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MINERALS MANAGEMENT SERVICES

CONTRACT NO. 1435-01-CT-99-31001
APPRAISAL AND DEVELOPMENT OF PIPELINE DEFECT ASSESSMENT METHODOLOGIES

QUARTERLY STATUS REPORT NO. 1

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1. INTRODUCTION

1.1 General

Offshore pipelines transport enormous quantities of oil and gas vital to the economies of virtually all nations. Any failure to ensure safe and continuous operation of these pipelines can have serious economic implications and possibly damage to the environment and cause fatalities. A prerequisite to pipeline safe operation is to ensure their structural integrity to a high level of reliability throughout their operational lives. Such integrity may be threatened by defects introduced into a pipeline system during its construction or operation. Since it is virtually impossible to prevent such defects from occurring and because not all defects are harmful to pipeline integrity, it is essential to be able to distinguish defects which can be tolerated from those which can not.

A large number of empirical and/or analytical tools for the assessment of pipeline defects are available. The project **Appraisal and Development of Pipeline Defect Assessment Methodologies** is to evaluate thoroughly all available methods for assessing offshore pipeline defects. The objective of this project is to establish a firm basis on all the major aspects of the methodology needed to assess the safety of offshore pipelines with geometric and material defects. Furthermore, it performs the necessary development to cover the remaining gaps in the state-of-the-art.

Based on the project proposal, the main tasks in the Phase 1 is the collation of pipeline defect related literature, including all available codes, standards, published reports and published papers. From the review of collated documents and interviews with Operators, a critical appraisal of current industry practice and code provisions would be undertaken. A database of screened test results for different defect forms would be created, and present-day inspection methodologies of offshore pipeline defects would be established.

This report represents a review of the progress of the project in Phase 1 of the above mentioned four aspects: Collation of pipeline defect related literature, Current industry practice, Code provisions, and Database of test results for different pipeline defect forms.

1.2 Background

A number of studies on the failure/loss of containment of pipelines have been conducted. Based on statistical analysis of information usually held by Regulatory Authorities and/or Pipeline Operators, these studies provide indications of the level of reliability achieved in the operation of pipelines. They also provide information on the likely level of failure frequency for an individual pipeline depending on factors such as:

- Cause of Failure
- Location of Pipeline

- Diameter of Pipeline
- Length of Pipeline
- Contents of Pipeline.

The most recent published studies on pipeline failures are as follows:

- Mandke - evaluation of failure rate data for Gulf of Mexico using the US office of Minerals and Management Service (MMS) database. This covered 690 incidents that occurred during the Period 1967-87. Information from 1987- onwards is currently not available.

- HSE/UKOOA commissioned a number of studies of pipeline failures in the North Sea. Some results of the study are reported by Williams et al covering the period up to 1989. Further reports covering periods 1989 to 1992, and 1992 to 1994 have been released by the HSE (PARLOC) and findings 1994 to 1996 are due to be released shortly by the HSE.

- The Office of Pipeline Safety (OPS) of US Department of Transport (DOT) collected all pipeline incident data from 1968-1999.

Comparison of Gulf of Mexico (Mandke) and North Sea Pipeline failure studies indicated that the primary cause of failures listed in decreasing frequency of occurrence/detection were as follows:

Gulf of Mexico:	Corrosion, third party, storm and slides, material and equipment failure.
North Sea:	Third Party, corrosion, material failure.

Data extracted from the Office of Pipeline Safety Database on incident and accident statistics for the period covering 1984-1999 is presented in Table 1.1 for hazardous liquids and Gas transportation/Distribution. It can be observed from Table 1.1 that the number of incidents and number of accidents etc are generally similar with no apparent decrease with time being noted. The primary cause for the incidents are presented in Tables 1.2 to 1.4. The tables indicate that the cause of damage resulted from a number of causes including the following:

- Corrosion (internal and external)
- Damage from outside forces (i.e mechanical damage)
- Defective weld and pipe
- Construction/material

The primary cause of failure listed in decreasing frequency of occurrence in general appears to be as follows:

- Damage from outside forces/outside damage, Corrosion (internal and external), defective pipe/weld.

Although the above information is incomplete and further information (eg. MMS Hurricane Andrew, HSE PARLOC updates) is to be considered, it can be observed that damage which require defect assessment procedures to be considered are required.

Year	Hazardous Liquid Pipeline Operators			Natural Gas Pipeline Operators Transmission			Natural Gas Pipeline Distribution		
	No. of Incidents	Fatalities	Injuries	No. of Incidents	Fatalities	Injuries	No. of Incidents	Fatalities	Injuries
1984	186	0	17	NA	NA	NA	NA	NA	NA
1985	183	5	18	NA	NA	NA	NA	NA	NA
1986	209	4	32	83	6	20	142	29	104
1987	237	3	20	70	0	15	164	11	115
1988	193	2	19	89	2	11	201	23	114
1989	163	3	38	103	22	28	177	20	91
1990	180	3	7	89	0	17	109	6	52
1991	216	0	9	71	0	12	162	14	77
1992	212	5	38	74	3	15	103	7	65
1993	230	0	10	96	1	18	121	16	84
1994	243	1	7	81	0	22	141	21	91
1995	188	3	11	64	2	10	97	16	43
1996	195	5	13	77	1	5	110	47	109
1997	175	0	5	73	1	5	108	10	83
1998	151	1	2	96	1	10	132	16	62
1999	2	0	0	2	0	0	8	0	2

Table 1.1: Offshore Pipeline Safety Summary of Incident/Accident Statistics by Year

Cause	Year				
	1994	**1995**	**1996**	**1997**	**1998**
Internal Corrosion	0 (0)	0 (0)	1 (0.92)	0 (0)	0 (0)
External Corrosion	5 (3.55)	3 (3.09)	1 (0.92)	3 (2.78)	5 (3.79)
Damage From Outside Forces	79 (56.03)	66 (68.04)	64 (58.72)	59 (54.63)	86 (65.15)
Construction/ Operating Error	13 (9.22)	5 (5.15)	6 (5.50)	4 (3.70)	5 (3.79)
Operator Error	10 (7.09)	6 (6.19)	6 (5.50)	6 (5.56)	8 (6.06)
Other	34 (24.11)	17 (17.53)	21 (28.44)	36 (33.33)	28 (21.21)
Total	141	97	109	108	132

Values in Bracket % of Total Incidents

Table 1.2: **Office of Pipeline Safety – Gas Distribution Pipeline Accident Summary by Cause**

Cause	Year				
	1994	**1995**	**1996**	**1997**	**1998**
Internal Corrosion	20 (25)	5 (7.81)	6 (8.22)	16 (23.88)	13 (13.54)
External Corrosion	13 (16.25)	4 (6.25)	7 (9.59)	5 (7.46)	7 (7.29)
Damaged From Outside Forces	23 (28.75)	27 (42.19)	37 (50.68)	28 (41.79)	36 (37.50)
Constructional/ Material/Defect	9 (11.25)	13 (20.31)	7 (9.59)	8 (11.94)	19 (19.79)
Other	15 (18.75)	15 (23.44)	16 (21.42)	10 (14.93)	21 (21.88)
Total	80	64	73	67	96

Values in Bracket % of Total Incidents

Table 1.3: Office of Pipeline Safety – Transmission and Gathering Pipeline Accident Summary by Cause

Cause	Year				
	1994	1995	1996	1997	1998
Internal Corrosion	10 (4.1)	13 (6.81)	21 (10.99)	18 (10.2)	19 (12.5)
External Corrosion	38 (15.57)	21 (12.04)	38 (19.90	34 (19.4)	17 (11.2)
Defective Weld	21 (8.61)	9 (4.71)	9 (4.71)	3 (1.7)	7 (4.6)
Incorrect Operation	8 (3.28)	26 (13.61)	11 (5.76)	11 (6.2)	7 (4.6)
Defective Pipe	11 (4.51)	14 (7.33)	9 (4.71)	11 (6.2)	6 (3.9)
Outside Damage	57 (23.36)	54 (28.27)	48 (25.13)	40 (22.8)	40 (26.4)
Malfunction of Equipment	22 (9.02)	5 (2.62)	6 (3.14)	7 (4.0)	9 (5.9)
Other	77 (31.56)	47 (24.61)	49 (25.65)	51 (29.1)	46 (30.4)
Total	244	191	191	175	151

Values in Bracket % of Total Incidents

Table 1.4: Office of Pipeline Safety – Hazardous Liquid Pipeline Accident Summary by Cause

2. PROJECT STATUS

2.1 Progress

The project began in April 1999 with the execution of Phase I (Phase II is presently an option item). Phase I is split into two sub-items as follows:

Item	**Description**
0001A	Creation of Database
0001B	Creation of Final Report

Phase I is to be completed within a 6 month timeframe. Various activities required to complete the scope of work were identified in MSL fax of February 17, 1999. These activities are listed below and a statement on progress is given for each.

a) Collate all available, pertinent, documents worldwide.

Approximately 400 references have been identified, of which 350 have been sourced. This number of references is at the upper end of expectations.

b) Undertake selective interviews in USA and UK.

Some thought has been given to the organisations that we would wish to interview, although none have yet been conducted. The interviews have been deliberately timed so that best use of them can be made, when data and experience gained from the references has been assimilated. An initial contact letter has been drafted, see Appendix, to facilitate arrangements for interviews. Since the letter makes reference to MMS, MMS may wish to review it.

c) Appraisal of documents and create database.

The source documents have been reviewed, see Section 3. A database has been established of test and numerical data for pipelines containing defects, see Section 6.

d) Critically appraise current industry practice.

Work has commenced on this activity with an examination of the various provisions of relevant codes. A summary is provided in Sections 4 and 5. This activity is to be enhanced with findings from the forthcoming interviews.

e) Establish present-day inspection methodologies.

Source documents containing references to inspection methodologies have been noted. However, this activity is yet to commence in earnest.

f) Preparation of final report.

This activity is yet to commence.

In summary, the project is on schedule and we expect to complete the study by the end of September 1999, ie. within the allocated Phase I period.

2.2 Activities Planned for Next Quarter

Phase I is expected to finish during the next quarter and therefore the planned activities are all those required to complete the scope of work. The remaining activities are:

- Source the 50 remaining references, extract the data, enter in the database and conduct QA checks on the entered data.
- Undertake interviews.
- Complete the appraisal of industry practice following the interviews.
- Document the inspection methodologies.
- Prepare final report.

2.3 Information Requested from MMS

We would appreciate an early response from MMS on whether the first contact letter (set out in the Appendix) is suitable or requires adjustment.

Furthermore, it is almost inevitable that interviewees will ask whether they would receive anything in return for supply of data. Advice is sought from MMS on a suitable response to this question.

3. LITERATURE CAPTURE

3.1 Methodology

The basic literature survey is the main task conducted in phase I of this project. There is a significant amount of literature on pipeline defect assessment. The literature search was performed in three categories. Category I includes codes and standards on offshore pipeline design and defects assessment. Category II includes all the technical papers relevant to defect assessment methodologies. Category III collects all the possible technical reports from governments and companies. The most popular and used codes and standards from different countries are also collected.

A literature database from all the collected codes, standards, technical papers from conference proceedings or journals was created which includes 400 references. Most of these references have been obtained although a small % (ie. approximately 12%) are still being sourced at the present moment. It is possible that the final number of references may be higher if new information is identified during the course of the project.

For each reference identified the following information has been recorded. Reference number, Title of paper, Author(s), organisation, date of publication, document reference (ie. conference, code, etc.).

In addition to this to enable searching of the database to be undertaken more efficiently, particularly in identifying those references which contain defect data, a number of key words have been identified (eg. defect assessment, code, corrosion damage, mechanical damage, weld damage, material, inspection, etc.). These key words are currently being further evaluated for future use in enabling interrogation of the database to be carried out more efficiently.

In this project, the emphasis was confined to offshore pipeline defect assessment and in particular to identifying those types of defect damage which commonly occur.

3.1.1 Definition of Defects

A defect is an imperfection of sufficient magnitude to warrant rejection based on the requirements of the codes or standards. An imperfection is a material discontinuity or irregularity that is detectable by inspection in accordance with the requirements of the codes and standards. Different codes and standards give different warranty of rejection of the defects. This will be explored in more detail when undertaking interviews and reviewing inspection methodologies.

3.1.2 Type of Defects

Pipeline defects can be grouped into three categories according to their cause. Mechanical damage, weld defect and corrosion defect can be defined as follows:

Mechanical Damage:

Dent: A depression caused by an event that produces a visible disturbance in the curvature of the wall of the pipe or component without reducing the wall thickness.

Gouge: A surface imperfection caused by mechanical removal or displacement of metal that reduces the wall thickness of a pipe or component.

Groove: Groove can cause stress concentration at the point and can be considered as a defect.

Surface Cracks: Pipe body surface cracks shall be considered defects.

Weld Defects:

Arc Burn: A localized condition or deposit that is caused by an electric arc and consists of remelted metal, heat-affected metal, a change in the surface profile, or a combination thereof.

Incomplete Penetration: The root head of weld does not completely fill the root of the joint.

Incomplete Fusion: There is lack of bond between the weld metal and the base metal at the root or top of the joint.

Internal Concavity: Incomplete filling of the joint.

Undercut: A groove melted into the base metal adjacent to a weld toe at the root or top of the joint.

Slag Inclusions: Non-metallic solid entrapped in the weld metal or between the weld metal and the base metal.

Hollow Bead: Linear porosity or cylindrical gas pockets occurring in the root bead.

Corrosion Defect:

General Corrosion: Uniform or gradually varying loss of the wall thickness over the area.

Localized Corrosion Pitting: Localized corrosion pitting can reduce the wall thickness to be less than the design thickness.

Stress Corrosion Crack: There are two kinds of stress corrosion cracking: sulphide stress corrosion cracking and hydrogen induced cracking. Suphide stress corrosion cracking occurs primarily in steels at a region subjected to applied or residual tensile stresses. Hydrogen induced cracking occurs at low stresses or even in the absence of stresses or under external compressive stresses.

The above types of damage are illustrated in Figures 3.1 and Figure 3.2.

3.2 Reference Sources

The following lists of reference sources were identified:

General Design Codes and Standards:

- Pipeline Transportation System for Liquid Hydrocarbons and other Liquids, ASME B31.4, 1998, US
- Gas Transmission and Distribution Piping Systems, ASME B31.8, 1995, US
- Code of Practice for Pipelines, BSI 8010, Part3, 1993, UK
- Oil and Gas Pipeline Systems, CAS-Z662-99, 1999, Canada
- Rules for Submarine Pipeline Systems, DnV 1996, 1996, Norway
- Rules for Subsea Pipelines and Risers, GL 1995, Germany
- Pipeline Transportation System for the Petroleum and Natural Gas Industries, ISO 13623, 1996
- Design of Long Distance Transmission Pipelines, SniP2.05.06-85, 1985, Russian

Codes and Standards on Pipeline Defect Assessment:

- Welding of Pipelines and Related Facilities, API - 1104, 1994, US
- Pipeline Maintenance Welding Practices, API – 1107, 1991, US
- Manual for Determining the Remaining Strength of Corroded Pipelines, ASME B31G, 1991, US
- Guide on Methods for Assessing the Acceptability of Flaws in Structures, BS 7910, 1999, UK
- Specification for Welding of Steel Pipelines on Land and Offshore, BS 4515, 1996, UK
- Assessment of the Integrity of Structures Containing Defects, R/H/R6 Revision 3, 1997, Nuclear Electric, UK
- Oil and Gas Pipeline Systems, CSA-Z662-99, 1999, Canada

The Specification and standards of the following organisations appear in the above codes and standards.

