Pipeline Group Factual Report

ATTACHMENT 20

Kiefner ERW Pipe HCA-Related Integrity Assessments

Carmichael, Mississippi
DCA 08 MP 001

DEALING WITH LOW-FREQUENCY-WELDED ERW PIPE AND FLASH-WELDED PIPE WITH RESPECT TO HCA-RELATED INTEGRITY ASSESSMENTS

by

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presented at

ETCE 2002
ASME ENGINEERING TECHNOLOGY CONFERENCE ON ENERGY

February 4-6, 2002
Houston, Texas

Paper No. ETCE2002/PIPE-29029

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INTRODUCTION

The new regulations, Part 195 Section 195.452, require that special integrity assessments be made to address potential seam-defect problems in low-frequency-welded ERW (electric-resistance-welded) pipe materials where a failure of such materials could have an impact on a high-consequence area (HCA). The spirit of this requirement appears to require action if, and only if, significant seam-related deficiencies are in evidence or if they can be reasonably anticipated. This leaves open the option of categorizing these types of pipelines by performance such that potentially problematic pipeline segments can be subjected to special (i.e., seam-quality) inspections while those that show little or no propensity for such problems can be subjected to metal loss and deformation inspections only. This document is intended to establish a systematic procedure to permit an operator to characterize the relevant ERW pipe segments as to the likelihood of significant seam-related deficiencies. The author is particularly grateful to Rich Turley of Marathon Ashland Pipe Line LLC for helping to formulate the essential steps in deciding when an integrity assessment is needed. Rich made significant inputs to Figure 1 of this document.

BACKGROUND

ERW line-pipe materials and a similar material called electric-flash-welded (EFW) pipe first appeared in the 1920s. Both processes involved making line pipe by cold forming previously hot-rolled plates or strips into round "cans" and joining the longitudinal edges of the cans by a combination of localized electrical resistance heating and mechanical pressure. The heat-softened edges were forced together extruding excess material to the outside and inside of the newly formed pipe. The excess material was immediately trimmed away leaving smooth surfaces or at most a small protrusion along the bondline. Both types of processes resulted in a narrow bondline and an associated local heat-affected zone. In many instances in the past and in all cases with modern ERW materials, the bondline/heat-affected-zone region was also subjected to a post-weld heat treatment, the purpose of which is to eliminate zones of excessive hardness from the initial welding process as such zones could be susceptible to various forms of environmental cracking. While EFW pipe is no longer made, ERW pipe is still manufactured currently, albeit by improved methods and with improved materials. Currently made ERW materials represent high-quality line pipe and offer one of the best choices of materials for pipeline construction. The need for this document arises because this was not necessarily the case in the distant past (i.e., 25 or more years ago). One must consider these older materials on a case-by-case basis, because the quality of some lots of older ERW pipe is better than the quality of others. The quality or lack thereof is not a function of the manufacturer. Both good and poor-quality lots have been made by most of the manufacturers in the time period of interest (roughly 1930 through 1980).

Prior to 1962, all ERW materials and EFW pipe were made by means of d.c. or low-frequency a.c. current (up to 360 cycles) using low-carbon steels made in open hearth or electric-arc furnaces and cast into ingots. The d.c. or low-frequency a.c. currents used for resistance heating required intimate contact between the rolling electrodes and the "skelp" (i.e., the plate or strip used to form the cans). Dirt, grease, scale, or other oxide films on the skelp could and often did cause enough interference to prevent adequate heating at the bondline interface. Momentary reductions or loss of current could and often did result in isolated or repeated areas of non-bonding called "cold welds". Cold welds could be partly through the wall thickness or all of the way through. Even if a through-wall cold weld was formed, it might not result in a leak, because typically such areas were completely filled with a scale that formed from the surfaces being exposed to oxygen while at a high temperature. A significant number of cold welds in close proximity could sufficiently reduce the strength of the bondline that a rupture would occur when the pipe was subjected to pressurization. In these cases, a hydrostatic test to a sufficiently high pressure if performed by the manufacturer at the pipe mill or the user prior to putting the pipeline into service would usually eliminate the most injurious areas. An adequate test in this respect would be one carried out at 90 percent of the specified minimum yield strength (SMYS) for a pipeline to be operated at 72 percent of SMYS. Prior to 1960, many sizes and grades of ERW pipe were tested by the manufacturer to levels of only about 75 percent of SMYS, and prior to 1970, it was typical for liquid pipelines to be tested to no more than 1.1 times their maximum operating pressure (MOP).

