National Transportation Safety Board
Internal Inspection Factual
Bellingham, Washington
Accident DCA99-MP008

Appendix 12 **Dents and gouges evaluation article provided by Olympic**

Dents and Gouges Can be Hazardous to Your Pipeline's Health

By Joe R. Fowler, Ph.D., P.E., Christopher R. Alexander,
Larry M. Connelly, Ph.D., P.E. and Paul J. Kovach, P.E.

The Problem

Backhoes, trashmen, shrimpers, boat keels, and anchors have done serious damage to many pipelines. The major New Jersey failure in the spring of 1994 is a case in point.

Often a dent, gouge, or both are inflicted on a line months or years before a major failure occurs. The damage grows by fatigue or corrosion until the catastrophic event results. Smart pigs can provide information about this damage, but operators often need experts to evaluate it.

The Solution

Stress Engineering Services, Inc. (SES) has performed considerable research to answer the following questions:

1. What dents, gouges or combinations should be treated immediately?
2. Which mechanical defects are of no concern?
3. What are the effects of dents or gouges being located on a weld?
4. Which dents or gouges may be tolerated for a specified period of time at a possibly lower operating pressure?

Our research consisted of analytical work, experimental work, and surveys of users to categorize dents and gouges. Figure 1 shows a sketch of typical kinds of dents which are commonly experienced.

The authors are with Stress Engineering Services, Inc., Houston, Texas

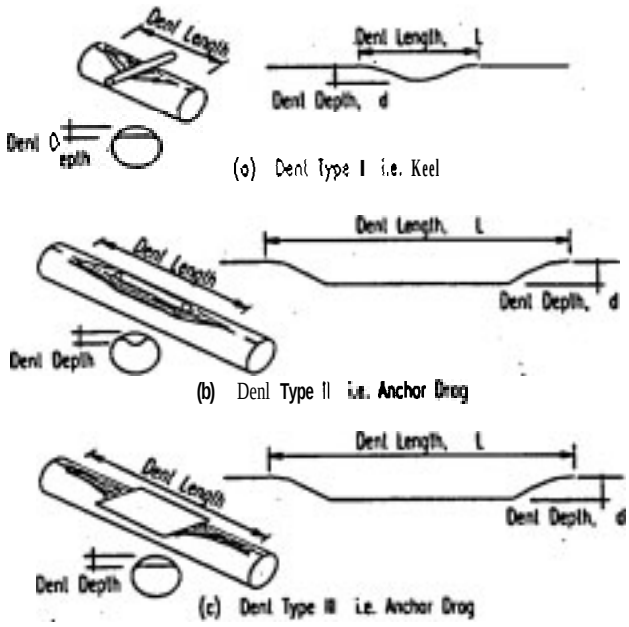

figure 1
Typical Dents

The main variables with plain dents or dents and gouges are their depth relative to the diameter, the size of the dent, the operating pressure fluctuations and whether or not a gouge is present.

To evaluate the questions experimentally, testing was done on 12" and 24" pipe. In this testing, gouges were first made in some of the pipes as shown in Figure 2. Then, the gouges were dented with the denting machine shown in Figure 3. This combination of dents and gouges creates a built-in crack, which is why gouges are so dangerous. Also, a considerable amount of testing was done without any gouges at all. The testing consisted of cyclic pressure testing the pipes in a manifold, as shown in Figure 4,

"This data teaches that deep gouges combined with dents are extremely dangerous. A gouge which is 15% of the wall may last only a few cycles."

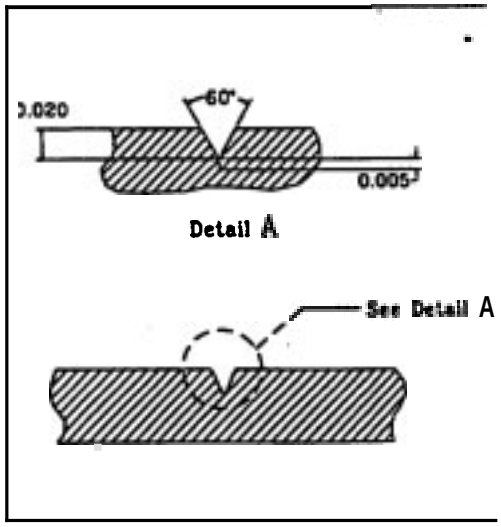

Figure 2
Mechanical Gouge
(Installed Before Denting)

Continued on back

until failure occurred. When a dent/gouge failed, it was cut out of the line, the pipe was re-welded, and testing continued.