API	American Petroleum Institute, USA
ASME	American Society of Mechanical Engineers, USA

BSI	British Standards Institute, UK
CEGB	Central Electricity Generating Board, UK
CSA	Canadian Standards Association, Canada
GL	Germanischer Lloyd, Germany
ISO	International Standards Organisation

The majority of sources concerning offshore pipeline defect assessment are the specific conferences and seminars. The following conferences and seminars are covered in the literature database.

- Offshore Technology Conference, API, 1985 - 1999
- International Pipeline Conference, ASME, 1996, 1998
- International Conference on Offshore Mechanics and Arctic Engineering, ASME, 1990 - 1998
- International Pressure Vessel Technology Conference, ASME 1990-1998
- Pressure and Piping Conference, ASME 1990 –1998
- International Offshore and Polar Engineering Conference, ISOPE, 1997, 1998
- API Pipeline Conference, API, 1990-1998
- Pipeline Engineering Symposium, ASME, 1985-1990
- Pipeline Engineering, ASME, 1991-1995
- International Conference on Pipeline Protection, MEP, 1991-1997
- Advances in Subsea Pipeline Engineering, ASPECT, 1994
- International Workshop on Offshore Pipeline Safety, MMS, 1991
- Pipeline Crossing, ASCE, 1996
- Deepwater Pipeline Technology Conference and Exhibition, Clarion, 1997-1999

In addition, the following Journals were sourced.

- International Journal of Pressure Vessels and Piping, ASME
- Oil And Gas Journal, OGJ

- Civil engineering, ASCE
- Welding Journal, AWS
- World Oil, Gulf

Several technical reports from government and companies such MMS, BP, EXXON, API are also reviewed.

To illustrate how the reference source database has been used to identify information on available data, Tables 3.1 to 3.6 provide extracts of information obtained from those references which contain data for different defect damage types. It can be observed that there is a significant number of references which contain data particularly for corrosion damage. It should be noted that further data may be identified from references still being sourced.

Ref No.	Author	Main Topic.	General Description
296	Chouchaoui and Pick	Interaction of Corrosion Pits	Describes results of experimental and finite element studies on burst strength of pipes with multiple corrosion pits
297	Chouchaoui and Pick	Corrosion assessment procedures	Proposes a comprehensive 3 level corrosion procedure drawn from series of burst tests on pipe sections with both service and simulated corrosion and a complementary series of FE analyses.
222	Roberts and Picks	Longitudinal stress assessment of corroded line pipe	Most techniques consider only the circumferential stress in the pipe in predicting the burst pressure of corroded pipe. Tests on experimental pipe sections and FE analyses to investigate longitudinal stress are assessed.
223	Wang, Smith, Popelar and Maple	Assessment procedure for corrosion under combined loading	Full scale tests of 48 inch diameter corroded pipe with FE data under combination of bending and other secondary loads.
140	Smith and Grigory	Assessment procedure of corrosion under combined loading	Full scale, small scale and FE studies on corroded pipes subjected to combined loading.
141	Cronin, Roberts and Pick	Assessment procedure for long corrosion grooves in pipes	Measured burst pipe tests with various corrosion geometries compared with FE analyses for long corrosion grooves.
313	Bubenik	Corrosion under combing loading	Combination of linear and non-linear FE studies supported by experiments under internal pressure and axial loading.
307	Stewart, Klever and Ritchie	Burst strength intact and corroded pipes	Validation of model against limited set of burst tests on uncorroded and corroded pipes.
302	Kanninen, Grigory et al.	Corrosion assessment procedure under combined loading	Validation of FE data against existing experimental data.
337	Hopkins and Jones	General corrosion assessments	Extensive full scale burst test experimental study into the behaviour of long and complex shaped corrosion and interacting corrosion. Results compared with other data.

Table 3.1: **Summary of Relevant References for Data on Corrosion (continued...)**

Ref No.	Author	Main Topic	General Description
359	Wang	Corrosion method (combined loading)	Finite element analyses conducted for combined loading compared to existing database of 86 burst tests on corroded pipes.
349	Kiefner and Vieth	Remaining strength of corroded pipe lines	Experimental database of burst tests on corroded pipe
346	Jones et al.	General corrosion assessment	Results of experimental and finite element study under internal pressure with corrosion occurring at bottom of pipe.
309	Andrews	Effect of corrosion on fracture/fatigue resistance	Results in heat affected zone of girth weld seam examined using FE and experimental data.
74	Rosenfeld et al.	Corrosion assessment procedure	A proposed corrosion procedure is compared with full scale burst tests of 168 pipes containing actual or simulated metal loss corrosion of various configurations

Table 3.1: Summary of Relevant References for Data on Corrosion (...continued)

Ref No.	Author	Main Topic	General Description
192	Stevick, Haart and Flanders	Fatigue assessment of dented pipelines	Fatigue assessments of damages pipeline. Data compared with S-N predictions.
194	Hagiwarara et al	Fatigue assessment of severely gouged line pipes	Fatigue tests on ERW line pipes with severe denting/gouge carried out.
195	Rosenfeld and Kiefner	Fatigue behaviour of dented pipes	Dent fatigue tests compared with analytical model. Influence of dent geometry, pipe strength and pipeline operation on fatigue life estimated.
298	Fowler et al.	Fatigue of dented pipe	Describes an S-N based procedure for fatigue assessment of plain dents including stress concentration factors, based on FE and experimental validation.
336, 338, 340	Hopkins et al.	Fatigue/burst pressure of dented pipes	Experimental research on plain dents, combined dents carried out to provide guidelines for treatment of dents and combination of dents and defects.
55	Rosenfeld et al.	Fatigue of shallow dents in girth welds	Predicted fatigue lives compared with 5 experimental pipe tests with dents in girth welds.
50	Fowler et al.	Fatigue of pipes with dents/gouges	Further assessment of experimental data/FE data (i.e. above reference 298)

Table 3.2: **Summary of Relevant References for Data on Mechanical Damage Defects**

Ref No.	Author	Main Topic	General Description
304	Leggatt and Challenger	Weld defect assessment procedure	Validation of PD 6493 approach for assessment of girth weld defects against Canadian database of full scale pipe bend tests.
400	Roodbergen and Denys	Fracture methodology for assessing girth weld defects	Application of various methodologies (i.e. codes) to a variety of girth weld defects for different pipe diameter/wall thickness combinations and line pipe grades.
315	Coote et al.	Avoidance of brittle failure	Full scale tests on girth welds and pipes containing failure circumferential defects compared with Canadian code and PD 6493.
328, 327	Glover et al.	Fracture methodology	Extension of work undertaken by Coote et al.
312	Broekhoven and Rongen	Verification of fracture analysis	Structures of various degree of complexity were tested including forty-three full scale pipeline sections tested with internal pressure and wide plate tests. Failure data compared to various codes.
52	Pistone et al.	Assessment of girth weld defects in ductile/brittle transition zone	Full scale bend and wide plate tension tests on X65 pipe material compared with PD 6493 predictions
82	Balsara	Application of advance fracture mechanics	Results from a series of seven pipe ring tests using sections from 36" diameter, 15.9 mm nominal wall thickness, API 5 LX material with different notches, compared with PD 6493 and R6 procedures.

Table 3.3: Summary of Relevant References for Data on Girth Weld Defects

Ref No.	Author	Main Topic	General Description
46	Buitrago et al.	S-N data on critical girth weld components	Fatigue data on critical welds, development of S-N curves and methodology for assessment.
348	Jutta et al.	Review of S-N curves and data for pipelines	Derivation of S-N design curves from limited data.
355, 357, 358	Vosikovsky	Fatigue crack growth data	Fatigue crack growth data on several API pipeline steels for various environmental test conditions.
356	Vosikovsky et al.	Fatigue crack growth data	Fatigue crack growth data on API 5L X65 pipeline steel in crude oil saturated with H_2S.
348	Jutla et al.	Review of crack growth data	Fatigue crack growth data from various programs with additional data assessed for developing crack growth modes.
326	Ebara et al.	Fatigue crack growth data	Derivation of crack growth rates for HT50 TMCP steel in sour crude oil and comparison with other data.
44	Robinson et al.	Fatigue crack growth data	Derivation of crack growth and thresholds for high strength steel up to 700 MPa in sulphate reducing bacteria environment.

Table 3.4: Summary of Relevant References for S-N (Fatigue) and Crack Growth Data

Ref No.	Author	Main Topic	General Description
208	Willmot M. et al.	Growth of SCC under fluctuating load	Experiments to determine crack growth rates under different corrosion environments for pipe line steels.
212	Zheng W et al.	Growth of SCC under hydro-testing	Experiments on X52 pipeline steel with different coating conditions, crack lengths and depths.
151	Krishnamurthy et al.	Methodology procedure to manage SCC on X52 pipeline	Experiment on in-service X52 pipeline steel and methodology (fracture model) developed.
157	Plumtree	SCC, crack growth monitoring under field conditions	Experiments on API X60 grade pipeline steel placed in service in 1972 and removed in 1988. Measurements of crack growth rates and model to assist inspection monitoring.
150	Zheng	SCC crack growth subject to fluctuating pressure	Experiments on range of pipeline steels (X52, X60, X65 and X70) under different pressure fluctuations with range of different cracks.

Table 3.5: Summary of Relevant References for Stress Corrosion Cracking Data

Ref No.	Author	Main Topic	General Description
53	Irisarri et al.	Fracture behaviour of high strength pipeline steel	CTOD and Charpy impact tests on API 5L grade X70 pipeline steel.
237	Kostic et al.	Material aspects of X-80 pipeline steel	Metallurgical examination, fracture toughness of X-80 steel compared with other grades.
242	Mak and Tyson	Material assessment of pipeline steel	Eight pipes in service over a period of 30 years have been tested to evaluate toughness properties. Range of steel grades X52 - X70.
328, 327	Glover et al.	Pipeline using high strength steels	Toughness data on MMA girth welds for a 914 mm 11.1mm thick grade 50X pipeline steel evaluated.
339	Hopkins et al	Toughness data for different welding processes	Extensive program of CTOD tests from two pipelines.
317	Slater and Davey (OTH 86233)	Statistical assessment of weld fracture toughness data	Comprehensive analysis of pipeline girth weld data based on information gathered from nine offshore operators and other sources.
393	McKeehan et al.	High yield to tensile ratio assessment	Evaluation of higher strength steel pipeline material (ref. yield to tensile ratio)

Table 3.6: **Summary of Relevant References for Data on Material CTOD/Fracture Toughness**

4. OVERVIEW OF CODES/PRACTICES

4.1 General

The development of pipeline standards started in the US in the 1930's with the issue of the first B31 Code. Pipelines at that time were exclusively onshore pipelines. Later updating has resulted in a separation into a number of codes, in particular B31.4 for transportation of hydrocarbon liquids and B31.8 for transportation of natural gas. Amendments to cover offshore pipelines have been developed and issued. The ASME B31.4 and B31.8 codes, together with API 5L and the API 1104 specification for line pipe and pipeline welding, respectively, have been used and referenced by the petroleum and natural gas industries worldwide.

However, the development of significant hydrocarbon reserves in Europe and other parts of the world since the sixties has lead to diversity of pipeline standards and specifications on a national or company level. Many industrialised countries developed their own pipeline standards including the prevailing requirements of their own experts and approving authorities. Thus significant differences in safety and technical requirements for pipelines developed between the various national codes. On company level a similar process took place. This resulted in an increasing volume of standards and specifications with differences in their requirements not always relevant for the final product.

In recognition of this, the Technical Committee 67 of ISO (ISO/TC 67) was set up with the objective to develop truly international standards for the petroleum and natural gas industries. In parallel to the ISO work, Norway decided to establish the NORSOK organisation with the objective to establish common industry standards. Similar initiatives have been seen in other countries.

In particular one operator which is a strongly supporting the ISO work is STATOIL, because of its position as operator of the largest gas transmission system in the world. Secondly Statoil has clearly seen the consequences of different pipeline standards between neighbouring countries.(i.e. Gas transport pipelines like Zeepipe 1, Europipe I and NorFRa cross different national sectors along their routes from the North Sea to continental Europe. National pipeline regulations and industry standards apply within the sectors resulting in, for example, varying wall thickness for the same pipeline from one sector to the next. Thirdly, pipeline technology has improved over the years resulting in improved fabrication tolerances, and better welding and NDT techniques. Furthermore, improved knowledge of pressure behaviour, external loads, corrosion protection and operational aspects have also taken place.

Offshore pipeline system can be grouped into two categories based upon their usage, oil industry pipeline systems and gas industry pipeline systems. The design, installation, inspection, repair and maintenance of offshore pipelines are covered by a number of national codes and standards, which include the following:

- Pipeline Transportation System for Liquid Hydrocarbons and other Liquids, ASME B31.4, 1998, US

- Gas Transmission and Distribution Piping Systems, ASME B31.8, 1995, US
- Code of Practice for Pipelines, BSI 8010, Part3, 1993, UK
- Oil and Gas Pipeline systems, CAS-Z662-99, 1999, Canada
- Rules for Submarine Pipeline Systems, DNV 1996, 1996, Norway
- Rules for Subsea Pipelines and Risers, GL 1995, Germany
- Pipeline Transportation System for the Petroleum and Natural Gas Industries, ISO 13623, 1995
- Design of Long Distance Transmission Pipelines, SniP2.05.06-85, 1985, Russian

These codes and standards specify minimum requirements for the design, fabrication, installation, operation, re-qualification and abandonment of offshore pipeline systems. They serve, as guidelines for designers, clients, contractors and others not directly involved in the certification process. These codes and standards are not design handbooks, and the exercise of competent engineering judgement is a necessary requirement to be employed concurrently with their use.

To design an offshore pipeline system, hydraulic, mechanical and structural design manuals, even textbooks, are required besides the above mentioned codes and standards. The design process of offshore pipeline system is typified in Figure 4.1. The required design checks are also typified as shown in Figure 4.2.

4.2 Probabilistic Design Methods

A pipeline shall fulfill two basic functional requirements: the individual probabilities of excessive deformations, resulting in an unserviceable line, and burst, resulting in loss of contents, must be sufficiently low. The probabilities of excessive deformations and burst can be assessed using reliability analysis. There are generally three levels of such analysis at which structural safety may be treated.

