NISTIR 5479

Effect of Dents and Gouges on the Integrity of Pipelines

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June 1994

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

TECHNOLOGY ADMINISTRATION
Mary L. Good, Acting Under Secretary
for Technology

NATIONAL INSTITUTE OF STANDARDS
AND TECHNOLOGY
Arati Prabhakar, Director

U.S. DEPARTMENT OF ENERGY
Washington, D.C. 20858

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Executive Summary

A 1993 hazardous liquid pipeline failure in Reston, Virginia and a 1994 gas pipeline failure in New Jersey are thought to have been caused by prior outside damage occurring several years before the failures. The type of damage visible on the failed pipes consisted of scrapes or gouges and may have been associated with dents caused by some machinery such as a backhoe or bulldozer. This report examines the literature associated with dents and gouges in pipelines and similar shell structures. An analysis of rerounding of the damaged area is also carried out. It is concluded that dents in large pipelines are likely to reround under pressure and are, therefore, fairly innocuous. However, gouges and cracks associated with rerounded dents are not innocuous due to the superimposed residual stress field and should be removed if they are detected.

Background

The Office of Pipeline Safety (OPS), Department of Transportation, has kept records for many years of the causes of pipeline accidents. In their records (ref. 1) for 1991, outside damage (or 3rd party damage) was responsible for 52 percent of all accidents involving a gas or 21 percent involving hazardous liquids. Often this type of accident is caused by digging near the pipeline with earth moving equipment. Two recent failures in Reston, Virginia and New Jersey are presently thought to be due to outside damage inflicted several years prior to the failures. There were scrapes and gouges along the length of the failed pipe as though they had been scraped by some earth-moving equipment. It is also possible that there was denting of the pipe at the time of the damage.

The extent to which dents and gouges affect the performance of a pipeline by reducing its burst pressure or making it more sensitive to fatigue failure has been the subject of numerous scientific studies. OPS requested that NIST perform a literature search and evaluation of the effect of dents and gouges in pipelines. This report documents that literature search and evaluation.

Literature Search and Review

A search was made of all journals, books, and conference proceedings dating back to 1970 for the key words DENT(s) and GOUGE(s). Eighty-five citations were found. A review of these documents found 35 were germane to the pipeline issue. The 35 articles were classified according the following subtopics.

1. Occurrence, Causes, and Detection of Dents and Gouges in Pipelines and Similar Shell Structures;
2. Experimental Investigations on the Effect of Dents and Gouges on Pipeline Performance;
3. Theoretical Studies on the Effect of Dents and Gouges on Pipeline Performance; and
4. Guidelines for the Application of Research Studies to Pipelines.

The documents so classified are listed in Appendix A. Some documents fell into two categories and are listed in both.

A subset of documents was selected from the list in Appendix A and reviewed in detail. These formed the basis for many of the statements and conclusions that follow. These documents, in addition to other documents, are referenced (see the Reference section) as appropriate in the remainder of this report.

Effect of Dents

A dent in a pipe is a region where the radius of curvature of the wall differs from the average radius of the pipe. If this region is of the same dimensions as the radius of the pipe and the change in curvature is small, the dent may be classified as an out-of-roundness in the pipe. When the region is small and the curvature changes sign, the dent is severe. In the Code of Federal Regulations, Part 192 (ref. 2), a dent is defined as "a depression that produces a gross disturbance in the curvature of the pipe wall without reducing the pipe-wall thickness. The depth of a dent is measured as the gap between the lowest point of the dent and a prolongation of the original contour of the pipe." Dents are usually characterized by their maximum depth as a percentage of pipe diameter, even though this does not necessarily define their extent around the pipes circumference or their length along the pipe.

Dents may occur during manufacture, shipping, installation, or in-service operation of the pipe. Dents occurring during in-service operation are of most concern as these are usually caused by some earth-moving equipment and may not be brought to the attention of the pipeline operator for inspection and repair (if necessary).

A considerable amount of research and analysis on dents have been carried out. These studies show that, for dents in pressurized pipes (ref. 3) up to $d/D = 24$ percent, where d is the depth of the dent root and D is the pipe diameter, there is only a negligible effect on the pressure to rupture the pipe. This applies mainly to ductile pipes which fail by plastic yielding. Therefore, the presence of a plain dent in an otherwise undamaged, ductible pipe should not necessitate any reduction in maximum operating pressure. However, since the stress and strain needed to create a dent are quite large, embrittled pipes, corroded pipe, and old electric resistance welded seams may fail during the denting process.

Of greater concern than instantaneous failure is the possibility that the dent might make the pipe more susceptible to fatigue failure. The work of Fowler (ref. 4) clearly showed that, under certain circumstances, pressure cycling dents could initiate cracks and grow them to failure. This happened because the dent, acting like a flexure, locally magnified the stress to levels well beyond the maximum operating pressure-induced stress. It should be noted that these studies in reference 4 were performed on small diameter pipes with large diameter-to-wall-thickness, D/t, ratios. Furthermore, the pressure cycling was car-ried out with a maximum pressure well below 80 percent of the specified manu-facturer's yield strength (SMYS). These conditions were necessary to keep the pipes from rerounding, i.e., returning to their original shape. If rerounding occurs, the stress magnification of the dent is no

longer effective.

In Appendix B, a model for plastic rerounding is presented and analyzed. The conclusions of this analysis are summarized in Figure 1. This figure shows the maximum sustainable dents in pipes of various diameter/wall thickness ratios for different percentages of the SMYS. Larger dents will reround plastically (i.e., permanently) and smaller dents will remain at the maximum operating pressure. Note that rerounding occurs easily for pipes having a D/t of 50 or more even for 1 percent dents at operating pressures of 40 or 80% of SMYS. This prediction of the analysis in Appendix B is largely born out by the experimental studies (ref. 3 and 4, for example). Due to its flexibility, a typical large transmission pipeline with a D/t of 100, such as the one involved in the Reston accident should not have noticeable dents under pressure. Therefore, using the flexure fatigue mechanism in reference 4 and extrapolating the stress magnification from a D/t of 50 (the limit in reference 4) to 100, is not appropriate.

Two more points can be made based on the rerounding analysis. Thick walled pipes do not reround as easily as thin walled pipes. So, while a thick walled pipe may be harder to dent in the first place, they may be more sensitive to fatigue damage once dented because they are harder to reround. Also, application of a maximum pressure large enough to plastically reround a pipe would appear to be better than reducing the maximum pressure on a dented pipe and encouraging the flexure mechanism of stress magnification. This contention is supported in reference 5.

While rerounding would seem to be desirable, it is not without drawbacks. The deformation associated with rerounding results in residual stresses that add to the pressure-induced stresses (refs. 5 and 6). In addition, the strain of denting and rerounding exhausts some of the steel's ductility and may lead to cracking or an increased sensitivity to stress corrosion.

Analyses and experimental measurements on dented pipes have shown fairly high stresses and strains on pressurization of a dent. At a pressure corresponding to 0.57 SMYS, tensile stresses in excess of the yield strength and straining of 2 percent were observed in the vicinity of a dent in reference 6. It is interesting to note that the highest stresses and strains occur on the perimeter of the dent (shoulder) and not at its center (root). These observations are in qualitative agreement with the predictions of reference 5.

It is clear from the above discussion that dents can be of concern in pipelines where cyclic loading is significant, e.g., hazardous liquid pipelines. There are methods of detecting even quite small dents using instrumented internal inspection devices. If a dent is detected, particularly in a pipe where rerounding is expected, it should be examined and an evaluation made as to its significance.

Effects of Gouges

Gouges are defects in the pipe wall where the thickness is locally reduced. A gouge may be caused during welding (arc-gouge), by dragging a pipe over a sharp object like a rock, or by scraping a pipe with the tooth or similar part