Figure 3
Denting the Pipe

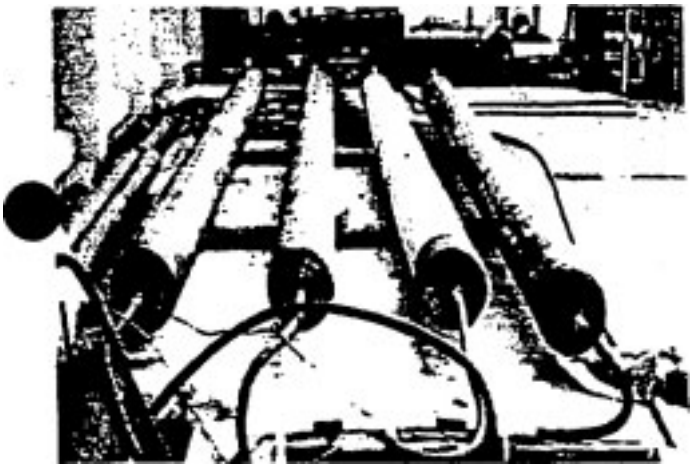

Figure 4
Pressure Cycling

SES Test Data

Figure 5 shows test data from these tests. This figure plots number of pressure cycles at a pressure variation of 1200 psi plotted against diameter to thickness ratio of the pipe (D/t). For instance, a 20" pipe with a 1/2" wall would have a D/t of 40. The data shown as a solid line are the results for a 4% residual dent. We use the term "residual dent" since a dent which is put in a pipeline with the pipeline subsequently pressurized will tend to "pop out" and result in a smaller dent than was originally put in the line.

The data shows that for a 4% residual dent with no gouge, the minimum number of cycles is about 10,000.

Also shown in Figure 5 are data for gouges of various depths, i.e., 5% of the wall thickness, 10% of the wall thickness, and 15% of the wall thickness. The G alongside some data points indicates that the gouge was ground out and checked with dye penetrant techniques to ensure all cracks had been removed.

Dents/Gouges Are Dangerous!

This data teaches that deep gouges combined with dents are extremely dangerous. A 15% gouge will last only a few cycles, in one case only one cycle (see D/t=58). A 10% gouge is also quite dangerous, and even a 5% gouge will result in significantly reduced life. Grinding the gouges out is a dramatic improvement. With a 15% gouge which is ground out, the cyclic life can be on the order of a few hundred cycles of full pressure.

Since the fatigue phenomena which causes these failures is very strongly dependent upon pressure variations (to the third or fourth power of pressure), if the pipelines sees pressure variations that are quite small, the life obtained by grinding out gouges and dents can be significant, and in many cases long enough to guarantee there will be no failures of the line.

Finite element modeling of the dents were used to answer questions about shape, size, and plastic action. Figure 5 shows typical stress concentration data from dents. This data shows that higher D/t pipes are generally more susceptible to this problem, although plasticity reduces the maximum size dent that can be obtained for the larger D/t pipe. The finite element data also teaches that the dent shape and size are not nearly as important as the dent depth.

Suggestions to Pipeline Operators

The research done by SES offers he following suggestions to operators:

- All dents/gouges should be evaluated and corrected immediately. Grinding out gouges is a dramatic improvement, but the safety aspects of grinding on an operating pipeline must be evaluated by each operator.
- Dents without gouges, particularly for gas lines are generally not a problem if the depth of the dent is less than 5% of the diameter.
- Dents which are on longitudinal welds do not seem to behave any worse than dents in the base metal.
- Dents in girth welds seem to be significantly worse than the base metal.

Stress Engineering Services, Inc. is available to help operaton provide expert evaluation of any particular dent or gouge. This evaluation may include a study of the gouge/dent shape, operating history of the line, fatigue analysis, and suggestions for repair/replacement or cause of failure.