Level 1. A semi-probabilistic design process in which the probabilistic aspects are treated specifically in defining partial safety factors to be applied to characteristic value of loads and structural resistances. A level 1 structural design is what is now commonly called a limit state design. It is used as a practical method of incorporating reliability methods in the normal design process.

Level 2. A probabilistic design process with some approximation. In this process, the loads and the strengths of materials and section are represented by their known or postulated distributions (defined in terms of relative parameters such as type, mean, and standard deviation) and some reliability level is accepted. Level 2 methods are not necessary for component designs (handled by level 1 limit state design) but are valuable for economic planning, monitoring, and maintenance decision-making and structural integrity evaluations.

Level 3. A design process based upon full probabilistic analysis for the entire structural system. Level 3 methods, which take into account joint probabilistic distributions of load and strength parameters and uncertainties in the analysis, are extremely complex and limited in practicality. They are used in special circumstances where the environment is particularly sensitive or where cost savings justify the additional expense of complex analysis.

Situations where probabilistic methods might be used include the determination of the factored resistance of new systems and materials and the levels of safety to control new hazards.

4.3 Reliability-Based Calibration

Any design code provides a certain safety margin against failure in design. This inherent safety margin is mainly related to the choice of safety factors sometimes selected on a more or less arbitrary basis. This has caused different safety levels for different design checks.

Limit state design implies that the performance of the pipelines is described in terms of a set of limit states for which adequate safety margins are quantified. For the entire limit states, a set of safety factors are calibrated for each safety class using a structural reliability approach. It introduces flexibility in specific conditions and provides design with a consistent safety level without compromising the safety objective. However, in a sound calibration process a varying degree of conservatism need to be introduced for individual design scenarios depending on the knowledge of the prevailing loads, pipe capacities, etc. Thus, the calibrated design criteria being generally applicable may be expected to be conservative on average.

4.4 Design Criteria and Methods in Codes

4.4.1 ASME B31.4 1998 and B31.8 1995

ASME B31.4 and ASME B31.8, together with the API 5L and API 1104 specifications for line pipe and pipeline welding, respectively, are the most widely applied pipeline codes for the Petroleum and Natural Gas Industries.

The Codes are based on traditional allowable stress design methods. The design factor for general route pipelines is 0.72 for liquid pipelines based on nominal wall thickness. In setting the design factor, due consideration has been given to and allowance has been made for the under-thickness tolerance and maximum allowable depth of imperfections provided for in the specification approved by the code.

For the gas transmission and distribution piping systems, the code specifies a Location Class as follows:

- Location Class 1 is any 1 mile section that has 10 or fewer buildings intended for human occupancy. Location Class 1 is intended to reflect areas such as wasteland, desert, mountains, grazing land, farmland, and sparsely populated areas.

- Location Class 2 is any 1-mile section that has more than 10 but fewer than 46 buildings intended for human occupancy. Location Class 2 is intended to reflect areas where the degree of population is intermediate between location Class 1 and Location Class 3 such as fringe areas around cities and towns, industrial areas, ranch or country estates.

- Location Class 3 is any 1 mile section that has 46 or more buildings intended for human occupancy except when a location Class 4 prevails. Location Class 3 is intended to reflect areas such as suburban housing developments, shopping centers, residential areas, industrial areas.

- Location Class 4 includes areas where multistory buildings are prevalent, and where traffic is heavy or dense and where there may be numerous other utilities underground. Multi-storey means 4 or more floors above ground, including the first or ground floors.

Allowable tensile and compressive stress values for materials used in structural supports and restraints shall not exceed 66% of the specified minimum yield strength. Allowable stress values in shear and bearing shall not exceed 45% and 90% of the specified minimum yield strength, respectively.

4.4.2 BS 8010

The code takes the allowable stress design method as the basic design method as in other codes. The design factors, appropriate to the assessment of allowable stress, are given below in Table 4.1.

Hoop stress		**Equivalent Stress resulting from functional and environmental or accidental loads**		**Equivalent stresses arising from construction or hydrotest loads**	
Riser	**Seabed**	**Riser**	**Seabed**	**Riser**	**Seabed**
0.6	0.72	0.72	0.96	1.0	1.0

Table 4.1: Design factors f_d

Alternatively, the code allows that the acceptability of construction loads may be assessed on an allowable strain basis. The limit on equivalent stress may be replaced by a limit on allowable strain, provided that all the following conditions are met:

- Under the maximum operating temperature and pressure, the plastic component of the equivalent strain does not exceed 0.001. The reference state for zero strain is the as-built state.

- Any plastic deformation occurs only when the pipeline is first raised to its maximum operating pressure and temperature, but not during subsequence cycles of depressurization, reduction in temperature to the minimum operating temperature.

- The D/t ratio does not exceed 60.
- Welds have adequate ductility to accept plastic deformation.
- Plastic deformation reduces pipeline flexural rigidity; this effect may reduce resistance to upheaval buckling and should be checked if upheaval buckling might occur.

This approach is only permissible where geometric considerations limit the maximum strain to which the pipeline can be subjected and where the controlled strain is not of a cyclic or repeated nature.

4.4.3 DNV 1996

The DNV Rules for Submarine Pipeline Systems were first issued in 1976 and have since been updated in 1981 and most recently in 1996. It has as one of the basic objectives to "Provide an internationally acceptable standard of safety with respect to strength and performance by defining minimum requirements for the design, material selection, fabrication, installation, commissioning, operation, maintenance, re-qualification and abandonment of submarine pipeline systems.

In DNV '96 limit state design principles are adopted but allows, as an alternative, probabilistic design provided an acceptable reliability method is applied by competent personnel. The design format of the DNV 96 Rules is called a Load and Resistance Factor Design LRFD except for the requirement for pressure containment which is given in the traditional Allowable Stress Design (ASD) format.

The principle of the LRFD design format is to ensure that the level of structural safety is satisfactory such that the effect of the design load on the pipeline does not exceed the design resistance of the pipeline.

The acceptable target failure probabilities should be in compliance with the implied safety in the rules. By performing a reliability analysis for a specific design case or for a more restrictive scope of scenarios the inherent conservatism may be reduced.

In DNV '96, a novel safety class concept is introduced. Based on the fluid category, location class and phase, the pipeline is classified into a safety class. See Tables 4.2 to 4.4.

Category	Description
A.	Typical non-flammable water-based fluids.
B.	Flammable and/or toxic substances which are liquids at ambient temperature and atmospheric pressure conditions. Typical examples would be oil, petroleum products, toxic liquids and other liquids which could have an adverse effect on the environment if released.
C.	Non-flammable substances which are gases at ambient temperature and atmospheric pressure conditions. Typical examples would be nitrogen, carbon dioxide, argon and air.
D.	Non-toxic, single-phase gas which is mainly methane.
E.	Flammable and toxic substances which are gases at ambient temperature and atmospheric pressure conditions and which are conveyed as gases or liquids. Typical examples would be hydrogen, methane (not otherwise covered under category D), ethane, ethylene, propane, butane, liquefied petroleum gas, natural gas liquids, ammonia, and chlorine.

Table 4.2: Categorisation of Fluids

Location Class	Description
1	The zone where no frequent human activity is anticipated along the Pipeline route
2	The part of the Pipeline/Riser in the near platform (manned) zone or in areas with frequent human activity. The extent of zone 2 should be based on appropriate risk analyses. If no such analyses are performed a minimum distance of 500 m could be adopted.

Table 4.3: Definitions of Location Classes

Phase	Fluid Category A and C		Fluid Category B, D and E	
	Location Class		Location Class	
	1	2	1	2
Temporary	Low	Low	Low	Low
Operational	Low	Low	Normal	High

Table 4.4: Normal Classification of Safety Classes

Determination of appropriate target safety levels is fundamental to the process of developing new design criteria through the application of reliability methods. A target safety level is defined as the maximum acceptable failure probability level for a particular limit state design to be accepted, see Table 4.5 below:

Limit State Category	**Probability**		**Safety Classes**	
	Bases	**Low**	**Normal**	**High**
Serviceability	Annual per Pipeline[1)]	10^{-2}	10^{-3}	10^{-3}
Ultimate	Annual per Pipeline[1)]	10^{-3}	10^{-4}	10^{-5}
Fatigue	Lifetime probability per Pipeline[2)]	10^{-3}	10^{-4}	10^{-5}
Accidental	Annual per km[3])	10^{-4}	10^{-5}	10^{-6}

1 Or the length of the period in the temporary phase

2 No inspection and repair is assumed, temporary and in-service conditions considered together

3 Refers to the overall allowable probability of severe consequences.

Table 4.5: Recommended Target Safety Levels

The evaluation of the target safety level for pipelines should primarily be based on the implied safety in currently accepted design practice, using uncertainty measures representative at the time when the code was made. Further, the nature of failure and the actual consequence potential in terms of hazard to human health and safety, damage to the environment, economic losses, and the amount of expense and effort required to reduce such hazard potential should be take into account.

With no implicit safety level available, the rules provide recommendations on target failure probabilities versus safety class and limit state category. The base for the values of safety factor rely on a conservative assessment of implied safety in current accepted design practice guided by accident statistics and engineering judgement.

Limit State Categories:

Typical Limit States and corresponding limit state categories for a pipeline may be:

Serviceability/Limit State (SLS) Category

- Ovality / ratcheting Limit State

- Accumulated plastic strain Limit State
- Damage due to or loss of weight coating
- Yielding

Ultimate Limit Sate (ULS) Category

- Bursting Limit State
- Local buckling Limit State (pipe wall Limit State)
- Global buckling Limit State(normally for load-controlled condition)
- Unstable fracture and plastic collapse Limit State

Fatigue Limit State (FLS)

- Fatigue due to cyclic loading

Accidental Limit State (ALS) Category

- Dropped objects
- Trawl gear hooking
- Earthquake.

The hoop stress formula in the DNV rules is the same as in the ISO standard. The design factor requirements for pressure containment is, however, formulated as a dual requirement, namely as a check against yielding and a check against bursting as shown in Table 4.6

Safety Class	**Low**	**Normal**	**High**
Yielding	0.83	0.77	0.77
Bursting	0.72	0.67	0.64

Table 4.6: DNV 96 Hoop Stress Design Factors

A further possibility to benefit the designer is in the application of high quality material. The design factors given in Table 4.7 below apply when specified material quality requirements are satisfied.

Safety Class	**Low**	**Normal**	**High**
Yielding	0.85	0.80	0.80
Bursting	0.74	0.70	0.67

Table 4.7: DNV 96 Hoop Stress Design Factors, best material

Differences can be noted when comparing DNV with ISO as follows:

- The design requirements of ISO are based on yielding exclusively, whilst DNV applies both yielding and bursting as actual failure modes and presents a dual requirement for both.
- The design factors specified by DNV for yielding are generally the same as the ones specified by ISO. Whilst the factors in ISO basically rest on ASME B31.4/B31.8 and long term industry practice, the design factors in DNV are supported by extensive research programmes.
- The design factors in ISO are specified depending on fluid category and location, whilst those of DNV 96 are given by safety Class and in spite of the fact that the two standards generally specify the same design factors for the yielding criterion, the two design formats are basically different and may give different results in some cases

4.4.4 CSA Z662- 1999

In the code CSA Z662-99, allowable stress design is still used for the design criteria. The stress design requirements are considered to be adequate under conditions usually encountered and for general stress design of conventional pipeline systems. The design factors are given in Table 4.8

System	**Load condition**		
	A	**B**	**Pressure Testing**
Pipelines	0.72	1.00	1.00
Risers	0.60	0.80	1.00

Table 4.8: Design Factors

As an alternative, it permits for oil and gas pipelines to be designed in accordance with the requirement of limit state design methods given in Appendix C of the code as illustrated in Figure 4.3, provided that the designer is satisfied that such designs are suitable for the conditions to which such pipelines are to be subjected.

Class Location:

- Class 1: Class location assessment areas that contain 10 or fewer dwelling units shall be designated Class 1 location
- Class 2: class location assessment areas that contain more than 10 but fewer than 46 dwelling units shall be designated Class 2
- Class 3: Class location assessment areas that contain 46 or more dwelling units shall be designated Class3 location

- Class 4: Class location assessment areas where buildings intended for human occupancy with 4 or more storeys above ground are prevalent shall be designated Class 4 location.

Limit State Categories:

Ultimate Limit States

- Rupture
- Yielding caused b primary loads
- Buckling resulting in collapse or rupture
- Fatigue
- Serviceability limit states
- Yielding caused by secondary loads
- Buckling not resulting in Collapse.

4.4.5 ISO/DIS 13623-1996

The standard uses maximum permissible stresses as the basic concept for ensuring pipeline integrity and serviceability. Formulas and design factors are given for hoop stress and equivalent stress. Strain based design is allowed in specific cases.

The use of the reliability based limit state design method may be applied with one important exception, namely that of design for pressure containment for the general route part of the pipeline.

The hoop stress formula of the ISO standard is based on the average between inner and outer diameter of the pipeline and on minimum wall thickness as shown in Figure 4.4. This is different from the traditional formulation (i.e. ASME) which is based on nominal outer-diameter and nominal wall thickness. The traditional formulation was established for thin wall pipelines, whilst modern offshore gas trunklines are designed to much higher pressures giving thicker walls.

The formulation in European standards varies between the countries. Statoil for example has used a formulation based on inner diameter and minimum wall thickness. The result of the different formulations is that different standards in reality express different levels of steel utilisation for pressure containment in spite of the fact that they all prescribe the same design (ie. utilisation factor of 72% of yield strength).

Another effect inherent in the traditional design formulation for pressure containment is that the real steel strength utilisation expressed by the formulation is different when applied to pipelines with highly different design pressures. Thus the requirement works differently for an onshore gas pipeline with a design pressure typically in the range 60-80 bars and a flowline with a design pressure of say 400 bars both fabricated with the same wall thickness tolerances (eg. API 8%).

The practical consequences are such that the requirement for pressure containment normally determines the wall thickness of the pipeline steel. Therefore for the above example this would mean that the flowline would need relatively more steel than an onshore gas line in order to meet the same requirements when using the traditional formulation.

The hoop stress factors were calibrated to lead to the same wall thickness as required in ASME B31.4 and B31.8 for an average pipeline with a D/T of 60 and a 8% wall thickness tolerance. These factors are given in Table 4.9 below:

Location	Design factor u
General Route*	0.77
Shipping Lanes, designated anchoring areas and harbour entrances	0.77
Landfalls	0.67
Pig traps and multipipe slug catchers	0.67
Risers and station piping	0.67

* The factor may be increased to 0.83 for pipelines conveying category C and D fluids

Table 4.9: ISO Hoop stress design factors for offshore pipelines

5. DEFECT ASSESSMENT METHODS IN CODES

5.1 Assessment of Weld Defects

5.1.1 API 1104

This standard cover the gas and arc welding of butt, fillet, and socket welds in carbon and low alloy steel piping used in the compression, pumping, and transmission of crude petroleum products and fuel gases and, where applicable, covers welding on distribution systems. This standard also covers the acceptance standards to be applied to production welds tested to destruction or inspected by radiography. It includes the procedure for radiographic inspection.