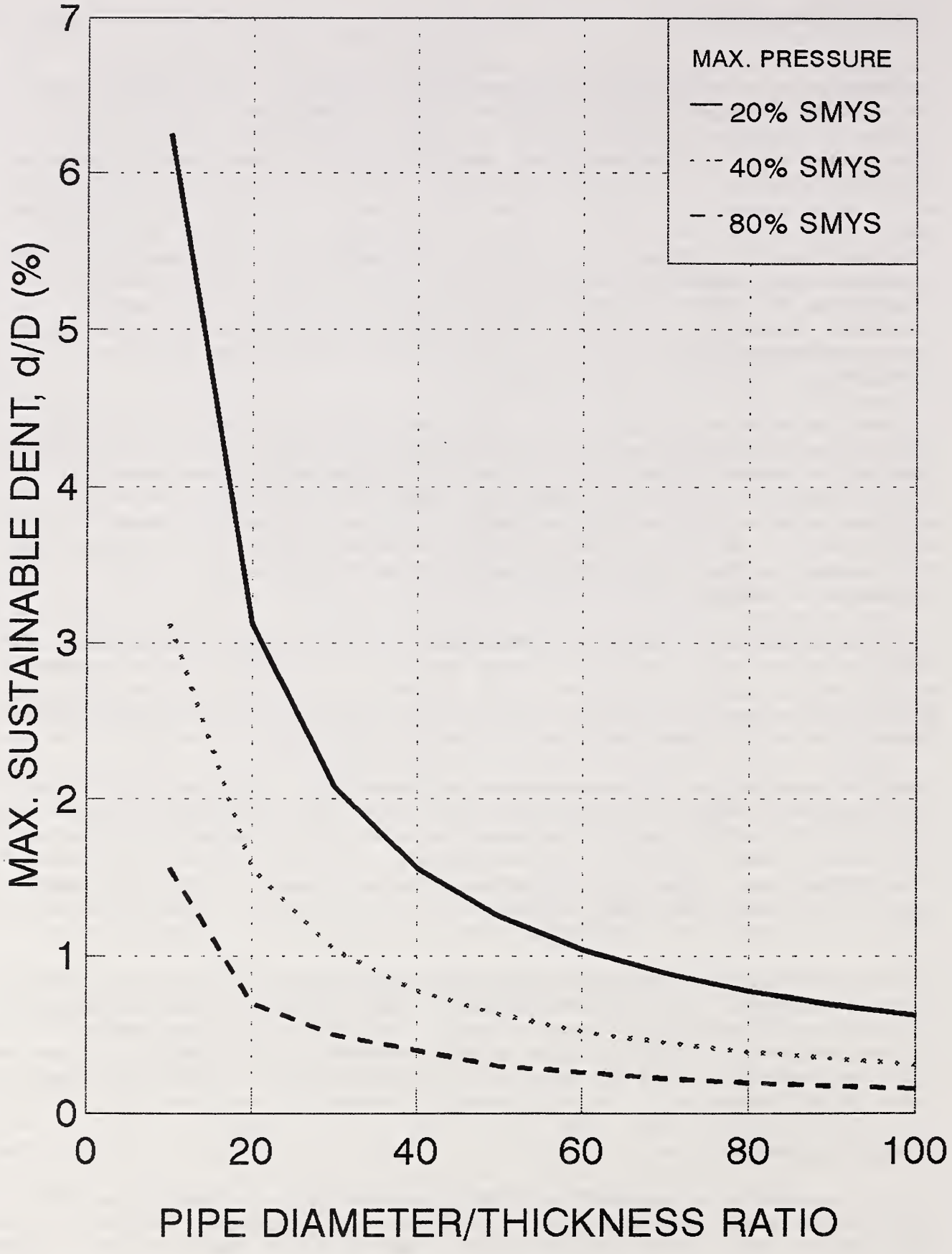

Figure 1. Maximum dent size that will not reround as a function of pipe size for several maximum operating pressures.

of earth-moving equipment. It may have been created on purpose by grinding out a more severe defect. The resulting gouge may be smooth, rough, or even contain or conceal cracks. Gouges may be introduced by themselves or alongwith a dent. In the case of a plain gouge unassociated with a dent, the Battelle Flow Stress Dependent Model, reference 7, has been shown by testing to well describe the failure behavior. The predicted failure pressure is

$$P_f = \frac{\bar{p}\ (1 - a/t)}{(1 - a/Mt)}$$

where $\bar{p}$ is the failure pressure of the undamaged pipe, a is the gouge depth, t is the wall thickness and M is the Folias bulging factor given by

$$M = \left\{(1 + 0.628\ \ell^2/Dt - 0.00338\ \ell^4/(Dt)^2\right\}^{0.5}$$

where ℓ is the length of the gouge and D is the pipe diameter. This equation has recently been shown (reference 6) to describe the behavior of gouges within dents as well for the cases tested. Therefore, a basis exists for assessing the severity of smooth gouges by themselves or within dents.

The research in reference 6 also indicated conditions that were not predicted by the Battelle equation. Any gouge, long or short, that intersected the perimeter of a dent resulted in a substantial reduction in burst pressure. Furthermore, these intersections were prime sites for crack nucleation on rerounding and/or fatigue. While cracks are not a topic in this report, cracks can be created at the time of the gouging. These cracks may be concealed by the metal smearing that sometimes takes place. If the cracked gouge is now associated with a dent, pressurization will open up the crack considerably more than would have happened without the dent. For this reason, gouges associated with dents are serious defects and the repairs specified in the Code of Federal Regulations Title 49 Part 192.309, covering gas pipelines, are fully justified. Since cyclic loading is even more pronounced in hazardous liquid lines, similar repairs should be required in Part 195 which covers such pipelines.

Rerounding of dents containing gouges will occur in a manner similar to plain dents and should be predicted by the analysis in Appendix B. Therefore, gouges in large D/t pipes may be associated with rerounded dents. The material there will be subjected to considerable plastic strain and unfavorable residual stresses, yet no dent will remain. These gouges are more susceptible to fatigue cracking than other areas of the pipe and should be removed.

Some internal inspection devices are able to detect the wall thinning associated with gouging. When gouges are detected in thin pipes $D/t > 50$, they should be inspected and probably removed. This is especially true in hazardous liquid pipelines.

Conclusion

A literature review has been carried out on the subject of dents and gouges in pipelines. Papers were found describing the existing capability for detecting dents and gouges. The reported effects of dents and gouges, particularly dents with gouges, were discussed. An analysis of rerounding was carried out and applied to the various conditions.

Research has shown that dents and plain dents containing short shallow gouges do not immediately affect the performance of a pipeline. However, dents that have long or deep gouges, particularly when the gouge intersects the dent perimeter, result in immediate and substantial reductions in burst pressure.

Dents and gouges may reduce the fatigue life of a pipeline. Dents are most likely to reround in transmission lines of large diameter-to-wall-thickness ratios. A plain dent that is rerounded by the maximum applied pressure will have little or no effect unless a surface crack is nucleated by the rerounding (unlikely in a ductile pipe material). If the dent does not reround, it will act like a flexural element and concentrate strain, magnifying the effects of pressure, and lead to premature fatigue failure. This effect will be most pronounced in hazardous liquid lines which receive many more and larger cycles than gas line.

Gouges that are smooth and shallow enough not to cause ligament yielding will (like plain rerounded dents) also have little effect on the fatigue life. Deeper gouges, i.e, ones which result in remaining ligament yielding, will reduce the fatigue life in proportion to their depth. Rough gouges or gouges with cracks will significantly reduce the fatigue life of a pipe.

Short, smoother gouges completely within dents that reround will probable have a negligible effect on fatigue life. Short smooth and shallow gouges within dents will not significantly change the fatigue life of a dented pipe. Gouges that are deep, cracked, or intersect the perimeter of a dent, rerounded or not, will significantly reduce the fatigue life of a pipe.

Calculating the quantitative effect of most of the cases listed above would require the development of new analyses. Any uncracked situation has the added uncertainty associated with estimating the cycles or strain to nucleate a crack. The cases of a gouge with a crack and a dent with a small central crack may be handled with existing analyses.

Recommendations

The regulations in 49 CFC Ch 1, Part 192.309 are sufficient to assure safe operation of all dented and/or gouged pipes at the time of installation. However, since pipes can be damaged after installation, further guidelines or regulations may be warranted. In particular, if it is known that a pipe may have been damaged, the pipe should be visually inspected from the outside and repaired according to the above regulations. In addition, any dent that does not reround on a hazardous liquid pipeline after pressurizing should be repaired. Any gouge that intersects the perimeter of a dent, rerounded or

not, should be repaired. All cracks should be repaired especially if they are associated with a dent or gouge.

Inspection of pipelines by instrumented internal inspection devices provides a way to ascertain the condition of pipelines at almost any time. As noted in the literature survey, devices are now available that can detect gouges and dents. Indications of gouges and dents should require a visual examination followed by repairs according to the guidelines in the preceding paragraph. Indications of other defects should also receive attention, but that is beyond the scope of this report.

References

1. Annual Report of Pipeline Safety: Calendar Year 1991, U.S. Department of Transportation, Research and Special Programs Administration, Office of Pipeline Safety, Washington, D.C. 20590.

2. Code of Federal Regulations, Title 49 -- Transportation, Subchapter D -- Pipeline Safety, Government Printing Office, Washington, D.C., 1993.

3. Jones, D. G., and Hopkins, P.; "The Influence of Mechanical Damage on Transmission Pipeline Integrity," in Proceedings of the 1983 International Gas Research Conference, edited by L. H. Hirsch, published by Government Institutes, Rockville, MD, 1983, pp. 106-115.

4. Fowler, J. R.; "Criteria for Dent Acceptability in Offshore Pipeline," in Field Drilling and Development Systems Proceedings--Annual Offshore Technology Conference, Part 4 (1993). Published by Offishore Technology Conference, Dallas, Texas, pp. 481-488.

5. Ong, L. S.; Chan, Y. W.; and Seet, G.; "Elastic Analysis of a Dent on a Pressurized Pipe," International J. of Pressure Vessels and Piping, 38, #5, (1986), pp. 369-383.

6. Lancaster, E. R.; Palmer, S.C.; "Assessment of Mechanically Damaged Pipes Containing Dents and Gouges,": PVP 261, (1993), pp. 61-68.

7. Kiefner, J. F.; Maxey, W. A.; Eiber, R. J.; and Duffey, A. R.; "Failure Stress Levels in Pressurized Cylinders," ASTM STP 536 (1973), pp. 461-481.

