the seminar were describing engineering standards as 'laws of man' – they were not 'laws of nature', and pipelines always follow the latter, but not always the former....

This is an interesting philosophy, and does illustrate how standards should be viewed, **Figure 4:** if we want to understand pipelines (Laws of Nature), we need to invest into a basic understanding of the underlying science (Laws of Science), and then incorporate the findings into our standards (Laws of Man). You cannot obtain this understanding in the reverse order.

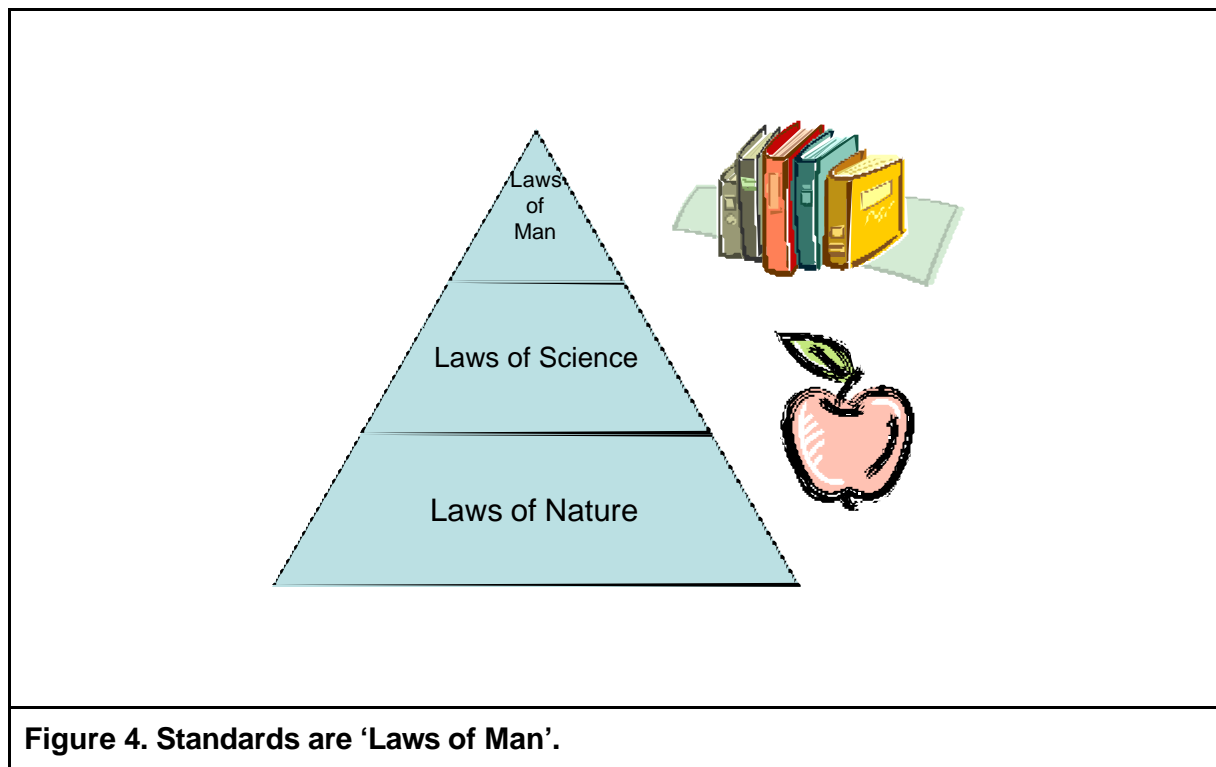


Figure 4. Standards are 'Laws of Man'.

5. CONCLUSIONS

Our pipeline systems are now mature and receiving regular inspections. This is leading to more and more defects being reported, and an increased need in pipeline operators to understand defect behaviour, assessment and repair.

We now have many 'best practices' in assessing pipeline defects that can be applied to today's pipelines, and we have a selection of repair methods that can be applied to defects that exceed acceptable levels. These assessment methods are primarily for internal pressure loading only, and the repair methods are mainly for onshore pipelines; consequently, they have limitations.

As we change our pipeline designs (e.g. to deepwater pipelines), or materials (e.g. to high strength line pipe steels) we will need to extend and update our defect assessment and repair methods. This will require investment.

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