The standard presents the acceptance standards for nondestructive testing, which apply to discontinuities located by radiographic, magnetic particle, liquid penetrant, and ultrasonic test methods. These acceptance standards are based on empirical criteria for workmanship and place primary importance on flaw length. Such criteria have provided an excellent record of reliability in pipeline service for many years.

In addition, API 1104 allow the use of alternative fitness-for-purpose criteria based on fracture mechanics analysis, which incorporates evaluation of the significance of both flaw depth and flaw length. The fit-for-purpose criteria provide more generous allowable flaw sizes, but only when additional procedure qualification tests, stress analysis, and inspections are performed.

The method requires that the welding procedures are qualified for either of two minimum CTOD toughness levels: 0.005 inch or 0.010 inch. Then, for a given maximum applied strain, the allowable defect depth is inferred. Limits on defect length are dependent on defect depth.

A residual strain of 0.2% has been included in developing the acceptance criteria in order to account for postulated residual stresses of yield magnitude. Defect depth may be determined by NDT techniques or by consideration of inherent size limitations due to weld pass geometry.

5.1.2 BS 7910

As the replacement of PD 6493 and PD 6539, this code outlines methods for assessing the acceptability of flaws in all types of structures and components. Although emphasis is placed on welded fabrications in ferritic and austenitic steels and aluminium alloys, the procedures developed can be used for analysing flaws in other materials and in non welded applications.

The fracture assessment procedures described in this guide are a development of the 1991 edition of PD 6493. Although there are continuing advances and improvements in fracture assessment methods, the procedures presented are felt to represent approaches which have been validated extensively and are intended to provide consistently accurate and safe predictions. They combine the Crack Tip Opening Displacement Methods introduced by the Welding Institute via the 1980 edition of

PD6493 with approaches based on the R6 procedures published by Nuclear Electric/Magnox Electric (formerly Central Electricity Generating Board).

The code contains improvements to the approaches in PD6493:1991 based on user experience, additional solutions and improved guidance from various literature sources, and a fuller integration of R6 Rev 3 procedures.

As in the 1991 edition of PD 6493, three levels of fracture assessment are available to the user. The choice of level depends on the input data available, the level of conservatism and the degree of complexity required.

Level I: this is the screening level introduced into the 1991 version of PD6493 and broadly compatible with the 1980 edition of the document. This level provides a conservative estimate from its use of the simplified FAD with in built safety factors and required conservative estimates of the applied stress, residual stress and fracture toughness.

Level II: this is considered to be the normal assessment route applicable for general structural steel application and makes use of a more accurate FAD with no inherent safety factors. The procedure permits the prediction of acceptability of the structure when all three input parameters are known and also allow limiting values of any one parameter to be predicted.

Level III: This level employs a full tearing instability approach and therefore provides a more accurate description of the performance of ductile materials.

All levels refer to tensile Mode I failure only. Shear failure is dealt with the method in Annex B. All three levels of assessment use a Failure Assessment Diagram (FAD) which combines consideration of fracture and local plastic collapse.

5.1.3 CSA Z662-99

Work quality standards of acceptability have been based on experience with traditional welding and inspection practices. This experience has indicated the capabilities of welding procedures and personnel in minimizing the incidence of welding imperfections during production welding of pipe girth welds.

Appendix J is to outline the application of the concept of engineering critical assessment to fusion welds. Standards of acceptability based on ECA include consideration of the measured weld properties and intended service conditions for a specific application. Alternatives to the work quality standards of acceptability can be derived for sections of a new pipeline.

Appendix K provides the analytical methods that shall be used to derive standards of acceptability for weld imperfections, which may be used as an alternative to the standards. The standards of acceptability that are derived are based on engineering critical assessment and include consideration of the measured weld properties and the intended service conditions.

5.1.4 R/H/R6 Revision 3

R/H/R6 was originally published as a CEGB Report entitled " Assessment of the Integrity of Structures Containing Defects" 1976.

The R6 defect assessment procedure uses the concept of a failure assessment diagram (FAD) to define the boundary between the safe and unsafe operating conditions of the flawed structures.

The procedure described in the main document adopts a deterministic approach in which specific combinations of defect size and material property values are chosen to ensure a conservative result in the assessment of defect structures. The elastic-plastic assessment procedure used in the R6 approach can form the basis of a probabilistic assessment procedure where the uncertainties in the main assessment parameters are included. In appendix 10, a probabilistic assessment procedure based on the R6 analysis is described which takes account of developments in probabilistic fracture mechanics in recent years. This extends previous applications of probabilistic fracture mechanics, which have been based mainly on linear elastic fracture mechanics, to elastic-plastic fracture analysis more appropriate for the assessment of general engineering structures.

5.2 Corrosion Defect Assessment

5.2.1 ASME B31G

This is a supplement to ASME B31 code for pressure piping. It provides a semi-empirical procedure for the assessment of corroded pipes. The procedure was developed in the late sixties and early seventies at Battelle Memorial Institute.

Based on an extensive series of full-scale tests on corroded pipe sections, it was concluded that the experiments on corroded pipe indicated that line pipe steels have adequate toughness and that the toughness is not a significant factor. The failure of blunt corrosion flaws is controlled by their size and the flow stresses or yield stresses of the materials.

Limitations on the use of the B31G procedure include:

1. It applies to corrosion defects only in the body of the pipe which have relatively smooth contours and cause low stress concentration
2. It applies to pipes under internal pressure loading only.

The assessment procedure considers the maximum depth and longitudinal extent of the corroded area, but ignores the circumferential extent and the actual profile.

If the corroded region is found to be unacceptable, B31G allows the use of more rigorous analysis or a hydrostatic pressure test in order to determine the pipe remaining strength. Alternatively, a lower maximum allowable operating pressure may be imposed.

6. DATABASE

6.1 Database Requirements

A prime deliverable from this project is a database on the strength of pipelines containing defects. The usefulness of any database is very dependent on the care exercised during its development, particularly with such issues as completeness of captured data, quality assurance and database structure.

MSL's experience in the area of database preparation would indicate that time spent during the initial set-up (i.e. in defining the fields of the database) pays dividends during data entry, data checking and eventual use. As an example, different source documents will use different units (e.g. inches v. millimetres) whereas the data in the database needs presenting in consistent units. However, to facilitate the checking of data entry against the source documents, it is easier to use the original unit systems of those documents. The database therefore contains a degree of duplicated columns; one set based on original units and the other with consistent units. After data entry checking, the columns with original units can then be hidden for presentation purposes.

It is important to capture the data fully. For instance, the pipe thickness will normally be quoted but it may be relevant in subsequent analyses to know whether this value was nominal, measured or inferred (from other variables such as D and D/T). This information has therefore been carefully recorded. In a similar vein, the steel yield stress is preferably a measured value but may have been given in terms of the specified minimum value. Again, such information needs to be recorded, including both measured and specified values if available. The inclusion of a 'comment' field is essential for recording peculiar testing characteristics. In all cases, tabular information in the source documents is to be preferred over graphical information as the latter may introduce scaling errors when extracting data.

Consideration was given to setting up a number of separate databases according to defect type: dent, gouge, cracks, corrosion, etc. However, many of the fields would be common, e.g. fields describing pipe geometry, materials, loading, etc. It was therefore decided to generate a Master Database, subsets of which could be extracted later for subsequent appraisal. A detailed description of all fields is given in the next subsection.

6.2 Description of Fields

The fields defined in the Master Database are reproduced in Table 6.1. In the actual database, the field headings stretch along one horizontal line. The numbers in the first row refer to Notes given in Table 6.2.

See Note:					1	2	3			3			3	3			
SPECIMEN IDENTIFICATION							**PIPE GEOMETRY**										
Ref No	Author	Spec ID	Sequence No.	Type	Screening Level	Type of Defect	Dia (source)			Thk. (source)			D [mm]	T [mm]	D/T	L [mm]	L/D
								Unit	Type		Unit	Type					

4			3			3			3			3				
PIPE SPECIFICATION			**MATERIAL PROPERTIES**													
Manufac. Process	Material Grade	SMYS	σ_{yhoop} (source)			$\sigma_{ulthoop}$ (source)			σ_{ylong} (source)			$\sigma_{ultlong}$ (source)			σ_y	σ_u
				Unit	Type		Unit	Type		Unit	Type		Unit	Type	[N/mm^2]	[N/mm^2]

LOADING						
Load Type	Loading (source)			Loading Stress Range		No. of Cycles
	Min	Max	Unit	Min	Max	

Table 6.1: Database fields (continued...)

MATERIAL PARAMETERS																
Fracture Parameters									Residual Stresses			FM Parameters				
Charpy	Unit	Temp	CTOD	Unit	J_{IC}	Unit	K_{IC}	Unit	σ_{rhoop}	σ_{rlong}	Failure Mode	A_a	A_b	m_a	m_b	K_{th}

	5							6									
MECHANICAL DAMAGE																	
Type	DENT								GOUGE								
	Shape	d_d	Unit	l_d	Unit	d_d [mm]	l_d [mm]	Location	d_g	Unit	l_g	Unit	d_g [mm]	l_g [mm]	Orientation	Finish	SCF

7											6							
CORROSION											**CRACK**							**COMMENTS**
Corrosion Type	Length	Unit	Width	Unit	Depth	Unit	L_c [mm]	W_c [mm]	d_c [mm]	Surface Finish	Location	depth (a)	Unit	length (2c)	Unit	a [mm]	2c [mm]	

Table 6.1: Database fields (...continued)

Notes:

1 SL1 = Fully acceptable data
SL2 = Acceptable data but some nominal values used
SL3 = Acceptable data but peculiarities
SL4 = Incomplete data, reject

2 M = Mechanical damage (dent and/or gouge)
C = Corrosion
F = Fatigue crack
W = Weld defect
O = Other

3 N = Nominal
M = Measured
C = Calculated
U = Unknown

4 SMLS = Seamless
SAW = Submerged Arc Welding
ERS = Electric Resistance Welding
N/A = Not applicable (for FE data)

5 Sq = Square indentor
Cyl1 = Cylinder transverse to pipe
Cyl2 = Cylinder longitudinal to pipe
Sph + Spherical indentor
O = Other

6 GW = Girth weld
LW = Longitudinal weld
P = Parent material

7 G = General
I = Internal
E = External
P = Pit
L = Localised

Table 6.2: Database notes

Inspection of Table 6.1 shows that the data has been entered under ten main headings, with sub-headings as follows:

i) Specimen Identification

The 'reference number' and 'author' are the same as in the list of References herein. The 'spec ID' is the specimen identification as used in the source document. The author and spec ID fields are useful in weeding out duplicate sets of data. Each specimen is given a unique 'sequence number' to facilitate traceability following screening and the creation of data subsets. Where a specimen requires multi-row entries (e.g. for the recording of crack growth data) then letters a, b, c etc. are used after the sequence number to distinguish the row entries. The 'type' column refers to whether the data are test data or finite element (FE) data. The entries under 'screening level' and 'type of defect' are defined in Notes 1 and 2 in Table 6.2 respectively. The latter will be useful for sorting the database and in preparing data subsets.

ii) Pipe Geometry

The sub-headings under this grouping are self-explanatory especially when read in conjunction with Note 3 in Table 6.2. As explained above, the 'source' columns are used for data entry purposes and can be hidden after the data has been checked.

iii) Pipe Specification

The three sub-headings under 'pipe specification' record the pipe manufacturing process and the type of material.

iv) Material Properties

Again, these sub-headings are self-explanatory.

v) Loading

The 'load type' identifies the loading regime as appropriate, e.g. pressure, axial, bending, etc. The loading range (or ranges if multi-row entries are being used for crack growth tests) is entered under the 'source' column in the original units. The 'number of cycles' is only relevant for fatigue or crack growth tests, otherwise N/A is entered.

vi) Material Parameters

Sub-headings are provided for brittle fracture parameters, Fracture Mechanics parameters and residual stresses. These parameters might be given in some source documents and will become relevant during appraisals of the various defect assessment methodologies.

vii) Mechanical Damage

The entries under this heading are to characterise the shape, size and location/orientation of dents and gouges. Once again, duplicate columns allow for data entry using source document units and then transposition to a consistent set. The first column under this heading, 'type', allows for subsequent sorting.

viii) Corrosion

The corrosion section allows data pertaining to the nature and extent of any corrosion to be entered. The 'corrosion type' is a qualitative field and is used to define whether the corrosion is internal or external, localised or general, etc.

ix) Crack

The location, depth and length of a crack are entered here.

x) Comments

This section allows the embellishment of any noteworthy aspects gleaned from the source document. It is particularly useful for recording any peculiar testing procedure or observation that is not addressed in other fields.