APPENDIX A: Selected Literature on Dents and Gouges

Occurrence, Causes and Detection of Dents and Gouges in Pipelines and Similar Shell Structures

Title: Detection, Location, and Quantification of Structural Damage by Neural-Net-Processed Moire Profilometry.
Author: Grossman, Barry G.; Gonzalez, Frank S.; Blatt, Joel H.; Hooker, Jeffery A.
Corporate Source: Florida Inst. of Technology, Melbourne, FL, USA
Conference Title: Optics, Illumination, and Image Sensing for Machine Vision VI
Conference Location: Boston, MA, USA
Conference Date: 1991 Nov 14-15
Sponsor: SPIE - Int Soc for Opt Engineering, Bellingham, WA, USA
E.I. Conference No.: 16459
Source: Proceedings of SPIE - The International Society for Optical Engineering v 1614. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA. p 194-205
Publication Year: 1992
CODEN: PSISDG ISSN: 0277-786X ISBN: 0-8194-0751-8
Language: English
Document Type: PA (Conference Paper) Treatment: A (Applications); T (Theoretical); X (Experimental)
Journal Announcement: 9207
Abstract: The development of efficient high speed techniques to recognize, locate, and quantify damage is vitally important for successful automated inspection systems such as ones used for the inspection of undersea pipelines. Two critical problems must be solved to achieve these goals: the reduction of nonuseful information present in the video image and automatic recognition and quantification of extent and location of damage. Artificial neural network processed moire profilometry appears to be a promising technique to accomplish this. Real time video moire techniques have been developed which clearly distinguish damaged and undamaged areas on structures, thus reducing the amount of extraneous information input into an inspection system. Artificial neural networks have demonstrated advantages for image processing, since they can learn the desired response to a given input and are inherently fast when implemented in hardware due to their parallel computing architecture. Video moire images of pipes with dents of different depths were used to train a neural network, with the desired output being the location and severity of the damage. The system was then successfully tested with a second series of moire images. The techniques employed and the results obtained are discussed. 19 refs.

Title: Pigging the Capline.
Author: Watts, Jim
Corporate Source: Edgell Communications, Inc., Cleveland, OH, USA
Source: Pipeline and Gas Journal v 217 n 11 Nov 1990 p 43-45
Publication Year: 1990
CODEN: PLGJAT ISSN: 0032-0188

Language: English
Document Type: JA (Journal Article) Treatment: A (Applications)
Journal Announcement: 9112
Abstract: The longest continuous instrumentation pig runs ever conducted have proven the integrity of the Capline crude oil pipeline system operated by Shell Pipe Line Corp. Shell ran two smart pigs through the 632-mile, 40-in. Capline in 1989 to determine the condition of the pipeline, which was placed in service in 1968. Two in-line inspection pigs, built specifically for the Capline pipeline by Vetco Pipeline Services, Houston, were used in the project. Use of the in-line devices allowed the pipeline to remain in service during the pig runs. In reverse of the usual order, Shell ran a magnetic flux pig, which detects metal loss in the line pipe due to corrosion, through Capline in July 1989 and a deformation slope pig, to locate dents and deformities in the pipe, in December 1989. The investigation methods and the pigs are described.

Title: Pipeline Geometry Pigging: Application of Strapdown INS.
Author: Porter, Todd R.; Knickmeyer, Ernest H.; Wade, Ron L.
Corporate Source: Pigco Pipeline Services Ltd, Calgary, Alberta, Can
Conference Title: IEEE PLANS '90 - Position Location and Navigation Symposium
Conference Location: Las Vegas, NV, USA Conference Date: 1990 Mar 20-23
Sponsor: IEEE Aerospace & Electronic Systems Soc
E.I. Conference No.: 13523
Source: Record - IEEE PLANS, Position Location and Navigation Symposium. Publ by IEEE, IEEE Service Center, Piscataway, NJ, USA. Available from IEEE Service Cent (cat n 90CH2811-8), Piscataway, NJ, USA. p 353-358
Publication Year: 1990
CODEN: RPLSDW
Language: English
Document Type: PA (Conference Paper) Treatment: A (Applications); T (Theoretical)
Journal Announcement: 9011
Abstract: An autonomous pipeline pigging system has been developed for determining position, orientation, curvature, ovality, and deformations such as dents and wrinkles of operating pipelines. At the heart of this integrated system is a Strapdown Inertial Measurement Unit (SIMU), which is integrated with velocity and distance sensors, caliper sensors, weld detection system, and digital recording device. The Geometry pig (Geopig) is designed to operate continuously and autonomously for a week or longer in operating fluid or gas pipelines with diameters of 25-30 cm and larger. The design concepts, system integration, data acquisition, processing, analysis, and database management are discussed. Results from a recently completed 335-km Arctic crude oil pipeline are presented. 5 Refs.

Title: Corrosion Surveys with the Ultrascan pig.
Author: Goedecke, H.
Corporate Source: Pipetronix GmbH, West Ger
Source: Corrosion Prevention & Control v 37 n 2 Apr 1990 p 33-36

Publication Year: 1990
CODEN: CRPCAK ISSN: 0010-9371
Language: English
Document Type: JA (Journal Article) Treatment: A (Applications); G (General Review)
Journal Announcement: 9011
Abstract: Corrosion inspection of long-distance pipelines is increasingly carried out by electronic surveying robots, so-called intelligent pigs. These devices locate dents, cracks, and corrosion damage by utilizing modern electronic NDT technology. A 2nd-generation corrosion-detecting pig is described in this paper, a device whose development has only been made possible due to recent advances in microprocessor technology. (Author abstract)

Title: Aluminum Can Metrology Using Sub-pixel Image Measurement.
Author: Cormack, R. H.; Brown, C.
Corporate Source: Ball Corp, Westminster, CO, USA
Source: SME Technical Paper (Series) MS 1989 var paging
Publication Year: 1989
CODEN: TPSSDL ISSN: 0161-6382
Language: English
Document Type: JA (Journal Article) Treatment: X (Experimental)
Journal Announcement: 9008
Abstract: Metrology of unfilled aluminum cans is difficult because the thin sidewalls will deflect significantly under the slightest pressure. This paper describes a noncontact optical method of producing a complete surface profile of an aluminum can. Data points can be generated at a rate more than 2000 per second, with a resolution of better than 0.0002 inches (5 microns). An image processing computer is then used to analyze and visualize this data for the purpose of quantifying dents, estimating column strength, and determining the adverse effects of forming and handling processes. (Author abstract)

Title: Development of Pipeline Inspection Pig
Author: Yoshida, Masahito; Suzuki, Noritaka; Hagio, Akira; Fujisawa, Tomoji; Sato, Tomoaki; Kawai, Kouichi; Aoki, Masanori
Corporate Source: Tokyo Electric Power Co
Source: NKK Technical Review n 53 Aug 1988 p 44-50
CODEN: NTERED ISSN: 0915-0544
Language: English
Document Type: JA (Journal Article) Treatment: X (Experimental)
Journal Announcement: 9003
Abstract: Tokyo Electric Power Co. and NKK have developed three (3) types of inspection pigs for long gas pipeline, i.e., TV pig, inspection pig for measuring inside-diameter and inspection pig for measuring pipeline profile. These pigs propelled by gas pressure can observe the internal condition and configuration of 20-24 inch diameter pipelines, and can pass through 1.5 DR bends and riser sections. This report describes the favorable results of field tests performed at a test line having artificial dents. (Author abstract)

Title: Review of In-line Inspection Capabilities.
Author: Kiefner, J. F.; Hyatt, R. W.; Eiber, R. J.
Corporate Source: Battelle Columbus Lab, Columbus, OH, USA
Conference Title: Pipeline Safety and Leak Detection Presented at the Petroleum Div Fall Workshop
Conference Location: Houston, TX, USA Conference Date: 1988 Oct 20-21
Sponsor: ASME, Petroleum Div, New York, NY, USA
E.I. Conference No.: 12524
Source: American Society of Mechanical Engineers, Petroleum Division (Publication) PD v 19. Publ by American Soc of Mechanical Engineers (ASME), New York, NY, USA. p 29-40
Publication Year: 1988
CODEN: ASMPEX
Language: English
Document Type: PA (Conference Paper) Treatment: G (General Review)
Journal Announcement: 8911
Abstract: Several types of in-line inspection tools are presently available to pipeline operators for use in evaluating the structural integrity of their pipeline systems. These tools can be used to locate dents, gouges and corrosion-caused metal loss. This presentation reviews the capabilities and limitations of current in-line inspection tools, and looks toward future developments in in-line inspection technology. (Edited author abstract) 23 Refs.