To speak with a denf evaluation expert, contact SES at 713 - 955-2900 or fax request fo 713 - 955-2638 (Fax)

Number of Cycles versus D/t for a System with a Pressure Differential of 1200 p.s.i.

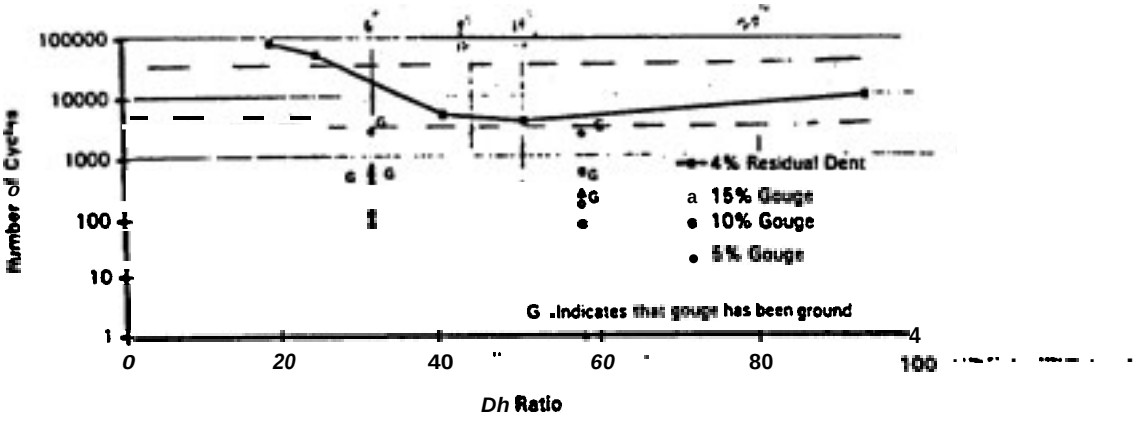

Figure 5
Experimental Data

Stress Concentration Factor as a Function of D/t Ratio and Dent Depth (d/D) for a Mean Pressure of 500 psi and Piping with 52,000 psi Yield Strength

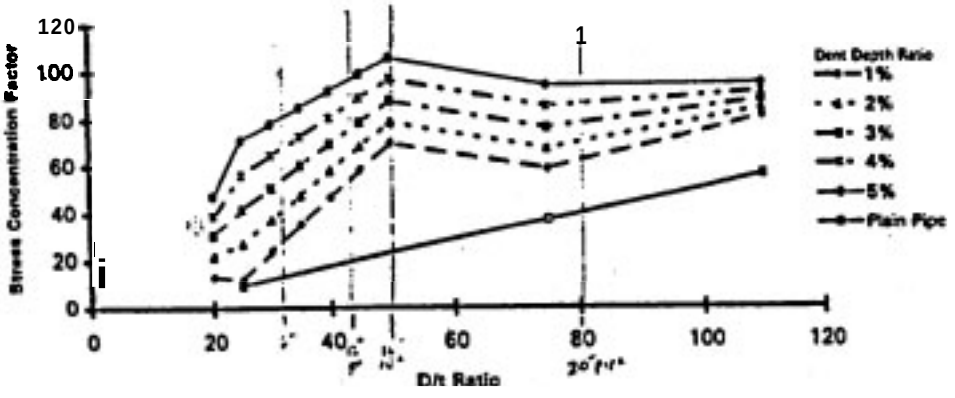

Figure 6
CalculatedStress ConcentrationFactor

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STRESS ENGINEERING SERVICES, INC.