REFERENCES

No.	Title	Author	Conference	Ref.
1	Rules for Submarine Pipeline System	Det Norske Veritas		DNV 96
2	Oil and Gas Pipeline System	Canadian Standard Association		CSA Z662-99
3	Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids	American Society of Mechanical Engineer		ASME B31.4
4	Manual for Determining the Remaining Strength of Corroded Pipelines	American Society of Mechanical Engineer		ASME B31G
5	Gas Transmission and Distribution Piping Systems	American Society of Mechanical Engineer		ASME B31.8
6	Welding of Pipelines and Related Facilities	American Petroleum Institute		API RP 1104
7	Piping Inspection Code	American Petroleum Institute		API 570
8	Piping Maintenance Welding Practice	American Petroleum Institute		API RP 1107
9	Rules for Submarine Pipeline System	Det Norske Veritas		DNV 81
10	Code of Practice for Pipelines	British Standards Institute		BS 8010
11	Guidance on Methods for Assessing the Acceptability of Flaws in fusion welded structures	British Standards Institute		BS 6493
12	Guidance on Methods for Assessing the Acceptability of Flaws in fusion welded structures	British Standards Institute		BS 7910
13	Petroleum and National Gas Industries - Pipeline Transportation Systems	International Organization for Standardization		ISO/TC67/SC2
14	Code of Federal Regulations, Title 49 Transportation	National Register		CFR 40
15	A Review of Current Practice in Pipeline Defect Assessment	Billington Osborne Moss engineering Ltd		OTO 1999 002
16	A Review of Current Practice in Pipeline Defect Assessment - User Guide	Billington Osborne Moss engineering Ltd		OTO 1999 003
17	A Review of Current Practice in Pipeline Defect Assessment - Annex	Billington Osborne Moss engineering Ltd		OTO 1999 004
18	GL Rules for Subsea Pipelines and Risers	Thomas Plonski	Pipeline Technology	OMAE
19	An Introduction to the DNV 1996 Rules for Submarine Pipeline Systems	Leif Collberg	7th International Offshore and Polar Engineering Conference	ISOPE
20	R6 Developments in the Treatment of Secondary Stresses	Dennis G Hooton	Pressure Vessels and Piping	ASME
21	Development of a Russian Standard for Submarine Pipeline Design, Installation and Operation	M.A. Kamyshev	7th International Offshore and Polar Engineering Conference	ISOPE
22	Arctic Pipeline Risk Assessments	Bernard J. Weber and Krishna S. Mudan	2nd International Offshore and Polar Engineering Conference	ISOPE
23	Reliability-based Pipeline Design and Code Calibration	Torbiorn Sotberg and Brent J. Leira	Pipeline Technology	OMAE
24	The Development and Implementation of a Strain Methodology for Installation of Pipelines on Uneven Seabeds	Kyriacou A.	Pipeline Technology	OMAE
25	Reliability Based Calibration of Partial Safety Factors For Design of Free Pipeline Spans	Knut O. Ronold	Pipeline Technology	OMAE
26	Comparison Between Limit State Equations for Deepwater Pipelines Under External Pressure and Longitudinal Bending	Segen F. Estefen	Pipeline Technology	OMAE
27	Compressive Strain Limits for Buried Pipelines	T.J.E. Zimmerman	Pipeline Technology	OMAE
28	Strain Based Design of Pipelines	Alastair C Walker	Pipeline Technology	OMAE
29	New Test Data on Structural Behaviour of Gre Pipe and Joint Systems	A Ma	Pipeline Technology	OMAE
30	The Superb Project: A New Safety Philosophy for Submarine Pipeline Design	Torbiorn Sotberg	Pipeline Technology	OMAE
31	Reliability-Based Limit-State Design and Re-Qualification of Pipelines	Yong Bai	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
32	System Reliability of Offshore Structures	Alberto C. Morandi	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
33	Expansion of Pipelines Under Cyclic Operational Conditions: Formulation of Problem and Development of Solution Algorithm	Ibrahim Konuk	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
34	Probabilistic Design of Burial Depth for Offshore Pipelines and Cables in Dynamic Seabed	Zhiwen Chen	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
35	A Limit States Approach to the Design of Pipelines for Mechanical Damage	Robert G. Driver	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
36	Reliability-Based Approach to the Operation of Gas Transmission Pipelines at Design Factors Greater than 0.72	Andrew Francis	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
37	Technical Basis for the Extension of ASME Code Case N-494 for Assessment of Austenitic Piping	Joseph M. Bloom	Pressure Vessels and Piping	ASME
38	The Use of GE-EPRI Handbook Solutions in ETA Factor Methodologies for Determining J Crack Growth Resistance Curves	E. Smith	Pressure Vessels and Piping	ASME
39	Modifications to the GE/EPRI J-Estimation Scheme Using Reference Stress Methods	Robert A Ainsworth	Pressure Vessels and Piping	ASME
40	Wave Induced Forces on a Submarine Pipeline	R. Raichlen	7th International Offshore and Polar Engineering Conference	ISOPE
41	Surface Roughness in Internally Coated Pipes (OCTG)	F. Farshad	Offshore Technology Conference	OTC
42	Wave Induced Fatigue of Free-Spanning Pipelines	Yong Bai	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
43	Detection of Fatigue Crack Closure Using Thermoelastic Stress	Hannah Batchelor	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
44	A Review of the Effects of Sulphate Reducing Bacteria in the Marine Environment on Corrosion Fatigue and Hydrogen Embrittlement of High Strength Steels	M. J. Robinson	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
45	Effect of Welding Sequence and Line Heating on Fatigue Strength for Welded Structures	Masahiro Toyosada	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
46	Fatigue Design of Critical Girth Welds for Deepwater Applications	Jaime Buitrago	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
47	A Model for Predicting Vessel Failure Probabilities due to Fatigue Crack Growth	F. A. Simonen	Pressure Vessels and Piping	ASME
48	Fracture Behavior Under Low Cycle Fatigue Loadings in Japanese Carbon Steel Welded Pipe Joints with a Defect	Katsumasa Miyazaki	Pressure Vessels and Piping	ASME

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49	Fatigue Risk Assessment Procedures	Achintya Haldar	Pressure Vessels and Piping	ASME
50	Fatigue Life of Pipelines with Dents and Gouges Subjected to Cyclic Internal Pressure	J. R. Fowler	Pipeline Engineering	ASME
51	Some Test Results for Wrinkling of Girth-Welded Line Pipe	Nader Yoosef-Ghodsi	Pipeline Technology	ASME
52	Assessment of Girth Weld Defects in Transmission Pipelines in the Ductile to Brittle Transition Region	Valentino Pistone	Pipeline Technology	ASME
53	Fracture Behaviour of Overmatched Girth Welds	Angel M. Irisarri	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
54	Underwater Wet Repair-Welding and Strength Testing on Pipe-Patch Joints	Robert Wernicke	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
55	Toward and Acceptance Criterion for Shallow Dents Affecting Girth Welds in Gas Transmission Pipelines	M. J. Rosenfeld	Pressure Vessels and Piping	ASME
56	Fracture Toughness Estimation Methodology in the 'SINTAP' Procedure	Pekka Nevasmaa	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
57	Practical Application of Fracture Mechanics with Consideration of Multiaxiality of Stress State to Degraded Nuclear Piping	K. Kussmaul	Pressure Vessels and Piping	ASME
58	A Fracture Strength Evaluation Method for Carbon Steel Pipes Subjected to Dynamic/Cyclic Loadings - Evaluation of Dynamic/Cyclic Pipe Fracture Tests at Elevated Temperature	Terutaka Fujioka	Pressure Vessels and Piping	ASME
59	The Application of Local Approach To Assess the Influence of In-Plane Constraint on Cleavage Fracture	Andrew H Sherry	Pressure Vessels and Piping	ASME
60	The Effect of Crack Location on the Net Section Stress Criterion for Failure of a Cracked Piping System	E. Smith	Pressure Vessels and Piping	ASME
61	Experience with Corrosion Resistant Pipelines	Liane M. Smith	Pipeline Technology	OMAE
62	Non-Linear Finite Element Prediction of Wrinkling in Corroded Pipe	Daniel P. Nicolella	7th International Offshore and Polar Engineering Conference	ISOPE
63	Corrosion Resistance Evaluation of 22Cr Duplex Stainless Steel Weldments	A. Kopliku	Pipeline Technology	OMAE
64	Reliability Prediction of Corroding Pipelines	John E Strutt	Pipeline Technology	OMAE
65	Corrosion Risk Assessment and Planned Maintenance for Corrosion Control: An Application to an Oil Field in Egypt	Sayed Abdel Hameed	17th International Concerence on Offshore Mechanics and Arctic Engineering	ISOPE
66	Pipeline Buckling, Corrosion and Low Cycle Fatigue	Roland Palmer-Jones	17th International Concerence on Offshore Mechanics and Arctic Engineering	ISOPE
67	Comprehensive Overline Diagnostics to Determine Actual Pipeline and Protective Coating Condition	G. A. Euwe	Pipeline Technology	OMAE
68	Predicting Failure Pressure of Internally Corroded Linepipe using the Finite Element Method	Bin Fu	Pipeline Technology	OMAE
69	New Developments in Burst Strength Predictions for Locally Corroded Pipelines	Frans J. Klever	Pipeline Technology	OMAE
70	Prevention of Hydrate Formation in Pipelines by Electrical Methods	Jens Kristian	7th International Offshore and Polar Engineering Conference	ISOPE
71	Internal Corrosion Monitoring of Subsea Production Flowlines - Probe Design, Testing, and Operational Results	M. W. Joosten	Offshore Technology Conference	OTC
72	Deep Water: Considerations of the Cathodic Protection Design Basis	K. P. Fischer	Offshore Technology Conference	OTC
73	Overview of Britannia Subsea Corrosion-Control Philosophy	J. Kolts	Offshore Technology Conference	OTC
74	A Proposed Corrosion Assessment Method and In-service Safety Factors for Process and Power Piping Facilities	M. J. Rosenfeld	N/A	N/A
75	Pipeline Inspection Using an Autonomous Underwater Vehicle	Per Egeskov	Pipeline Technology	OMAE
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77	Probabilistic Tools for Planning of Inspection and Repair of Corroded Pipelines	D. Ritchie	17th International Concerence on Offshore Mechanics and Arctic Engineering	ISOPE
78	Insulated Pipe-In-Pipe Subsea Hydrocarbon Flowlines	Robert H. Nuttall	17th International Concerence on Offshore Mechanics and Arctic Engineering	ISOPE
79	Development and Application of Proposed ASME Section XI Code Changes for Risk-Based Inspection of Piping	Raymond A. West	Pressure Vessels and Piping	ASME
80	Application of Risk-Based Methods to Inservice Inspection of Piping Systems	Nancy B. Closky	Pressure Vessels and Piping	ASME
81	34" Onshore Gasline: Integrity Assessment and Rehabilitation Costs	A. Amorelli	Pipeline Technology	ASME
82	Application of Advanced Fracture Mechanics to the Assessment of Linepipe Defects	Mukesh N. Balsara	Pipeline Technology	ASME
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93	New Technologies in Underwater Pipeline Management	Stefano Dicorrado	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
94	Arctic Pipeline Limit States for Secondary Loadings	I.F. Kharib	2nd International Offshore and Polar Engineering Conference	ISOPE
95	Plastic Buckling of Pipes Under Bending and Internal Pressure	H.O. Kim	2nd International Offshore and Polar Engineering Conference	ISOPE
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98	The Behaviour of High Pressure, High Temperature Flowlines on Very Uneven Seabed	Knut Tornes	7th International Offshore and Polar Engineering Conference	ISOPE
99	Intrinsic Coordinate Elements for Large Deflection of Offshore Pipelines	Poh C. Andrew Ngiam	7th International Offshore and Polar Engineering Conference	ISOPE
100	3-D Dynamic Buckling and Cyclic Behaviour of HP/HT Flowlines	Per R. Nystrom	7th International Offshore and Polar Engineering Conference	ISOPE
101	A Simplified Analysis of Imperfect Thermally Buckled Subsea Pipelines	James G.A. Croll	7th International Offshore and Polar Engineering Conference	ISOPE
102	Reeline of Pipelines with Thick Insulation Coating, Finite-Element Analysis of Local Buckling	Tim Crome	Offshore Technology Conference	OTC
103	Buckle Arrestors for Deepwater Pipelines	Carl G. Langner	Offshore Technology Conference	OTC
104	Seismic Qualification of Existing Pipeline Systems	G. M. Manfredini	Pipeline Technology	ASME
105	Structural Integrity of Offshore Pipelines in Seismic Conditions	R. Bruschi	Pipeline Technology	ASME
106	Field Experiences of Pipelines in Geologically Unstable Areas	Giuseppe Scarpelli	Pipeline Technology	ASME
107	Failure Modes for Pipelines in Landslide Areas	R. Bruschi	Pipeline Technology	ASME
108	Ground Movement Hazards to Pipeline Integrity: Quantifying the Effect of Snowmelt	Dimitri A. Grivas	17th International Concerence on Offshore Mechanics and Arctic Engineering	OMAE
109	How to Avoid Major Hazards From Oil and Gas Pipelines in the Coastal and Inner Waters of Denmark	Jens Erik Thygesen	Pipeline Technology	ASME
110	Scour around Pipelines in Combined Waves and Current	B. M. Summer	Pipeline Technology	ASME
111	Materials Selection for Offshore Pipelines	Liane M. Smith	Pipeline Technology	ASME
112	Expansion Analysis of Subsea Pipe-In-Pipe Flowline	Gary E. Harrison	7th International Offshore and Polar Engineering Conference	ISOPE
113	Local Scour Around Submarine Pipelines Under Wave Conditions	E. Ozkan Cevik	7th International Offshore and Polar Engineering Conference	ISOPE
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117	Quantitative Examination of Segregation in Slabs for the Production of Sour Service Linepipe	Bernhard Hoh	First International Pipeline Conference 1996	IPC
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119	Determination of the Crack-Arrest Toughness of the Pipeline Steel x 70	S. Felber	First International Pipeline Conference 1996	IPC
120	Manufacture, Properties, and Installation of X80 (550 MPa) Gas Transmission Linepipe	M. Milos Kostic	First International Pipeline Conference 1996	IPC
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124	External Pipeline Coating Selection for New and Existing Buried Pipelines	Mick D. Brown, Ph.D.	First International Pipeline Conference 1996	IPC
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153	Hydrogen-Induced Stress Corrosion Cracking of Pipe Lines of Russia	Tatyana K. Sergeyeva	First International Pipeline Conference 1996	IPC
154	Investigation of the Passivity, Hydrogen Embrittlement and Threshold Stress of Duplex Stainless Steel	Mirko Gojic	First International Pipeline Conference 1996	IPC
155	Study of Stress-Corrosion Cracks:Physical and Mechanical Properties of Steel After Hydrostatic Re-Testing	S. Karpov	First International Pipeline Conference 1996	IPC
156	Mechanisms of High-pH and Near-Neutral-pH SCC of Underground Pipelines	John A. Beavers	First International Pipeline Conference 1996	IPC
157	Stress Corrosion Crack Growth of Pipeline Steels in NS4 Solution	A. Plumtree	First International Pipeline Conference 1996	IPC
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192	Fatigue Curves for Damage Calculations for a Dented and Ovalled Section of the TransAlaska Pipeline System	Glen R. Stevick	International Pipeline Conference 1998	IPC

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227	Use of the Elastic Wave Tool to Located Cracks Along the DSAW Seam Welds in a 32-inch (812.8-mm) OD Products Pipeline	Willard A. Maxey	International Pipeline Conference 1998	IPC
228	In-Line Inspection Tools for Crack detection in Gas and Liquid Pipelines	H. H. Willems	International Pipeline Conference 1998	IPC
229	Comparison Between In-Line Crack Detection and Hydrostatic Testing in IPL's Line 3	Michael A. Gardiner	International Pipeline Conference 1998	IPC
230	Application of Material Standards & ISO Quality Management Systems	Keith E. W. Coulson	International Pipeline Conference 1998	IPC
231	The Australian Petroleum Pipeline Code AS 2885 - 1997	Ken J. Bilston	International Pipeline Conference 1998	IPC
232	Reliability of Mechanised UT Systems to Inspect Girth Welds During Pipeline Construction	Jan A. de Raad	International Pipeline Conference 1998	IPC
233	Customized Ultrasonic Systems for Gas Pipeline Girth Weld Inspections	Michael D. C. Moles	International Pipeline Conference 1998	IPC
234	Three Layer Epoxy/Polyethylene Side Extruded Coatings for Pipe for High Temperature Application"	Mike Alexander	International Pipeline Conference 1998	IPC
235	Deformation and Fracture Behaviors of Polyethylene Coatings on the Natural Gas Transmission Line With Ultraviolet Exposure	Seong-Min Lee	International Pipeline Conference 1998	IPC
236	Pipeline Design and Construction Using Higher Strength Steels	Alan G. Glover	International Pipeline Conference 1998	IPC
237	Development of Heavy Gauge X80 Linepipe	M. Milos Kostic	International Pipeline Conference 1998	IPC
238	An Investigation of the Factors Influencing the Formation of Hollow Bead Bores in Pipeline Girth Welds	Gersende M. Delphine Cantin	International Pipeline Conference 1998	IPC
239	Quality and Productivity Improvements in the Field Welding of High Strength Thin Walled Pipelines	Frank J. Barbaro	International Pipeline Conference 1998	IPC
240	Transition Temperature Determination for Thick Wall Line Pipe	G. Demofonti	International Pipeline Conference 1998	IPC