Title: Tools Locate, Measure Dents and Metal Loss.
Author: Kiefner, John F.; Hyatt, Roger W.; Eiber, Robert J.
Corporate Source: Battelle Columbus Lab, Columbus, OH, USA
Source: Oil and Gas Journal v 87 n 16 Apr 17 1989 p 30-38
Publication Year: 1989
CODEN: OIGJAV ISSN: 0030-1388
Language: English
Document Type: JA (Journal Article) Treatment: A (Applications)
Journal Announcement: 8909
Abstract: Several in-line inspection tools are currently available to pipeline operators for use in evaluating the structural integrity of their pipeline systems. These tools can be used to locate dents, gouges, and most importantly corrosion-caused metal loss. Reviewed in this two-part series are the capabilities and limitations of current in-line inspection tools and possible future developments in in-line inspection technology. The types of in-line tools currently available for monitoring pipeline integrity include gauging tools, camera tools, magnetic-flux-leakage tools, ultrasonic wall-thickness tools, and an ultrasonic tool for detecting stress-corrosion cracks. 16 Refs.

Title: Anatomy of a Pipe Line Internal Inspection Program
Author: Robinson, Gary C.
Corporate Source: Trans-Northern Pipelines Inc, Engineering Dep, Toronto, Ont, Can
Source: Pipe Line Industry v 62 n 6 Jun 1985 p 24-26

Publication Year: 1985
CODEN: PLINAH ISSN: 0032-0145
Language: ENGLISH
Document Type: JA (Journal Article) Treatment: A (Applications); G (General Review)
Journal Announcement: 8509
Abstract: Trans-Northern Pipelines Inc. regularly inspects its pipelines to improve the integrity of its system and to reduce costs and disruption due to leaks. In 1982 Trans-Northern developed a six-year program to inspect its pipe lines internally in search of serious mechanical damage such as gouges, gouges in dents, as well as ongoing corrosion activity. The three stages of the internal inspection program are: a broad approach identifying which pipe line segments need to be surveyed, in which order and when; identification of the particulars of each survey segment, organization of the workload and actual survey performed; and assessment of survey results.

Experimental Investigations on the Effect of Dents and Gouges on Pipeline Performance

Title: Assessment of Mechanically Damaged Pipes Containing Dents and Gouges
Author: Lancaster, Earl R.; Palmer, Stephen C.
Corporate Source: Cambridge Univ, Cambridge, UK
Conference Title: Proceedings of Pressure Vessels and Piping Conference
Conference Location: Denver, CO, USA
Sponsor: ASME
E.I. Conference No.: 19192
Source: Service Experience and Life Management: Nuclear, Fossil, and Petrochemical Plants American Society of Mechanical Engineers, Pressure Vessels and Piping Division (Publication) PVP v 261 1993. Publ by ASME, New York, NY, USA. p 61-68
Publication Year: 1993
CODEN: AMPPD5 ISSN: 0277-027X ISBN: 0-7918-0988-9
Language: English
Document Type: CA (Conference Article) Treatment: T (Theoretical); X (Experimental)
Journal Announcement: 9401W5
Abstract: A gouge within a dent has long been recognized as the most severe form of mechanical damage on oil and gas transmission pipelines, and can result in failures at very low pressures. Yet despite two decades of expensive full-scale testing, the behavior of such damaged pipes under subsequent pressurization is not well understood. This paper presents the main findings of a three-year experimental model-testing programme, and compares the results with those of full-scale tests performed by Battelle, CANMET and British Gas. The results of strain-gauge tests, photoelastic studies and displacement measurement surveys have identified growing zones of high stress commencing at the edge of the dent when internal pressure is applied. Gouges located in these zones were observed to burst at relatively low pressures. The paper reviews this experimental programme and proposes new criteria to assist in assessing damaged pipes, and in evaluating procedures for repair. (Author abstract) 9 Refs.

Title: Impact Damage and Assessment of Offshore Tubulars
Author: Frieze, P.A.; Cho, S-R.
Corporate Source: Paul A. Frieze & Assocs
Conference Title: Proceedings of the 25th Annual Offshore Technology Conference. Part 2 (of 4)
Conference Location: Houston, TX, USA
Sponsor: Amer Inst of Mining, Metallurgical and Petroleum Engineers; AAPG; AIChE; ASCE; ASME - Petroleum Division; et al
E.I. Conference No.: 18812
Source: Platform and Marine System Design Proceedings - Annual Offshore Technology Conference pt 2 1993. Publ by Offshore Technology Conference, Dallas, TX, USA. p 193-197
Publication Year: 1993
CODEN: OSTCBA ISSN: 0160-3663
Language: English
Document Type: CA (Conference Article) Treatment ; X (Experimental)
Journal Announcement: 9312W2

Abstract: Two series of experiments are described in which tubulars typical of offshore construction are subjected to dynamic lateral impact and then residual strength tests. Model material selection and preparation which involves heat treatment are reported together with the lateral impact test procedure. Damage in the form of local dents and overall bows is reported and dimensionless semi-empirical relationships presented which relate this damage to the initial kinetic energy. It is possible to identify the range of parameters for which damage will not occur. To determine residual strength a selection of damaged and undamaged tubulars was subjected to axial compression alone and when combined with external pressure. The test rig and procedure are briefly described and results presented. A semi-empirical relationship between axial compressive residual strength and extent of damage is presented. Finally, a method is presented by which full scale measurements of damaged tubulars can be interpreted for use in the residual strength equations. (Author abstract) 23 Refs.

Title: Criteria for Dent Acceptability in Offshore Pipeline
Author: Fowler, J.R.
Corporate Source: Stress Engineering Services
Conference Title: 25th Annual Offshore Technology Conference
Conference Location: Houston, TX, USA
Sponsor: American Institute of Mining, Metallurgical and Petroleum Engineers; American Association of Petroleum Geologists; AICE; ASCE; ASME-Petroleum Division; et al
E.I. Conference No.: 18812
Source: Field Drilling and Developmenet Systems Proceedings - Annual Offshore Technology Conference pt 4 1993. Publ by Offshore Technology; Conference, Dallas, TX, USA. p 481-488
Publication Year: 1993
CODEN: OSTCBA ISSN: 0160-3663
Language: English
Document Type: CA (Conference Article) Treatment: T (Theoretical); A (Applications)
Journal Announcement: 9311W2

Abstract: This paper discusses testing and analysis work done to establish the effects of pipeline dents (without gouges) under cyclic internal pressure loading. Operators were surveyed regarding the expected dent shapes and failures from dents that had been experienced. A full scale test program utilizing 12-3/4 double prime pipe with controlled dents and cyclic pressure was carried out. Elastic and plastic finite element analyses was used to determine stresses so that a fatigue analysis could be done. The results indicate that plain smooth dents less than 5% of the diameter for pipe with a diameter to thickness of less than 30 are not a problem for normal pipeline service. Plain dents are probably not a concern for normal gas line service. An analytical procedure was developed to predict the fatigue life of a pipeline subjected to a combination of plain dents and cyclic pressure. (Author abstract) 13 Refs.

Title: Stress Concentration in Vessels with Local Shape Imperfections
Author: Likhman, V. V.; Kopysitskaya, L. N.; Muratov, V. M.
Source: Khimicheskoe i Neftekhimicheskoe Mashinostroenie n 6 Jun 1992 p 22-24
Publication Year: 1992
CODEN: 500067
Language: Russian
Document Type: JA (Journal Article) Treatment: A (Applications); T (Theoretical); X (Experimental)
Journal Announcement: 9304
Abstract: The paper deals with the results of experimental and theoretical studies into the deformed-stressed states of cylindrical and spherical vessels with dents under internal pressure effect. The experiments were made with the welded 12Kh18Ni10Ti steel cylindrical vessels 250-800 mm in-diameter with wall thickness of 1.6-2.5 mm. The circular dents were made mechanically and had the 60-250 mm diameters and the initial depths in the centre equal to 2.7-6.4 mm. The experimental result analysis have shown that calculations in the elastic zone are sufficient for the vessel cyclic strength estimation. The calculations made using the finite element method gave an opportunity to conclude that the dent relative depth and reduced radius have the greatest effect on the stress concentration in the dent zone. 2 Refs. In Russian.

Title: Model Testing of Mechanically Damaged Pipes Containing Dents and Gouges.
Author: Lancaster, E. R.; Palmer, S. C.
Corporate Source: Cambridge Univ, Cambridge, Engl
Conference Title: 1992 Pressure Vessels and Piping Conference
Conference Location: New Orleans, LA, USA; Conference Date: 1992 Jun 21-25
Sponsor: ASME, Pressure Vessels & Piping Div
E.I. Conference No.: 16915
Source: Design and Analysis of Pressure Vessels, Piping, and Components - 1992 American Society of Mechanical Engineers, Pressure Vessels and Piping; Division (Publication) PVP v 235. Publ by ASME, New York, NY, USA.; p 143-148

Publication Year: 1992
CODEN: AMPPD5 ISSN: 0277-027X
Language: English
Document Type: PA (Conference Paper) Treatment: T (Theoretical)
Journal Announcement: 9211
Abstract: A gouge within a dent has long been recognized as the most severe form of mechanical damage on oil and gas transmission pipeline, and can result in failures at very low pressures. Yet despite two decades of expensive full-scale testing, the behavior of such damaged pipes under subsequent pressurization is not well understood. This paper describes how small-scale model testing of pipes with combined dents and gouges, but specifically excluding cracking, can be a valuable supplement to the full-size tests. Model tests using aluminum alloy tubes are outlined, and the results throw much light on the published results of tests on full-scale steel pipes, particularly regarding the effects of cracks, and the phenomenon of dent flip-out. It is concluded that these model tests will be a valuable new tool for further studies in this area. (Author abstract) 5 Refs.