OFFICE AND TEST LAB
13800 Westfair East Drive
Houston, Texas 77041, USA
(713) 955-2900
Telefax: (713) 955-2638

MIDWESTERN OFFICE
415 Glensprings Drive, Suite 200
Cincinnati, Ohio 45246
(513) 589-3950
Telefax: (513) 742-3124

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451.6 Pipeline Repairs

(a)

451.6.1 General. Repairs shall be covered by a maintenance plan (see para. 450.2(a)] and shall be performed under qualified supervision by trained personnel aware of and familiar with the hazards to public safety, utilizing strategically located equipment and repair materials. The maintenance plan shall consider the appropriate information contained in API Publ. 2200, API Publ. 2201, API RP 1107, and API RP 1111. It is essential that all personnel working on pipeline repairs understand the need for careful planning of the job, be briefed as to the procedure to be followed in accomplishing the repairs, and follow precautionary measures and procedures outlined in API Publ. 2200. Personnel working on repairs to pipelines handling LPG, carbon dioxide, liquid alcohol, or liquid anhydrous ammonia shall also be informed on the specific properties. characteristics. and potential hazards associated with those liquids, precautions to be taken following detection of a leak, and safety repair procedures Set forth for LPG pipelines in API Publ. 2200. Approvals, procedures, and special considerations described in API Publ. 2201 shall be observed for welding, as well as making hot taps on pipelines, vessels, or tanks which are under pressure. Piping in the vicinity of any repair shall be adequately supported during and after the repair.

451.6.2 Disposition of Defects

(a) Limits and Dispositions of Imperfections

(1) Gouges and grooves having a depth greater than 12½% of the nominal wall thickness shall be removed or repaired.

(2) Dents meeting any of the following conditions shall be removed or repaired:

(a) dents which affect the pipe curvature at the pipe seam or at any girth weld;

(b) dents containing a scratch. gouge, or groove: or

(c) dents exceeding a depth of ¼ in. (6 mm) in pipe NPS 4 and smaller, or 6% of the nominal pipe diameter in sues greater than NPS 4.

(3) All arc bums shall be removed or repaired.

(4) All cracks shall be removed or repaired.

(5) All welds found to have defects as set forth in para. 434.8.5(b) or in the appropriate pipe specification shall be removed or repaired.

(6) General Corrosion. Pipe shall be replaced. or repaired if the area is small, or operated at a reduced pressure (see para. 451.7) if general corrosion has reduced the wall thickness to less than the design thickness calculated in accordance with para. 404.1.2 decreased by an amount equal to the manufacturing tolerance applicable to the pipe or component.

(7) Localized Corrosion Pitting. Pipe shall be repaired. replaced. or operated at a reduced pressure (see para. 451.7) if localized corrosion pitting has reduced the wall thickness to less than the design thickness calculated in accordance with para. 404.1.2 decreased by an amount equal to the manufacturing tolerance applicable to the pipe or component. This applies if the length of the pitted area is greater than permitted by the equation shown below. The following method applies only when the depth of the corrosion pit is less than 80% of the nominal wall thickness of the pipe, This method does not apply to corrosion in the girth or longitudinal weld or related heat affected zones. The corroded area must be clean to bare metal. Care shall be taken in cleaning corroded areas of a pressurized pipeline when the degree of corrosion is significant.

$$L = 1.12B\sqrt{Dt_n}$$

where

$$B = \sqrt{\left(\frac{c/t_n}{1.1\,c/t_n - 0.15}\right)^2 - 1}$$

L = maximum allowable longitudinal extent of the corroded area as shown in Fig. 451.6.2(a)(7), in. (mm)

B = a value not to exceed 4.0 which may be determined from the above equation or Fig. 451.6.2(a)(7)

D = nominal outside diameter of the pipe, in. (mm)

t_n = nominal wall thickness of the pipe, in. (mm)

c = maximum depth of the corroded area, in. (mm)

(8) Areas where grinding has reduced the remaining wall thickness to less than the design thickness calculated in accordance with para. 404.1.2 decreased by an amount equal to the manufacturing tolerance applicable to the pipe or component. may be analyzed the same as localized corrosion pitting [see para. 451.6.2(a)(7)] to determine if ground areas need to be replaced. repaired, or the operating pressure reduced (see para. 451.7). ANSI/ASME B31G may be used for guidance.

(9) All pipe containing leaks shall be removed or repaired.

(b) Allowable Pipeline Repairs

(1) If practical, the pipeline should be taken out of service and repaired by cutting out a cylindrical piece of pipe containing the defect and replacing the same with pipe meeting the requirements of para. 401.2.2 and having a length of not less than one-half diameter.

and physical properties of the weld. Welding procedures on pipe not containing liquid shall be qualified in accordance with para. 434.8.3.