No.	Title	Author	Conference	Ref.
241	On the Evaluation of Dynamic Stresses in Pipelines Using Limited Vibration Measurements and FEA in the Frequency Domain	Walied A. Moussa	International Pipeline Conference 1998	IPC
242	Material Assessment of Canadian Saw Line-Pipes	D. K. Mak	International Pipeline Conference 1998	IPC
243	Relationship Between Apparent (Total) Charpy Vee-Notch Toughness and the Corresponding Dynamic Crack-Propagation Resistance	Brian N. Leis	International Pipeline Conference 1998	IPC
244	Large Deformation Behavior of Pipe Fbends Subjected to In-Plane Bending	Koji Yoshizaki	International Pipeline Conference 1998	IPC
245	Seismic Hazard Assessment and Remediation of Pipelines	Trevor P. Fitzell	International Pipeline Conference 1998	IPC
246	Analysis of Stresses on Buried Natural Gas Pipeline Subjected to Ground Subsidence	Hyoung-Sik Kim	International Pipeline Conference 1998	IPC
247	In-Situ Evaluation of Pipeline Bedding and Padding Spring Constants	Rupert G. Tart	International Pipeline Conference 1998	IPC
248	Strain-Based Pipeline Design Criteria Review	Aaron S. Dinovitzer	International Pipeline Conference 1998	IPC
249	Field Full Scale Tests on Longitudinal Pipeline-Soil Interaction	Andrea Cappelletto	International Pipeline Conference 1998	IPC
250	A Full-Scale Investigation Into Pipeline/Soil Interaction	Michael J. Paulin	International Pipeline Conference 1998	IPC
251	Laboratory Tests and Numerical Modelling of Sleeper-Supported Line Pipe	Jeffery D. DiBattista	International Pipeline Conference 1998	IPC
252	Incorporating Muskeg Soil Shear Strength Into Buoyancy Control Design	Gordon R. Simmonds	International Pipeline Conference 1998	IPC
253	Determination of Pipe Roughness and Heat Transfer Coefficient in Pipeline Networks Using Multidomain Solution Method	Jaroslaw Jelen	International Pipeline Conference 1998	IPC
254	Full Flow high Pressure Hot Taps: The New Technology and Why it's Indispensable to Industry	John A. McElligott	International Pipeline Conference 1998	IPC
255	Slackline Testing of the TransAlaska Pipeline System at Thompson Pass	U. J. Baskurt	International Pipeline Conference 1998	IPC
256	Pipeline Fault Diagnosis System Enhancement	Tang Xiujia	International Pipeline Conference 1998	IPC
257	Requirements of Pipeline Simulation: Accurately Modeling Transient Pipeline Operation	Kenneth H. Hanks	International Pipeline Conference 1998	IPC
258	Physical Basis of Software-Based Leak Detection Methods	Jim C. P. Liou	International Pipeline Conference 1998	IPC
259	Improved Leak Detection by Method Diversity	Ruprecht M. J. Pichler	International Pipeline Conference 1998	IPC
260	Field Monitoring of Gases Using III-V Semiconductor Diode Laser Technology	Hu Wang	International Pipeline Conference 1998	IPC
261	Support Operation and Monitoring Application of Pipeline Simulator (SMAPS)	Hideki Kondoh	International Pipeline Conference 1998	IPC
262	Gas Demand Forecasting Based on Artificial Neural Network	Kauyoshi Miura	International Pipeline Conference 1998	IPC
263	The A.R.T. of Supervisory Control and Data Acquisition	George L. Germain	International Pipeline Conference 1998	IPC
264	Implementation of the Fast Track Express Pipeline SCADA Project	Greg Sande	International Pipeline Conference 1998	IPC
265	Pipeline Control: Merging SCADA and Gas Measurement	Ian M. Clark	International Pipeline Conference 1998	IPC
266	SCADA Designs: The Evolution of the User Interface for the Pipeline Industry	Chad G. Wagner	International Pipeline Conference 1998	IPC
267	Effect of Flow Conditioners and Pulsation of the Performance of 8 Inch Multi-Path Ultrasonic Meters	U. Karnik	International Pipeline Conference 1998	IPC
268	Application of CFD to the Design of Multirun Meter Station With Ultrasonic Meters	Jaroslaw Jelen	International Pipeline Conference 1998	IPC
269	Alarm Management Plan for Pipeline Facilities	Alex Dvorkin	International Pipeline Conference 1998	IPC
270	Pipeline Operations Training Using a Pipeline Simulator	Dale Sutherland	International Pipeline Conference 1998	IPC
271	Exploring the Potential for constructivist Learning Theory in SCADA Domains	Lynne Cox	International Pipeline Conference 1998	IPC
272	Early Public Notification	Douglas V. Ford	International Pipeline Conference 1998	IPC
273	Development and Implementation of the Nova Gas Transmission Ltd. Conservation & Reclamation Standard	Jeannette K. Nixon	International Pipeline Conference 1998	IPC
274	Identifying and Accounting for Environmental Costs	Doug Jagger	International Pipeline Conference 1998	IPC
275	Environmental Management for Regulated Industrial Wastes	Larry Loven	International Pipeline Conference 1998	IPC
276	Response, Remediation and Risk Management of a Crude Oil Pipeline Spill	J. T. Doupe	International Pipeline Conference 1998	IPC
277	Hydrostatic Pressure Testing Program for a Liquid Petroleum Products Pipeline	Robert V. Hadden	International Pipeline Conference 1998	IPC
278	Inspection and Rehabilitation of Crude Oil Pipelines in Eastern Europe and the FSU	Adolf H. Feizlmayr	International Pipeline Conference 1998	IPC
279	Impacts and Recovery in a Coldwater Stream Following a Natural Gas Pipeline Crossing Installation	Paul G. Anderson	International Pipeline Conference 1998	IPC
280	A Process Using Risk Analysis to Select Construction Methods for Pipeline Crossings of Major Rivers	Terri J. Covlin	International Pipeline Conference 1998	IPC
281	Environmental Inspection: Down in the Trenches	Mario e. Buszynski	International Pipeline Conference 1998	IPC
282	Suspended Sediment and Turbidity Restrictions Associated with Instream Construction Activities in the United States: An Assessment of Biological Relevance	Scott M. Reid	International Pipeline Conference 1998	IPC
283	Minimizing the Impacts of Pipeline Development on Native Prairie Ecosystems: A Public Land Manager's Perspective	Heather S. Gerling	International Pipeline Conference 1998	IPC
284	Sediment Entrainment During Construction of River Pipeline Crossings: Occurrence, Prediction and Control	Dejiang Long	International Pipeline Conference 1998	IPC
285	Field Performance and Surge Testing of Centrifugal Compressors	David A. CanderSchee	International Pipeline Conference 1998	IPC
286	Improvements to a Centrifugal Compressor Surge Control System	Blair J. Martin	International Pipeline Conference 1998	IPC
287	Installation of Pipeline Pumps	Jim W. Horner	International Pipeline Conference 1998	IPC
288	Analysis of Thermal Shock on Nuclear Power Station Pump	Cao Qing	International Pipeline Conference 1998	IPC

No.	Title	Author	Conference	Ref.
289	Pipeline Pumps for Energy Efficiency and High Reliability	H. Samarasekera	International Pipeline Conference 1998	IPC
290	Analysis and Field Tests of a New Adjustable Frequency Drive Technology for the Pipe Line Industry	Paul W. Astley	International Pipeline Conference 1998	IPC
291	Reliability, Interfacing and Standardization Aspects in High Power AC Drive Applications	Heinz Kobi	International Pipeline Conference 1998	IPC
292	Proposed Design for Gas Turbine Ingestion of Dry Gas Seal Primary Vent Fugitive Methane	Todd Parker	International Pipeline Conference 1998	IPC
293	Building a 5000 hp, VFD Controlled, Pump Station in 105 Days: "Fact or Fantasy"	Roy C. Spencer	International Pipeline Conference 1998	IPC
294	Inspection of Offshore Pipelines by Using In-Line Inspection Tools	Barbian A O.	3rd International Offshore and Polar Engineering Conference	ISOPE
295	Evaluating the Remaining Strength of Corroded Pipelines **	Chouchaoui B A.	Ontario	
296	Interaction of Closely Spaced Corrosion Pits in Line Pipe	Chouchaoui B A.	12th Offshore Mechanics and Arctic Engineering Conference, Glasgow	
297	A Three Level Assessment of the Residual Strength of Corroded Line Pipe	Chouchaoui B A.	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
298	Criteria for Dent Acceptability in Offshore Pipeline	Fowler J R.	25th Offshore Technology Conference	OTC
299	Failure of Spiral Corrosion in Linepipe **	Fu B.	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
300	The Development of Fitness for Purpose Flaw Acceptance Criteria for Sleeve Connections **	Gordon J R.	8th Annual Symposium on Line Pipe Research	
301	The European Pipeline Research Groups Guidelines on Acceptable Girth Weld Defects in Transmission Pipelines **	Hopkins P.	8th Annual Symposium on Line Pipe Research	
302	An Axisymmetric Analysis Model for corroded Pipelines	Kanninen M F.	12th Offshore Mechanics and Arctic Engineering Conference, Glasgow	
303	Generalised Guidelines for Determining the Residual Strength in Service Conditions **	Kanninen M F.	International Pipeline Rehabilitation Seminar, Texas	
304	Investigation of Validity of BS PD 6493: 1991 Defect Assessment Procedures by Analysis of Full Scale Pipe Bend Tests **	Leggatt R H.	8th Annual Symposium on Line Pipe Research	
305	Integrity of Steel Pipe During Reeling	Pisarski H G.	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
306	Effect of Orientation on Near-Threshold Crack Growth in TMCP Steels	Salama M M.	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
307	An Analytical Model to Predict the Burst Capacity of Pipelines	Stewart G.	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
308	Pipeline Reliability and Investigation of Pipeline Characteristics and Analysis of Pipeline Failure Rates for Submarine and Cross Country Pipelines **	Anderson, T.	Journal of Petroleum Technology	
309	The Effect of Corrosion on the Fracture and Fatigue Resistance of Welds in Pipelines	Andrews, R M.	11th International Conference on Offshore Mechanics and Arctic Engineering	
310	On the Problem of Detecting and Assessing Cracks in Pipelines	Beller M.	10th International Conference on Offshore Mechanics and Arctic Engineering	
311	Ensuring the Integrity of Ageing Pipelines Using Online Inspection Tools and Fitness-for-Purpose Methods **	Braithwaite, J C	North Sea Innovations and Economics Conference, Institute of Civil Engineers	
312	Reliability of Some Widely Applied FM Based Fitness for Purpose Analysis Methods **	Broekhoven, M J G	SMIRT 10 Post Conference Seminar Nr. 3	
313	Analysing the Pressure Strength of Corroded Line Pipe	Bubenik, T A	11th International Conference on Offshore Mechanics and Arctic Engineering	
314	Burst Pressure Predictions of Line Pipe Containing Single Corrosion Pits Using the Finite Element Method	Chouchaoui B A.	11th International Conference on Offshore Mechanics and Arctic Engineering	
315	Alternative Girth Weld Acceptance Standards in the Canadian Gas Pipeline Code **	Coote, R I	3rd International Conference on Welding and Performance of Pipelines	
316	Online Inspection Techniques: Available Technology **	Cordell, J L	Conference on Pipeline Risk Assessment, Rehabilitation and Repair	
317	The Integrity of Offshore Pipeline Girth Welds **	Department of Energy	Offshore Technology Report	OTH 86 233
318	A Review of Information on Hydrogen Induced Cracking and Sulphide Stress Corrosion Cracking in Linepipe Steels **	Department of Energy	Offshore Technology Report	OTH 86 256
319	The Integrity of Offshore Pipeline Girth Welds: The Influence of Hydrogen on the Fracture Toughness of Cellulosic Coated Electrode Weld Deposits **	Department of Energy	Offshore Technology Report	OTH 88 524
320	Offshore Pipeline Girth Welds: MIG Database **	Department of Energy	Offshore Technology Report	OTI 88 525
321	An Investigation into the Cause of Low Fracture in Molybdenum Bearing Cellulosic Weld Metals **	Department of Energy	Offshore Technology Report	OTI 88 526
322	Vertical-Down Welding of Girth Welds using Low Hydrogen Basic Electrodes: An Evaluation of Weld Metal Toughness and Integrity **	Department of Energy	Offshore Technology Report	OTI 88 527
323	Offshore Pipeline Girth Welds: The Factors Influencing Mechanised MIG Weld Metal Toughness **	Department of Energy	Offshore Technology Report	OTI 88 528
324	Offshore Pipeline Girth Welds: Vertical Up-Weld Metal Database **	Department of Energy	Offshore Technology Report	OTI 88 529
325	Offshore Pipeline Grith Welds: Non-Destructive Testing **	Department of Energy	Offshore Technology Report	OTI 88 530
326	Fatigue Strength of HT50 Steel Plates in Sour Crude Oil	Ebara, R	11th International Conference on Offshore Mechanics and Arctic Engineering	
327	Assessment of Pipeline Girth Welds Subject to High Longitudinal Strain	Glover, A G	11th International Conference on Offshore Mechanics and Arctic Engineering	
328	Engineering Critical Assessment of Pipeline Girth Welds **	Glover, A G	Conference on Fitness for Purpose Validation of Welded Constructions	
329	Corrosion Inspection of the Trans-Alaska Pipeline **	Harle, J C	Conference on Pipeline Pigging and Inspection Technology	
330	The Pressure Systems and Gas Containers Regulations **	HSE	Statutory Instrument No 2169	
331	Pipeline and Risers Loss of Containment Study **	HSE	Offshore Technology Report	PARLOC 90
332	Pipeline and Risers Loss of Containment Study **	HSE	Offshore Technology Report	PARLOC 92
333	Assessment of Pipeline Defects Detected During Pigging Operations **	Hopkins, P	2nd International Conference on Pipeline Pigging and Integrity Monitoring	B.G. E728
334	The Application of Fitness-for-Purpose Methods to Defects Detected in Offshore Transmission Pipelines **	Hopkins, P	Conference on Welding Weld Performance on the Process Industry	
335	Interpretation of Metal Loss as Repair or Replce During Pipeline Refurbishment **	Hopkins, P	The European Pipeline Rehabilitation Seminar	B.G. E720
336	Limitations of Fitness for Purpose Assessments of Pipeline Girth Welds **	Hopkins, P	7th American Gas Association NG18-EPRG Seminar	