Title: Serviceability of Pressure Vessels with Local Faults in the Geometric Shape of the Casing.
Author: Mukhin, V. N.; Serebryannyi, V. B.; Samokhin, Yu. N.
Corporate Source: All-Union Scientific-Research & Inst of Petrochemical Equipment, Volgograd, USSR
Source: Strength of Materials (English translation of Problemy Prochnosti) Nov 1988 p 391-396
CODEN: SMTLB5 ISSN: 0039-2316
Language: English
Document Type: JA (Journal Article) Treatment: X (Experimental)
Journal Announcement: 9012
Abstract: When pressure vessels (column castings, etc.) are transported, assembled, and placed in service, they are subjected to local deformation in certain cases with the formation of dents, the dimensions of which exceed established norms. This study examines this problem. Results of this study show that in cases when progressive growth in a deformed segment of the casing is observed under operating conditions it is necessary to determine its critical dimensions, on attainment of which the vessel should be taken out of service. 12 Refs.

Title: Outside-force Damage of Pipe Analyzed.
Author: Maxey, W. A.
Corporate Source: Batelle Columbus Div, Columbus, OH, USA
Source: Oil and Gas Journal v 85 n 21 May 25 1987 p 74, 76
Publication Year: 1987
CODEN: OIGJAV ISSN: 0030-1388
Language: English
Document Type: JA (Journal Article) Treatment: X (Experimental)
Journal Announcement: 8708
Abstract: Damage from a force outside the pipeline has been established as the primary cause of natural-gas pipeline service failures in the U.S.

This second of three articles completes a discussion of characteristics of such damage. The concluding article will examine dynamic-damage research. Another series of experiments was aimed at examining the effect of external mechanical damage (gouged and dented) on the fracture-initiation transition temperature and on the reduction of failure pressure during hold time. BCD conducted several mechanical-damage experimental programs in which damaging consisted of a two-step process. A sharp notch was machined into the exterior of the pipe specimen surface and the entire area indented with a hydraulic ram. The root of the machined flaw was therefore cold-worked in compression. All pipe specimens were at ambient pressure when the flaws were produced.

Title: Interactive Buckling Tests on Cylindrical Shells subjected to Axial Compression and External Pressure - A Comparison of Experiment, Theory, and Various Codes.
Author: Galletly, G. D.; Pemsing, K.
Corporate Source: Univ of Liverpool, Dept of Mechanical Engineering, Liverpool, Engl
Source: Proceedings of the Institution of Mechanical Engineers, Part C: Mechanical Engineering Science v 199 n C4 1985 p 259-280
Publication Year: 1985
CODEN: MESCEO ISSN: 0263-7154
Language: ENGLISH
Document Type: JA (Journal Article) Treatment: A (Applications); N (Numeric/Statistical); X (Experimental)
Journal Announcement: 8603
Abstract: The buckling of welded steel cylindrical shells under the combined action of external pressure and axial compressive loads is of considerable interest to the offshore oil and nuclear industries. However, test results on this subject are scarce and some design rules which have been proposed recently have not been validated experimentally, especially in the plastic buckling region. One series of tests consisted of 19 machined and stress-relieved steel models having L/R ratios of 0.33, 0.74 and 1.45. The results obtained on these near-perfect machined models were compared with theoretical predictions of the behavior of perfect cylindrical shells and the agreement between the two was good. Some tests were also carried out on (a) the effect of the loading path on the failure loads and (b) models with localized dents. Other topics discussed in this paper are: the effects of residual stresses and initial geometric imperfections, the general procedure adopted by Codes to predict buckling loads and some discrepancies between the predictions of various Codes. (Edited author abstract) 40 refs.

Title: Influence of Mechanical Damage on Transmission Pipeline Integrity
Author: Jones, D. G.; Hopkins, P.
Corporate Source: British Gas Corp, Engineering Research Station, Newcastle upon Tyne, Engl
Conference Title: 1983 International Gas Research Conference, Proceedings.
Conference Location: London, Engl Conference Date: 1983 Jun 13-16

Sponsor: Int Gas Union, Paris, Fr; Gas Research Inst, Chicago, Ill, USA; American Gas Assoc, Arlington, Va, USA; DOE, Washington, DC, USA
E.I. Conference No.: 04938
Source: Proceedings of the International Gas Research Conference 1983. Publ by Government Inst Inc, Rockville, Md, USA p 106-115
Publication Year: 1983
CODEN: PGRCDV ISSN: 0736-5721 ISBN: 0-86587-125-6
Language: English

Title: Effect of Deliberately Induced Damage on the Burst Performance of LPG Cylinders - Supervised by AWRA Project Panel Pressure Vessels
Author: McLeod, A. J.
Corporate Source: Australian Welding Research Assoc, Aust
Source: Australian Welding Research v 11 Dec 1982 p 42-47
Publication Year: 1982
CODEN: AWRSAN ISSN: 0045-0960
Language: ENGLISH
Journal Announcement: 8402
Abstract: Imported LPG cylinders of 45 kg capacity were subject to hydrostatic burst testing. The circumferential joggle-butt welds of the cylinders contained lack of root fusion and porosity, but these defects did not take part in fracture and did not therefore reduce burst pressure or circumferential elongation to failure. The materials and construction of the cylinders were judged adequate for the intended service. In a further series of tests, vessel walls were damaged by single or multiple dents, grooves, gouges and/or welds prior to testing. There was no detrimental effect on performance due to dents. Grooves and gouges caused both burst and leakage failures, which were correlated with the dimensions of these defects. The cylinders are supervised by AWRA (Australian Welding Research Association).

Title: Bursting Pressures of Mechanically Damaged Pipe - AWRA Report P7-63-79.
Author: Wade, J. B.
Corporate Source: Snowy Mt Eng Corp
Source: Australian Welding Research v 8 Feb 1980 p 1-3
Publication Year: 1980
CODEN: AWRSAN ISSN: 0045-0960
Language: English
Journal Announcement: 8205
Abstract: Burst tests on API 5LX pipe were conducted to investigate the viability of treating mechanically damaged pipe by the criterion in Appendix L of Australian Standard AS1697 for corroded pipe. Providing the gouge in the damaged region is removed, a new operating pressure is established and the decision to repair is left to the operating authority. Acceptance criteria from ASME and AGA are also compared.

Theoretical Studies on the Effect of Dents and Gouges on Pipeline Performance

Title: Criteria for Dent Acceptability in Offshore Pipeline
Author: Fowler, J.R.
Corporate Source: Stress Engineering Services
Conference Title: 25th Annual Offshore Technology Conference
Conference Location: Houston, TX, USA
Sponsor: American Institute of Mining, Metallurgical and Petroleum Engineers; American Association of Petroleum Geologists; AICE; ASCE; ASME-Petroleum Division; et al
E.I. Conference No.: 18812
Source: Field Drilling and Developmenet Systems Proceedings - Annual Offshore Technology Conference pt 4 1993. Publ by Offshore Technology; Conference, Dallas, TX, USA. p 481-488
Publication Year: 1993
CODEN: OSTCBA ISSN: 0160-3663
Language: English
Document Type: CA (Conference Article) Treatment: T (Theoretical); A (Applications)
Journal Announcement: 9311W2
Abstract: This paper discusses testing and analysis work done to establish the effects of pipeline dents (without gouges) under cyclic internal pressure loading. Operators were surveyed regarding the expected dent shapes and failures from dents that had been experienced. A full scale test program utilizing 12-3/4 double prime pipe with controlled dents and cyclic pressure was carried out. Elastic and plastic finite element analyses was used to determine stresses so that a fatigue analysis could be done. The results indicate that plain smooth dents less than 5% of the diameter for pipe with a diameter to thickness of less than 30 are not a problem for normal pipeline service. Plain dents are probably not a concern for normal gas line service. An analytical procedure was developed to predict the fatigue life of a pipeline subjected to a combination of plain dents and cyclic pressure. (Author abstract) 13 Refs.

Title: Stress Concentration in Vessels with Local Shape Imperfections
Author: Likhman, V. V.; Kopysitskaya, L. N.; Muratov, V. M.
Source: Khimicheskoe i Neftekhimicheskoe Mashinostroenie n 6 Jun 1992 p 22-24
Publication Year: 1992
CODEN: 500067
Language: Russian
Document Type: JA (Journal Article) Treatment: A (Applications); T (Theoretical); X (Experimental)
Journal Announcement: 9304
Abstract: The paper deals with the results of experimental and theoretical studies intc the deformed-stressed states of cylindrical and spherical vessels with dents under internal pressure effect. The experiments were made with the welded 12Kh18Ni10Ti steel cylindrical vessels 250-800 mm in-diameter with wall thickness of 1.6-2.5 mm. The circular dents were made mechanically and had the 60-250 mm diameters and the initial depths in the centre equal to 2.7-6.4 mm. The experimental

result analysis have shown that calculations in the elastic zone are sufficient for the vessel cyclic strength estimation. The calculations made using the finite element method gave an opportunity to conclude that the dent relative depth and reduced radius have the greatest effect on the stress concentration in the dent zone. 2 Refs. In Russian.