(3) Materials used for pipeline repair shall be in accordance with at least one of the specifications or standards listed in Table 423.1, or as otherwise required by this Code.

(4) Temporary repairs may be necessitated for operating purposes and shall be made in a safe manner. Such temporary repairs shall be made permanent or replaced in a permanent manner as described herein as soon as practical.

(5) Welded patches shall have rounded comers and a maximum dimension of 6 in. (150 mm) along the pipe axis. The patch material shall be of a similar or higher grade with a wall thickness similar to the pipe being repaired. Patches shall be limited to pipe sizes NPS 12 and less and conforming to API 5L, Grade X42 and lower. Patches shall be attached by fillet welds. Insert patching is prohibited. Special consideration shall be given to minimize stress concentrations resulting from the repair.

(6) Full encirclement welded split sleeves installed to repair leaks or otherwise to contain internal pressure shall have a design pressure of not less than the pipe being repaired and shall be fully welded, both circumferentially and longitudinally. Length of full encirclement split sleeves shall not be less than 4 in. (100 mm). If the sleeve is thicker than the pipe being repaired, the circumferential ends shall be chamfered (at approximately 45 deg.) down to the thickness of the pipe. For full encirclement split sleeves installed for repair by reinforcement only and not internal pressure containment. circumferential welding is optional. Special consideration shall be given to minimize stress concentrations resulting from the repair.

(7) Mechanically applied full encirclement repair fittings shall meet the design requirements of paras. 401.2 and 418.

(8) Welded fittings used to cover pipeline defects shall not exceed NPS 3 and shall have a design pressure of not less than the pipe being repaired.

(9) For repairs involving only deposition of a weld filler metal. welding processes shall be in accordance with the requirements of the appropriate pipe specification for the grade and type being repaired. Welding procedure qualifications shall be in accordance with para. 451.6.2(c)(2).

(10) Where repairs are made to a coated pipe. all damaged coating shall be removed and new coating applied in accordance with para. 461.1.2. Replacement pieces of pipe, welded patches, and full encirclement welded split sleeves used in making repairs shall also be coated when installed in a coated line.

(11) Pipe containing liquid shall be examined to determine that the material is sound and of adquate thickness in the areas to be affected by grinding, welding, cutting. or hot tapping operations.

(12) If the pipeline is not taken out of service, the operating pressure shall be reduced to a level which will provide safety during the repair operations.

(13) Fully welded partial encirclement half soles may be used to repair corroded areas only on pipe and shall not be used to repair leaks, gouges, dents, or other defects. The use of half soles shall be limited to pipe sizes NPS 12 or less and may only he used on pipe made prior to 1942 with a specified minimum yield strength not exceeding 40,000 psi (276 MPa). The half sole material shall be of a similar or higher grade with a well thickness not less than 87.5% or more than 125% of that of the pipe being repaired. Half soles shall have rounded comers and a maximum length of 10 ft (3 m) along the pipe axis. Half soles shall not be used across girth welds and the minimum clearance between the end of half s o l s or the ends of half soles and girth welds shall be 2 in. Combinations of a half sole and patches shall not be used in parallel around a given circumference. To ensure optimum performance of half soles, the annular space between the corroded pipe and the half sole may be filled with a hardenablc filler material such as epoxy. Special consideration shall be given to ensuring a close fit between the edges of the half sole and the pipe being repaired and to minimizing stress concentrations resulting from the repair.

451.6.3 Testing Repairs to Pipelines Operating at a Hoop Stress of More Than 20% of the Specified Minimum Yield Strength of the Pipe

(a) Testing of Replacement Pipe Sections When a scheduled repair to a pipeline is made by cutting out a section of the pipe as a cylinder and replacing it with another section of pipe, the replacement section of pipe shall be subjected to a pressure test. The replacement section of pipe shall be tested as required for a new pipeline in accordance with para. 437.4.1. The tests may be made on the pipe prior to installation provided radiographic or other acceptable nondestructive tests (visual inspection excepted) are made on all tie-in butt welds after installation.

(b) Examination of Repair Welds Welds made during pipeline repairs shall be examined by accepted nondestructive methods or visually examined by a qualified inspector.