No.	Title	Author	Conference	Ref.
337	A Study of the Behaviour of Long and complex Shaped Corrosion in Transmission Pipelines	Hopkins, P	11th International Conference on Offshore Mechanics and Arctic Engineering	
338	The Significance of Dents in Transmission Pipelines **	Hopkins, P	2nd Conference on Pipework Engineering and Operations, Institution of Mechanical Engineers	
339	Defect Tolerance in Pipeline Girth Welds **	Hopkins, P	Fourth National Congress on Pressure Vessels and Pipeline Technology	
340	The Resistance of Transmission Pipelines to Mechanical Damage **	Hopkins, P	International Conference on Pipeline Reliability	
341	The Fatigue Design of Gas Storage Systems Using Fracture Mechanics **	Hopkins, P	The 6th International Conference on Fracture	
342	A Study of the Behaviour of Defects in Pipeline Girth Welds **	Hopkins, P	International Conference on Pipeline Reliability	
343	Some Experiences of Applying the Pressure System Regulations to Older Systems **	Hopkins, P	Conference on Management of In-Service Inspection of Pressure Systems	
344	A Reliability Approach to Defining Fatigue and Fracture Design Criteria for Spanning Offshore Pipelines	Jiao, G	11th International Conference on Offshore Mechanics and Arctic Engineering	
345	Assessment of Weld Defects in Offshore Pipelines **	Jones, D G	Offshore Pipeline Technology	
346	Failure Behaviour of Internally Corroded Line Pipe	Jones, D G	11th International Conference on Offshore Mechanics and Arctic Engineering	
347	Methodologies for the Assessment of Defects in Offshore Pipelines and Risers	Jones, D G	10th International Conference on Offshore Mechanics and Arctic Engineering	
348	A Review of Fatigue Assessment Methods for Pipelay Operations	Jutla, T	5th International Conference on Offshore Mechanics and Arctic Engineering	
349	A Modified Criterion for Evaluating the Remaining Strength of Corroded Pipe **	Kiefner, J F	Final Report on Project PR 3-805 to the Pipeline Research Committee of the American Gas Associatio	
350	Evaluation of Offshore Pipeline Failure Data for Gulf of Mexico **	Mandke, J S	9th International Conference on Offshore Mechanics and Arctic Engineering	
351	Ultimate Pipe Strength Under Bending, Collapse and Fatigue	Murphy, C E	4th International Conference on Offshore Mechanics and Arctic Engineering	
352	Pigging of Subsea Pipelines	Schaefer, E F	23rd Offshore Technology Conference	OTC
353	Fatigue Failure of Submarine Pipelines: A Reliability Assessment	Sotberg, T	10th International Conference on Offshore Mechanics and Arctic Engineering	
354	Future Pipeline Design Philosophy - Framework	Sotberg, T	11th International Conference on Offshore Mechanics and Arctic Engineering	
355	Environmental Acceleration of Crack Growth in an X65 Line-Pipe Steel Under Cyclic Loading **	Vosikovsky, O	International Conference on Materials Engineering in the Arctic	
356	An Analysis of Crack Extension by Corrosion Fatigue in a Crude Oil Pipeline **	Vosikovsky, O	CANMET Report No. MRP/PMRL 76-25	
357	Fatigue Crack Growth in an X65 Line-Pipe Steel in Sour Crude Oil **	Vosikovsky, O	Corrosion-NACE	
358	Fatigue Crack Growth in an X65 Line-Pipe Steel at Low Cyclic Frequencies in Aqueous Environments	Vosikovsky, O		
359	A Elastic Limit Criterior for the Remaining Strength of Corroded Pipe	Wang, Y	10th International Conference on Offshore Mechanics and Arctic Engineering	
360	Assessing Ageing Pipelines - Online Inspection Methods	Whitfield, N	Conference on New Realitities in Pipeline Design, Constructionand Operation	
361	Loss of Containment of North Sea Pipelines	Williams, K A	23rd Annual Offshore Technology Conference	OTC
362	New International Standards for Offshore Pipelines	Herman Moshagen, Erling giertvert	Internatinal offshore and Polar engineering Conference	ISOPE
363	Design Through Analysis Applying Limit-State Concepts and Reliability Method	Yong Bai and Per Damsleth	Internatinal offshore and Polar engineering Conference	ISOPE
364	Experience from Operation, Inspection and Monitoring of Offshore Pipeline System on the Norwegian Continental Shelf	Ase Katrine Thomsen	Internatinal offshore and Polar engineering Conference	ISOPE
365	Realtime Monitoring to Detect Third-Party Damage	B.N. Leis, R.B. Francini	Internatinal offshore and Polar engineering Conference	ISOPE
366	Direct Electrical heatig of Pipelines as a Method of Preventing Hydrate and Wax Plugs	Jens Kristian Lervik	Internatinal offshore and Polar engineering Conference	ISOPE
367	Pressure-Displacement Behavior of Transmission Pipelines under Outside Forces--Towards a Services Criterion for Mechanical damage	B.N. Leis, R.B. Francini	Internatinal offshore and Polar engineering Conference	ISOPE
368	Assessment of Free Spanning Pipelines Using the DnV guideline	Olav Fyrileiv and Kim Mork	Internatinal offshore and Polar engineering Conference	ISOPE
369	Plastic Failure of Pipelines	Michelle S. Hoo Fatt	Internatinal offshore and Polar engineering Conference	ISOPE
370	Plastic Deformation and Local Buckling of Pipelines Loaded by Bending and Torsion	A. M. Gresnigt	Internatinal offshore and Polar engineering Conference	ISOPE
371	The effect of Tesion-Fractured and Compression-Crushed Zones on Pipe Uplift Resistance in Frozen Soil	A. Foriero	Internatinal offshore and Polar engineering Conference	ISOPE
372	Analytical Collapse Capacity of Corroded Pipes	Yong Bai and Soren Hauch	Internatinal offshore and Polar engineering Conference	ISOPE
373	Pipeline Design Strategies for Deep Water	Andrew palmer	Deepwater Pipeline Technology Conference	
374	Strength Design of Deepwater Pipelines	Yong Bai, Per Damsleth	Deepwater Pipeline Technology Conference	
375	Integrity Assessment of Deep Water Pipelines	Majid Al Sharif	Deepwater Pipeline Technology Conference	
376	External Corrosion Control and Corrosion Inspection of deepwater Pipelines	Jim Britton	Deepwater Pipeline Technology Conference	
377	The Effect of Plastic Deformation on the Fatigue Performance of Steel Catenary Risers	Elie Kodaissi	Deepwater Pipeline Technology Conference	
378	Complexities of Fatigue Analysis for Deepwater Riser	Mike Campbell	Deepwater Pipeline Technology Conference	
379	Development of Fatigue and Inspection Criteria for Steel Catenary Risers	Robert Carnes,	Deepwater Pipeline Technology Conference	
380	Failure of Spiral Corrosion in Linepipe **			
381	Integrity Assessment of Offshore Pipelines by Use of Intelligent Inspection Tools	M. Beller and W. Garrow	12th International Conference on Offshore Mechanics and Arctic Engineering	OMAE
382	A Decade of Inspection Findings Compared with Design Aspects of Two North Sea Pipelines	Michael A. Krogh	12th International Conference on Offshore Mechanics and Arctic Engineering	OMAE
383	Testing of Susceptibility to Environmentally Assisted Cracking (EAC) in H_2S Environment	John D. Edwards	12th International Conference on Offshore Mechanics and Arctic Engineering	OMAE
384	Sour Resistant X65 UOE Line Pipe for Low-Temperature Service	Y. Terada	7th International Offshore and Polar Engineering Conference	ISOPE

No.	Title	Author	Conference	Ref.
385	Non-Linear Finite Element Prediction of Wrinkling in Corroded Pipe	Daniel P. Nocolella	7th International Offshore and Polar Engineering Conference	ISOPE
386	Limit-State Design of High-Temperature Pipelines	Frans J. Klever	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
387	Wall Thickness Design for High Pressure Offshore Gas Pipelines	Richard Verley	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
388	Submarine Pipeline Inspection: The 12 Years Experience of Transmet and Future Developments	Luigi Ioventti	13th Offshore Mechanics and Arctic Engineering Conference, Houston	
389	TMCP - Application for Production of High Strength, High Toughness Line Pipe Steels	A. Streibelberger	10th Offshore Mechanics and Arctic Engineering Conference	
390	Development and Mass Production of X80 Line Pipe	Shigeru Endo	10th Offshore Mechanics and Arctic Engineering Conference	
391	Sour Service Large-Diameter Line Pipe Having Good Field Weldability and Sulphide Stress Corrosion Cracking Resistance	H. Tamehiro	10th Offshore Mechanics and Arctic Engineering Conference	
392	Future Needs for Integrity Evaluation	Andrew Palmer	International Workshop on Offshore Pipeline Safety	
393	Design and Installation issues for integrity	Dave McKeehan	International Workshop on Offshore Pipeline Safety	
394	Evaluation of Integrity, Reliability Assessment	Tom Zimmerman	International Workshop on Offshore Pipeline Safety	
395	Appendix A - Inspection Considerations	D. W. Barry	International Workshop on Offshore Pipeline Safety	
396	Corrosion Control Survey Methods for Offshore Pipelines	Clark Weldon	International Workshop on Offshore Pipeline Safety	
397	Recent Developments in Pipeline Integrity Technology	Tom Bubenik	International Workshop on Offshore Pipeline Safety	
398	Effects of Stress Ratio on Fatigue Crack Growth Rates in X70 Pipeline Steel in Air and Saltwater	Vosikovsky, O		
399	An Analysis of Crack Extension by Corrosion Fatigue in a Crude Oil Pipeline **	Vosikovsky, O	International Journal of Pressure Vessels and Piping	
400	Limitations of Fitness for Purpose Assessments of Pipeline Girth Welds **	Roodbergen, A H	International Conference on Pipe Technology	
	SCC - Stress corrosion cracking			