Title: Stress Concentrations in Pipelines Due to the Presence of Dents.
Author: Beller, M.; Mattheck, C.; Zimmermann, J.
Corporate Source: PREUSSAG Anlagenbau GmbH, Karlsruhe, Ger
Conference Title: Proceedings of the First International Offshore and Polar Engineering Conference
Conference Location: Edinburgh, Scotl
Conference Date: 1991 Aug 11-16
Sponsor: Int Soc of Offshore & Polar Engineers (ISOPE); Offshore Mechanics & Polar Engineering Council (OMPEC)
E.I. Conference No.: 16383
Source: Proc First Int Offshore Polar Eng Conf. Publ by Int Soc of Offshore and Polar Engineers (ISOPE), P.O.Box 1107, Golden, CO, USA. p 421-424
Publication Year: 1991
ISBN: 0-9626104-7-x
Language: English
Document Type: PA (Conference Paper) Treatment: A (Applications); T (Theoretical)
Journal Announcement: 9207
Abstract: Dents in the walls of pipes or plates are caused by plastic deformation due to the action of external forces. Such dents result in a local redirectioning of the existing force flow, giving rise to notch stresses. These stresses can initiate cracks. Two types of cracks can be observed, diametral and circumferential cracks. Following an initial 2D-investigation into the different crack paths observed, the paper presents a 3D-Finite-Element analysis of spherical and cylindrical indentations in plates. The analysis is carried out for linear-elastic material response and investigates the influence of the dent geometry on possible crack growth. The shape of a dent determines whether the maximum stress peaks occur at the root of the rim of the dent. This suggests the existence of a 'critical' dent geometry which determines the crack path followed. The paper presents part of a project concerned with the integrity assessment of pipelines containing flaws or defects. (Author abstract) 14 Refs.

Title: Study of the Effect of the Dimensions of an Initial Indentation on the Critical Parameters of Short-term External Pressure for a Spherical Shell.
Author: Amiro, I. Ya.
Corporate Source: Acad of Sciences of the Ukrainian SSR, Kiev, USSR
Source: Soviet Applied Mechanics (English Translation of Prikladnaya Mekhanika) v 26 n 9 Mar 1991 p 829-835
Publication Year: 1991
CODEN: SOAMBT ISSN: 0038-5298

Language: English
Document Type: JA (Journal Article) Treatment: T (Theoretical)
Journal Announcement: 9110
Abstract: An earlier study examined the problem of dynamic loss of stability by a spherical shell, with an initial chamber, that was subjected to a short-term external pressure. The solution of this problem is based on the use of linearized equations from the theory of structurally orthotropic shells. The spherical shell, reinforced by a square network of ribs, was regarded as shallow within the limits of the indentation that developed during loss of stability. In the present investigation, we assume that the in-plan dimensions and amplitude of the initial indentation are given, while the condition of minimality of the critical compressive forces is used to determine the parameters of the dent formed during loss of stability. Here, it is assumed that the latter does not extend beyond the boundaries of the initial indentation. The effect of the discrete arrangement of the ribs is evaluated by comparing the critical load for a structurally orthotropic shell with the critical pressure corresponding to the buckling of a panel between ribs. 4 Refs.

Title: Applications of the Stochastic Finite-Element Method in a Thin-Walled Pressure Vessel Containing Uncertainty.
Author: Mori, Masahiko; Ukai, Osamu; Kondo, Mitsuru
Source: Nippon Kikai Gakkai Ronbunshu, A Hen/Transactions of the Japan Society of Mechanical Engineers, Part A v 56 n 526 Jun 1990 p 1455-1460
Publication Year: 1990
CODEN: NKGADA ISSN: 0387-5008
Language: Japanese
Document Type: JA (Journal Article) Treatment: T (Theoretical)
Journal Announcement: 9011
Abstract: The effect of geometrical uncertainty and thickness variability on the stress distribution of a thin-walled pressure vessel is analyzed by the stochastic finite-element method based on the second-order perturbation technique. Numerical analyses are carried out in regard to an axisymmetric model and 3-D shell model with the circular dent due to the welding joint under internal pressure. Moreover, as an attempt to estimate the reliability of a thin-walled pressure vessel, the stochastic safety factor is evaluated with respect to the calculated stress by using the stochastic finite-element method, and it is compared with the conventional safety factor divided minimum strength of material by calculated maximum stress. (Author abstract) 5 Refs. In Japanese.

Title: Influence of Boundary Conditions on Stability of Cylindrical Shells.
Author: Tovstik, P. E.
Corporate Source: Vestnik Leningradskogo Univ
Source: Leningrad University Mechanics Bulletin (English Translation of Vestnik Leningradskogo Universiteta, Mekhanika) n 3 1989 p 39-45
Publication Year: 1989
CODEN: LUMBEO ISSN: 0883-623X

Language: English
Document Type: JA (Journal Article) Treatment: T (Theoretical)
Journal Announcement: 9009
Abstract: Stability loss is studied for momentless stressed state of a slender elastic cylindrical shape with characteristic dents along generators. The indentations can cover the entire median surface or be localized near the weakest generator. The latter case is possible, in particular, for a noncircular cylinder and/or cylinder with an oblique edge acted upon by external normal pressure. (Author abstract) 5 Refs.

Title: New Model for Calculating Propagation Pressure and Initiation Pressure of Pipelines with a Local Dent
Author: Huang, Yuying; Chen, Keming
Corporate Source: Huazhong Univ of Science and Technology, Wuhan, China
Source: China Ocean Engineering v 3 n 1 1989 p 119-130
Publication Year: 1989
CODEN: COCEEC ISSN: 0890-5487
Language: English
Document Type: JA (Journal Article) Treatment: T (Theoretical)
Journal Announcement: 9006
Abstract: An analytical model of a ring with six yield hinges and two deformable arc segments is presented for the prediction of the buckle propagation pressure and initiation pressure in offshore pipelines. The configuration of a fully collapsed ring is considered as a real dumbbell shape with a line touch between two 'bells', instead of the dumbbell shape with a point touch of two diametrically opposite points. Calculations are performed assuming that the dominant effect on plastic energy dissipation is the circumferential bending mode. For the linear strain-hardening materials it is found that theoretical predictions based on the above model for both propagation pressure and initiation pressure are in good agreement with experimental results of Kyriakides et al. (Edited author abstract) 8 Refs.

Title: Elastic Analysis of a Dent on Pressurized Pipe.
Author: Lin Seng, Ong; Yiu Wing, Chan; Seet, Gerald
Corporate Source: Nanyang Technological Inst, Singapore
Source: International Journal of Pressure Vessels and Piping v 38 n 5 1989 p 369-383
Publication Year: 1989
CODEN: PRVPAS ISSN: 0308-0161
Language: English
Document Type: JA (Journal Article) Treatment: T (Theoretical)
Journal Announcement: 8912
Abstract: The elastic analysis of a dent on a pressurized cylinder is investigated. The predetermined shapes of the dent are grouped into three categories according to the physical geometry of the dent width, namely the local dent, the short dent, and the long dent. The induced bending stresses associated with the dent are evaluated using Sanders' non-linear shell theory. Comparison of theoretical results with the finite element approach is made for a pipe of assumed dimensions and pressure. Good agreement of

the results is observed. The analytical approach of this paper is suitable for pipe or cylinder with a dent depth of up to five times the wall thickness. (Edited author abstract) 7 Refs.

Title: Experimental Investigation of Deformation and Load-Carrying Capacity of Elastoplastic Cylindrical Shells with Initial Shape.
Title: EKSPERIMENTAL'NOE ISSLEDOVANIE DEFORMIROVANIYA I NESUSHCHEI SPOSOBNOSTI UPRUGOPLASTICHESKIKH TSILINDRICHESKIKH OBOLOCHEK S NACHAL'NYMI NESOVERSHENSTVAMI FORMY.
Author: Gaiduchenko, A. P.; Demenkov, A. F.
Source: Problemy Prochnosti v 7 Jul 1987 p 74-76
Publication Year: 1987
CODEN: PPCNBG ISSN: 0556-171X
Language: Russian
Document Type: JA (Journal Article) Treatment: X (Experimental)
Journal Announcement: 8711
Abstract: Deformation process and exhaustion of the load-carrying capacity of cylindrical shells with initial shape imperfections, such as a lateral dent, and without them, are experimentally studied. Results of the study are presented. Loading is performed by a combination of the axial compressive force and lateral ambient pressure which change by different programs. Variation in the flexure development pattern for shells with different geometrical parameters and under different loading programs is noted. Results of the experiment are presented as graphs. (Author abstract) 7 refs. In Russian.