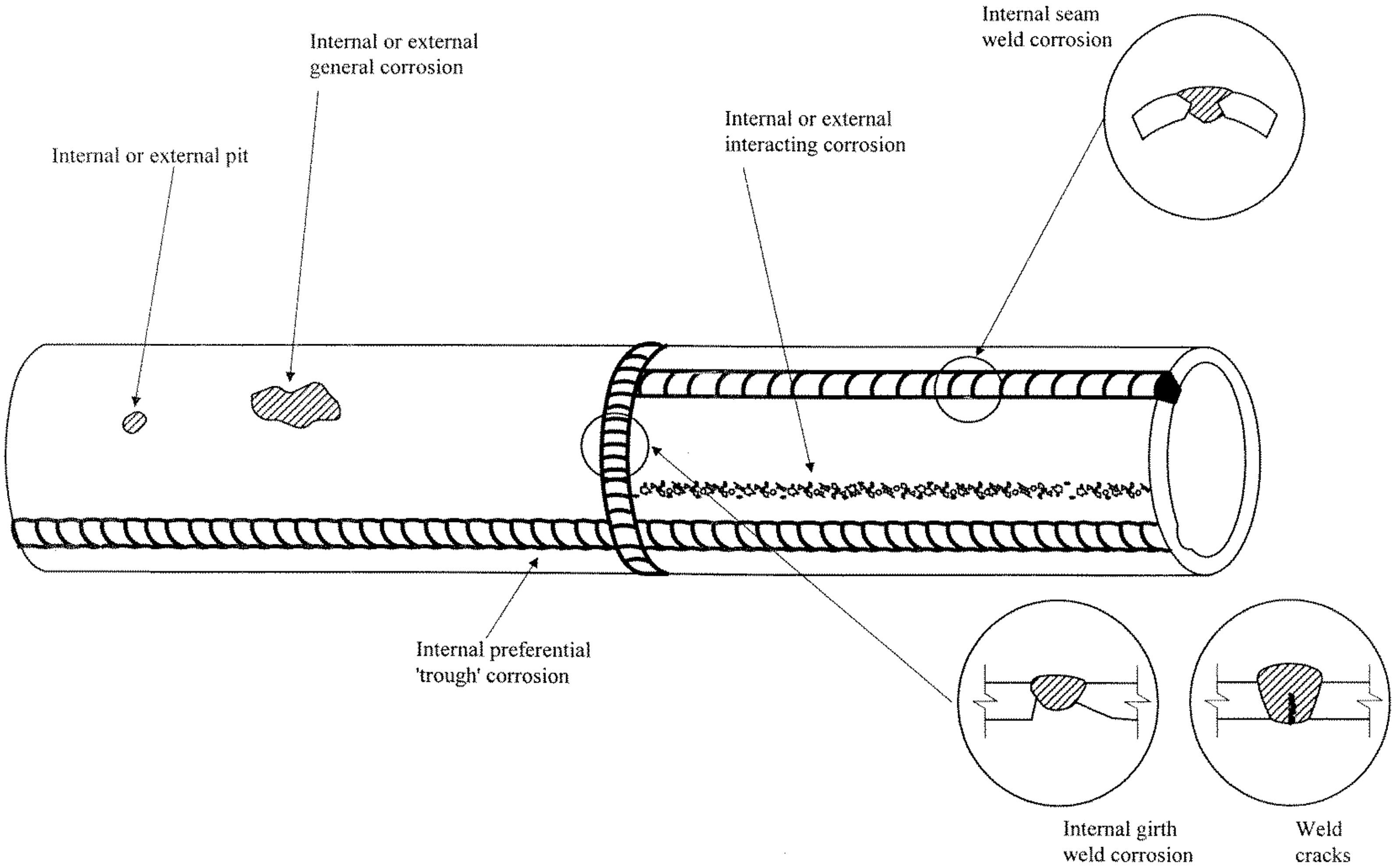

Figure 3.1: Some types of corrosion and cracking found in pipelines

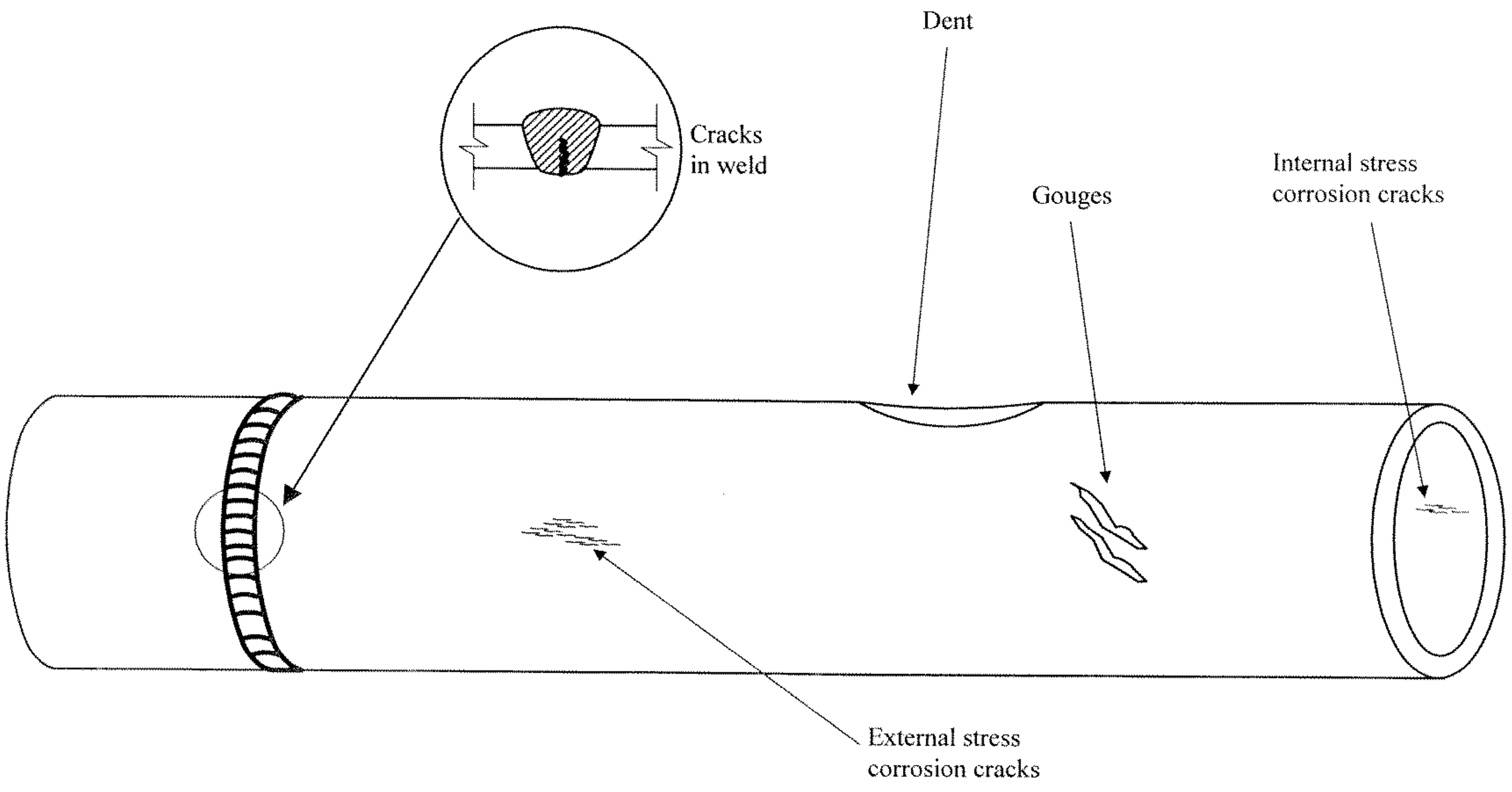

Figure 3.2: Mechanical damage and cracks found in pipelines

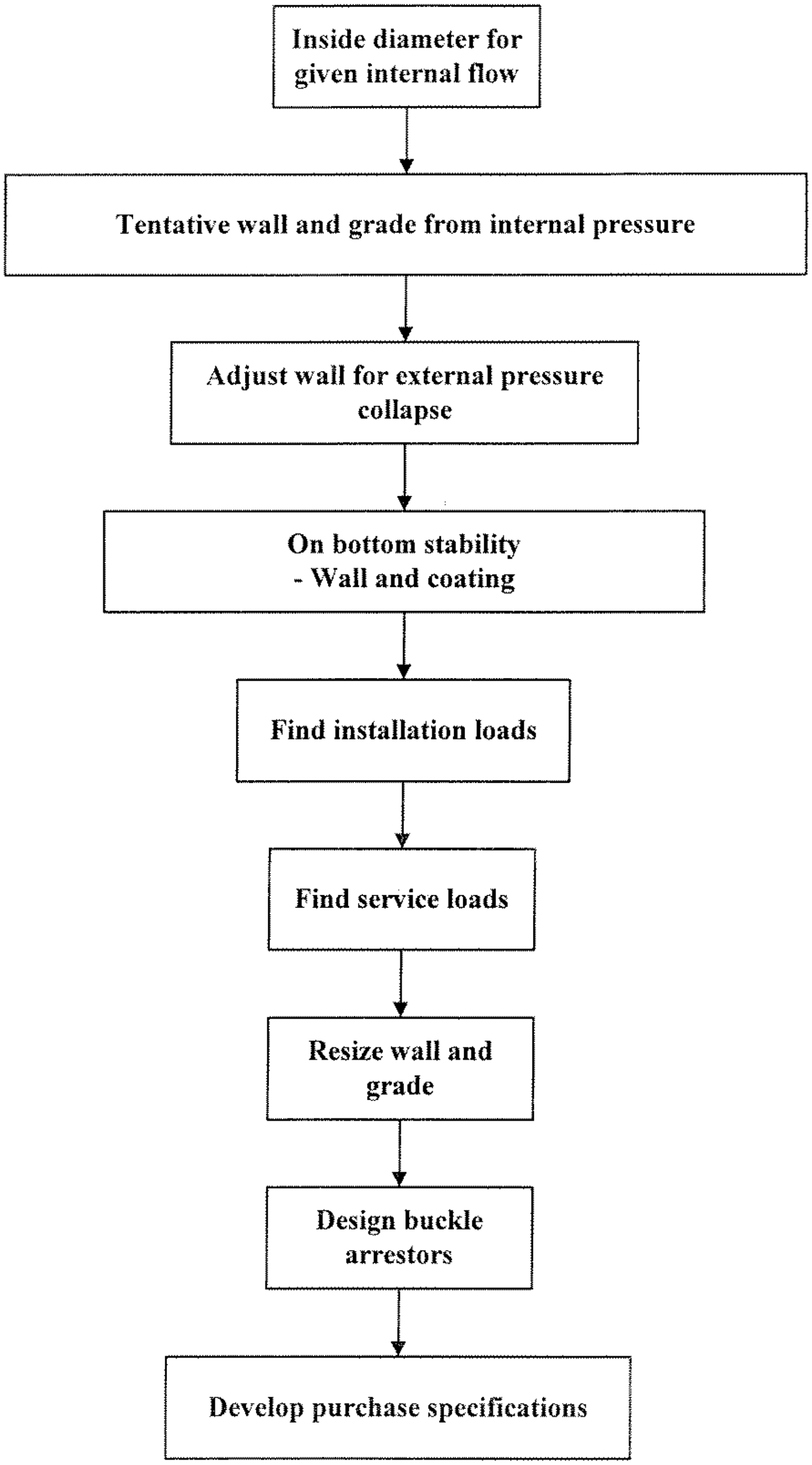

Figure 4.1: Offshore pipelines design flow chart

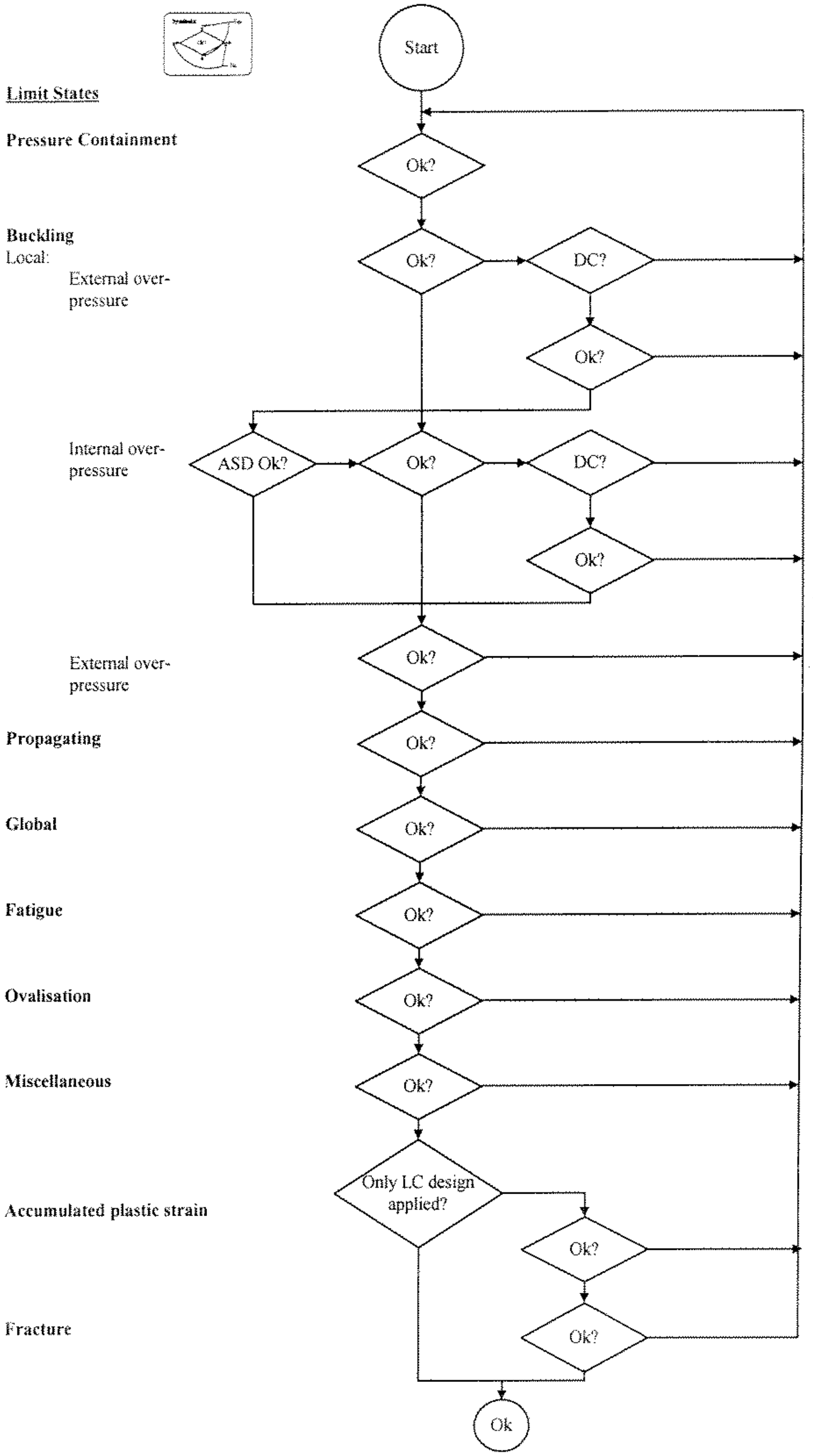

Figure 4.2: Typical flow diagram for design checks

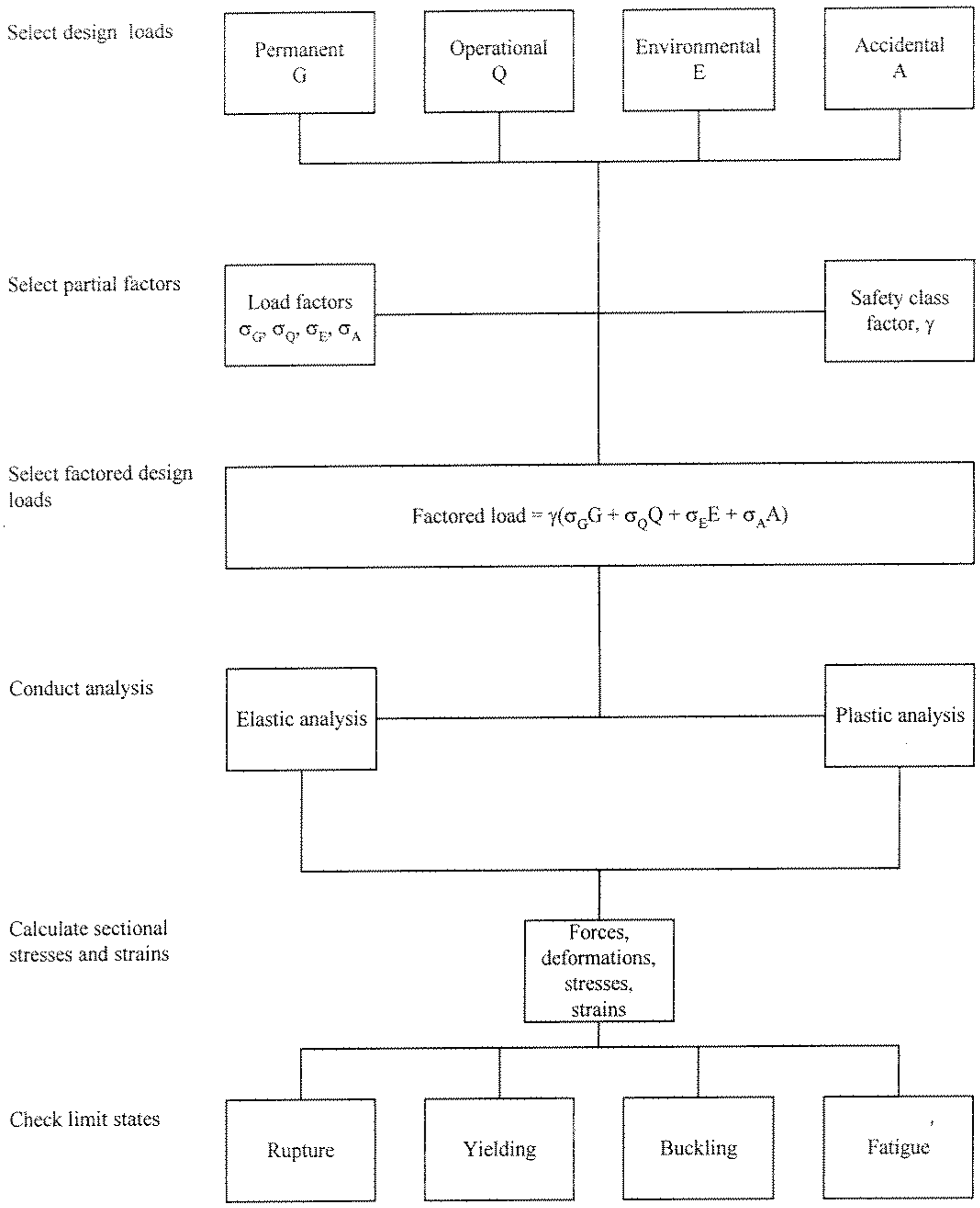

Figure 4.3: Limit state design methodology

APPENDIX

Letter Requesting Interview

To Operating Company

Dear ^^^^^

Pipeline Defect Assessment

MSL, an independent engineering consultancy, has been commissioned by the Minerals Management Service (MMS) to conduct a study on the methodologies applicable to assessing defects in pipelines. The objectives of the study are to collate available assessment approaches for pipeline defects (e.g. dents, gouges, corrosion and cracks) and to develop a database (of numerical and test data) on the strength of pipelines containing defects. The various assessment procedures can then be calibrated against the database.

Our purpose in writing to you is to explore the possibility of arranging a meeting with you, or a colleague, in the near future. It would be most helpful to our study if you could agree to a meeting. We would be particularly interested to learn about the assessment methodologies you might use for given defect scenarios. We would also be delighted to receive any test or numerical data of pipelines containing defects to enhance the database. Any such data will be de-sensitised. We appreciate that your time is valuable and therefore propose only a short meeting, say 20 minutes. We will call you shortly to see whether it would be advantageous for us to visit and, if so, to arrange a mutually convenient time.

Yours sincerely