Title: Deformation and Carrying Capacity of Elastoplastic Cylindrical Shells with Imperfect Forms and Residual Stress.
Author: Gudramovich, V. S.; Demenkov, A. F.
Corporate Source: Acad of Sciences of the Ukrainian SSR, Inst of Engineering Mechanics, Dnepropetrovsk, USSR
Source: Soviet Applied Mechanics (English Translation of Prikladnaya Mekhanika) v 21 n 7 Jul 1985 p 677-682
Publication Year: 1985
CODEN: SOAMBT ISSN: 0038-5298
Language: English
Document Type: JA (Journal Article) Treatment: T (Theoretical)
Journal Announcement: 8603
Abstract: Some aspects of the behavior of elastoplastic cylindrical shells with imperfect forms and residual stresses under combined loading are considered. A system of resolving equations is obtained on the basis of the variational principle of possible displacements. In using the method of statistical tests, the function of distribution of the carrying capacity of cylindrical shells according to the known function of distribution of parameters characterizing the initial shape imperfections is determined. Results of theoretical and experimental investigations of the carrying capacity of cylindrical shells with initial imperfections in the form of a lateral local dent under loading by an axial compressive force and a lateral external pressure are presented. 15 refs.

Title: Amplitude Modulation of Short-Wave Buckling Modes
Author: Koiter, W. T.
Corporate Source: Delft Univ of Technology, Delft, Neth
Conference Title: Behavior of Thin-Walled Structures. (Papers presented at the Retiral Conference for Professor James M. Harvey.)
Conference Location: Glasgow, Scotl Conference Date: 1983 Mar 29-30
Sponsor: Univ of Strathclyde, Glasgow, Scotl; Cold Rolled Sections Assoc; Conoco (UK) Ltd, Engl
E.I. Conference No.: 05751
Source: Publ by Elsevier Applied Science Publ, London, Engl and New York, NY, USA p 35-45
Publication Year: 1984
ISBN: 0-85334-246-6
Language: English
Document Type: PA (Conference Paper)
Journal Announcement: 8505
Abstract: Amplitude modulation of short-wave local buckling modes has proved to be a useful tool in the approximate analysis of a number of buckling problems for plates and shells. This concept seems to have been applied first in a modification of Hutchinson's analysis of a complete spherical shell under external pressure. More or less localized imperfections and the associated buckling analysis have improved our understanding of the effect of a local dent. Finally, the non-linear interaction between local sheet buckling and overall buckling of stiffened plate and shell structures may be described effectively as a modulation of the amplitude of the local short-wave mode due to the long-wave overall mode. 18 refs.

Title: On the Stability of Inelastic Circular Pipes Under Combine Bending and External Pressure
Author: Kyriakides, S.
Corporate Source: Univ of Tex, Austin, USA
Conference Title: Proceedings of the 1981 Spring Meeting - Society for Experimental Stress Analysis.
Conference Location: Dearborn, MI, USA Conf. Date: 1981 May 31-Jun 4
Sponsor: SESA, Brookfield Center, Conn, USA
E.I. Conference No.: 00276
Source: Paper - SESA (Society for Experimental Stress Analysis) Publ by SESA, Brookfield Center, Conn, USA p 372-378
Publication Year: 1981
CODEN: SEXSAN
Language: English
Document Type: PA (Conference Paper)
Journal Announcement: 8207
Descriptors: *PIPELINES--*Stability
Identifiers: INITIATION PRESSURE; RESPONSE AND STABILITY OF CIRCULAR PIPES; BENDING AND EXTERNAL PRESSURE PARAMETERS; PLASTIC EFFECTS; OFFSHORE PIPELINE APPLICATIONS; BUCKLING UNDER COMBINED LOADING APPLIED; PROPAGATING BUCKLE PHENOMENON; BUCKLING PRESSURE; PROPAGATION THICKNESS; PRESSURE-CURVATURE INTERACTION STABILITY BOUNDARY; DENT FORMATION

Title: Fracture Analysis of A Pneumatically Burst Seamless-Steel Compressed Gas Container.
Author: Christ, B. W.; Smith, J. H.; Hicho, G. E.
Corporate Source: NBS, Washington, DC
Source: ASTM Special Technical Publication n 677, Proc of the Natl Symp on Fract Mech, 11th, Pt 1 Fract Mech, Va Polytech Inst and State Univ, Blacksburg, Jun 12-14 1978. Publ by ASTM, Philadelphia, Pa, 1979 p 734-745
Publication Year: 1978
CODEN: ASTTA8 ISSN: 0066-0558
Language: English
Journal Announcement: 8003
Abstract: This paper describes the fracture analysis of a seamless steel compressed gas container which burst at a reported pressure of 17. 3 MPa (2500 psi) during filling. Design burst pressure was about 35. 2 MPa (5100 psi). The container was made of a quenched and tempered carbon-manganese steel with yield and tensile strengths of 517 and 687 MPa (75000 and 99800 psi), respectively. The vessel had been in service for about 6 months and had been filled perhaps twice before it burst. The fracture origin was a pair of part-through cracks in a gouged region on the outside surface. Fracture at the origin was ductile and the fast fracture was also ductile. The empirical methodology developed at Battelle-Columbus for analyzing the burst of line pipe was utilized to analyze the ductile fracture initiation of this compressed gas container. 17 refs.

Guidelines for Application to Pipelines

Title: Analytical and Experimental Assessment of Effect of Local Dents on Strength of Housings of Vessels and Apparatuses.
Author: Mukhin, V. N.; El'manovich, V. I.
Source: Khimicheskoe i Neftekhimicheskoe Mashinostroenie n 6 Jun 1991 p 24-26
Publication Year: 1991
CODEN: 500067
Language: Russian
Document Type: JA (Journal Article) Treatment: A (Applications); T (Theoretical)
Journal Announcement: 9212
Abstract: The specification has been drawn up where allowance in structural analysis of cylindrical cells is made for the deviations from the ideal round shape, including dents. The analytical techniques provided in the specification allow the estimation of the allowable internal pressure in the housing of vessel or apparatus with dent. The results of analytical assessment of the strength of dented housings are compared with the results of the their strain-gauge tests. 2 Refs. In Russian.

Title: Backgrounds of Criteria for Fitness for Purpose in In-service Gas Transmission Pipelines
Author: Spiekhout, J.
Corporate Source: NV Nederlandse Gasunie, Groningen, Neth

Conference Title: ECF 6: Fracture Control of Engineering Structures, Proceedings of the 6th Biennial European Conference on Fracture.
Conference Location: Amsterdam, Neth Conference Date: 1986 Jun 15-20
Sponsor: Int Congress on Fracture; Royal Inst for Engineers, Div for Mechanics, Neth; Dutch Electrical Supply Co, Neth; Ministry of Economic Affairs, Neth; Royal Dutch Shell, Neth; et al
E.I. Conference No.: 11624
Source: Publ by Engineering Materials Advisory Services Ltd, Warley, Engl v 2, p 761-775
Publication Year: 1986
ISBN: 0-947817-18-2
Language: English
Document Type: PA (Conference Paper)
Journal Announcement: 8812
Abstract: The basis and backgrounds for guidelines concerning defect criteria in in-service gas transmission pipelines are described and illustrated with examples of assessment diagrams. Two main defect types are distinguished. (a) Pressure controlled defects like axial notches, dents and most of the corrosion defects; and (b) Strain controlled defects like circumferential notches and weld defects in girth welds. (Author abstract) 16 refs.

Title: Safety Margin of High-Pressure Gas Cylinders with Minor Defects Caused by Wear and Tear
Author: Busch, W.; Huemmler, L.
Source: Linde Rep Sci Technol n 39 1985 p 30-35
Publication Year: 1985
CODEN: LRSTAF ISSN: 0024-3736
Language: English
Document Type: JA (Journal Article) Treatment: A (Applications); X (Experimental)
Journal Announcement: 8511
Abstract: During its service life a pressure cylinder is usually filled, emptied, transported etc. several hundred times. Deterioration sets in as a result of scratches, surface damage, dents, notches, corrosion scars and suchlike. The criteria and the procedures of everyday practice in which steel cylinders with surface defects are removed from circulation as not being above suspicion safetywise are relatively arbitrary. A pressure cylinder may only be filled with pressurized gas if it shows no defects, including in its fittings, that may endanger handling personnel or third parties.

APPENDIX B. Analysis of Rerounding

Given a pipe of outer diameter D, wall thickness t, and dented to a depth d, it is desired to know the internal pressure, P, that will approximately return the pipe to its original shape, i.e., that will reround it. A schematic diagram of the dented pipe is shown in Figure B1. The present analysis assumes that the dent in the pipe can be modeled as a uniformly loaded beam, built in at both ends (see Figure B2). For such a beam, it has been shown that complete plastic collapse occurs when the applied moment is given by (Reference B1).

$$M = Sy\ Lt^2/4 \qquad \text{(Eq. B1)}$$

where Sy is the yield strength and L is the extent of the dent in the axial direction. This moment can be generated by a uniformly applied load (Reference B1):

$$W = 16\ M/\ell \qquad \text{(Eq. B2)}$$

where ℓ is the extent of the dent in the around the circumference of the pipe. For the pipe, uniform load W is generated by the internal pressure according to

$$W = P\ell L \qquad \text{(Eq. B3)}$$

Combining Equations B1, B2, and B3, the rerounding pressure is predicted to be

$$P = 4\ \alpha_y \left(\frac{t}{\ell}\right)^2 \qquad \text{(Eq.B4)}$$

The extent of the dent in the circumferential direction, ℓ, is approximately related to the diameter of the pipe, D, and the size, d, of the dent:

$$\ell = 4 \left(\frac{d}{D}\right)^{1/2} D \qquad \text{(Eq.B5)}$$

Substituting Eq. B5 into B4 and rearranging,it is found that rerounding of the pipe should occur at a normalized pressure of

$$\frac{P}{S_y} = \frac{1}{4} \left(\frac{t}{D}\right)^2 \frac{D}{d} \qquad \text{(Eq.B6)}$$

The pressure at which a pipeline operates is usually determined by the strength of the pipe steel, i.e., the SMYS, according to

$$P = \frac{F(SMYS)(t)}{D} \qquad \text{(Eq.B7)}$$

where F is a safety factor like 80 percent. Equating the normalized operating pressure to the normalized rerounding pressure, results in the following

expression for the maximum sustainable dent size that will not reround on pressurization in terms of the D/t ratio:

$$\frac{d}{D} = \frac{1}{4F}\left(\frac{D}{t}\right)^{-1} \qquad \text{(Eq. B8)}$$

This equation is plotted for various safety factors in Figure 1.

References

B1. Baker, J. F.; Horne, M. R.; and Heyman, J.; The Steel Skeleton Vol. II, Plastic Behavior and Design, published by Cambridge University Press, Cambridge, England (1956).

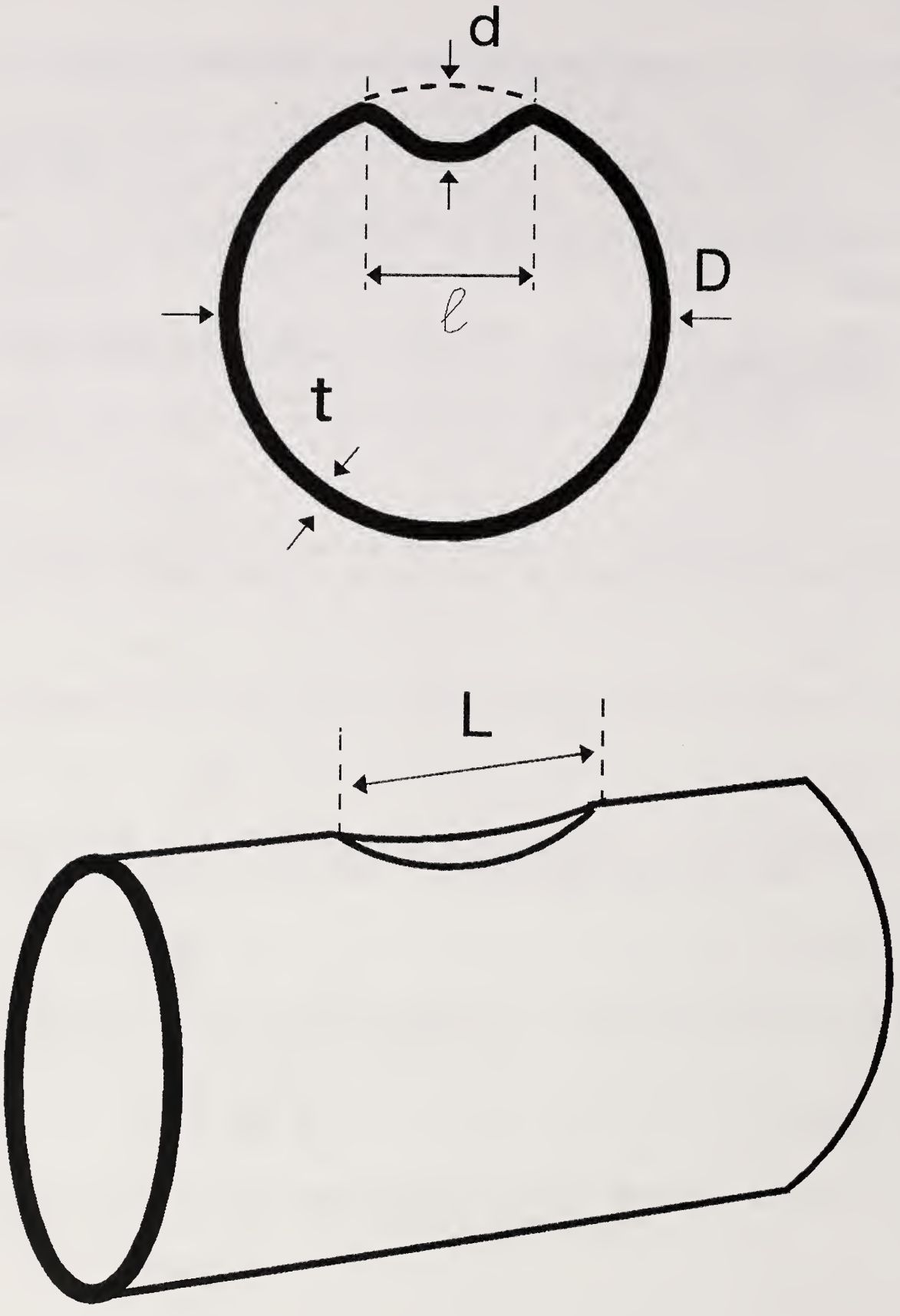

Figure B1. Schematic diagram of dent in pipe.

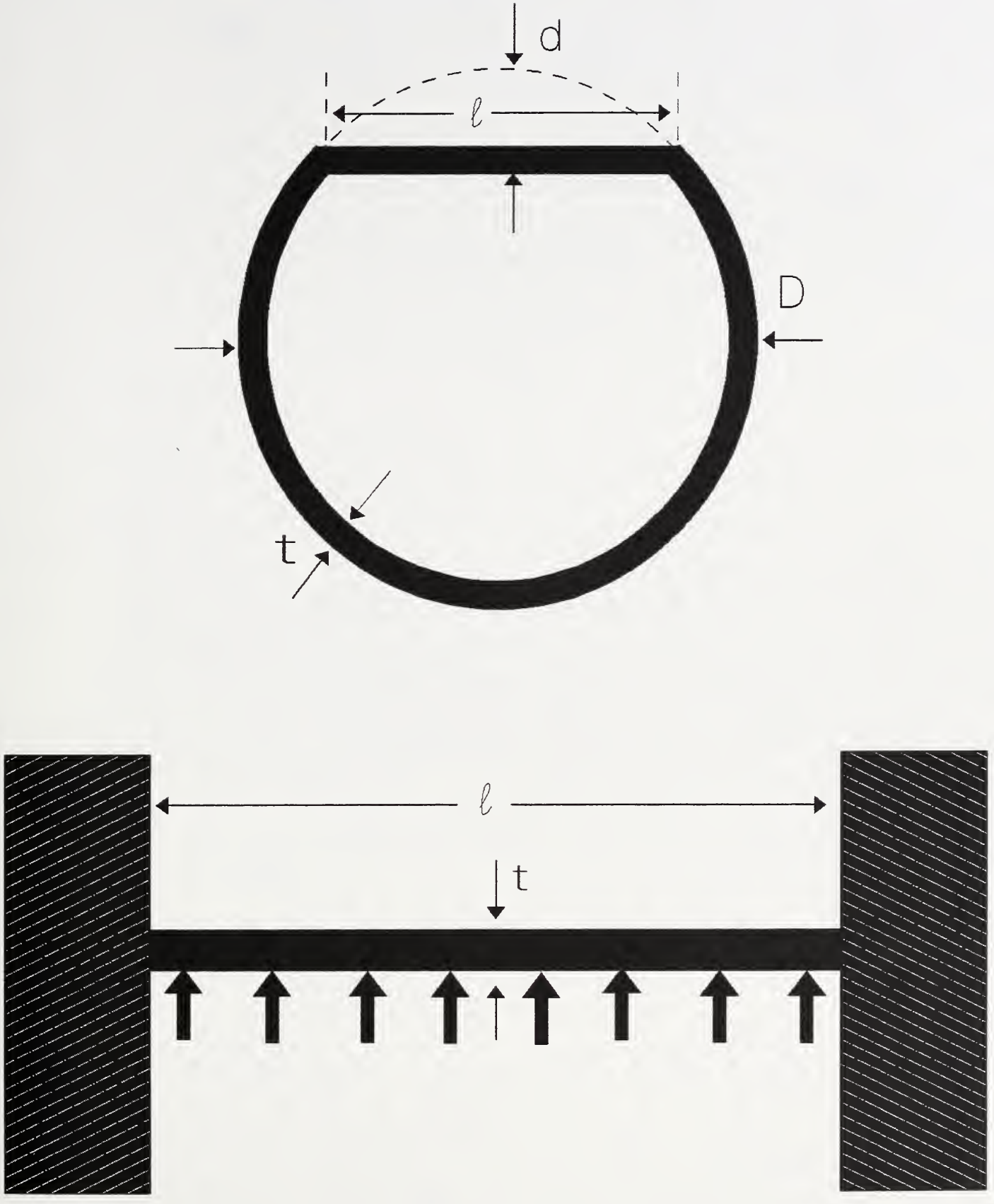

Figure B2. Dented pipe is modeled as an uniformly loaded beam built in on both ends.