Other phenomena that would result in poorly or weakly bonded ERW materials included electric power fluctuations during welding, poorly trimmed skelp, cambered or twisted skelp, and inadequate or excessive mechanical pressure at the instant of bonding. Running skelp too fast through an a.c. welder, for example, could cause the heat to fluctuate with the current cycle resulting in a periodic variation in properties along the seam. When broken along the bondline, these variations are made visible in terms of the fracture surface characteristics. The resulting pattern is referred to as "stitching". A stitched weld does not necessarily create a pipeline-integrity problem because a defect of some kind other than the stitching itself must be present to start a fracture in a stitched bondline. However, a stitched bondline is generally characterized by low toughness, and only a relatively small defect may be required to start a fracture. Poorly trimmed skelp may contain edge defects that end up on the bondline. Cambered or twisted skelp can result in offset edges at the bondline. The offset can be significant, reducing the net thickness by 30 to 40 percent in extreme cases. Unfortunately, offset edges were seldom caught by visual inspection because the outside surface trim tool removed the excess material from one side leaving the visible mismatch at the ID surface where it was hard to detect by visual inspection.

Starting in 1962, manufacturers began to convert ERW mills from low-frequency-welding equipment to high-frequency equipment (450,000 cycles). After 1978, it is believed that few if any low-frequency welders were still being used. With the use of high-frequency current, the problem of contact resistance is virtually nonexistent. As a result, high-frequency-welded pipe tends to be relatively free of the bondline defects that were common in the low-frequency and d.c.-welded material.

The performance of ERW materials has improved steadily with time as shown in Table 1. This table illustrates that the number of test failures per mile decreased from levels as high as 6.5 per mile in the 1940s to a level of 0.01 per mile in 1970 for pipelines tested to levels of 90 percent of SMYS or more. Not only has the ERW process itself improved, but cleaner, tougher steels have been developed as the result of the conversion throughout the 1970s and 1980s to basic oxygen steel making, continuous casting, microalloying, and thermomechanical processing. These trends have virtually eliminated three other potential problems associated with ERW seams, low-heat-affected-zone toughness, hook cracks, and grooving corrosion. These potential problems are not welding problems per se, but they have occurred in conjunction with ERW seams in the past. It is safe to say that all low-frequency* and d.c.-welded materials possess bondline regions that are prone to low toughness and brittle-fracture behavior. This is because there was no way to prevent grain coarsening in the heat-affected zones. The enlarged grains invariably made the weld zones less tough and more prone to brittle fracture than the parent material. To some extent, this tendency was reduced with the use of high-frequency welding because a smaller volume of material is heated than in the case of a low-frequency or d.c. process. In addition, by the 1970s most manufacturers were using microalloyed, thermomechanically treated skelp. These steps prevented or eliminated grain coarsening and thereby resulted in bondline regions of ERW pipe that are as tough as the parent metal.

The use of cleaner steels (i.e., with greatly reduced sulfur contents) has virtually eliminated the risks of hook cracks and grooving corrosion. The precursors for hook cracks are non-metallic inclusions, primarily manganese sulfide "stringers". These flattened, non-metallic inclusions are formed during hot rolling of plate or skelp. In general, they reduce the ductile toughness of the steel even in their normal position (i.e., layers interspersed between the rolling-elongated grain structure of the steel). In this position, they can cause poor through-thickness properties that inherently reduce ductile-fracture tearing resistance but not necessarily the yield or tensile strength of the material. Near an ERW bondline, however, these weak layers become reoriented such that they are subjected to tensile hoop stress when the pipe is pressurized. The layers may be of sufficient extent or so closely associated that the resulting planes of weakness separate, forming J-shaped (i.e., hook) cracks that curve from being parallel to the plate surfaces near mid-wall to being nearly parallel to the ERW bondline at the OD or ID surface. These cracks can be up to 50 percent of the wall thickness in depth and up to several inches in length.

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* Note that low frequency as used herein refers to the range of 360 Hz or less, typically used with "Yoder" mills prior to 1980. It is recognized that modern high-quality ERW pipe can be made with a variety of frequencies, though usually these are much higher than 360 Hz (e.g., 150 to 450 KHz).

They are in effect a pipe defect, not a weld defect, and their behavior is governed more by parent pipe toughness than bondline toughness. They tend to be much larger than bondline defects in the older materials because the low toughness of the bondline regions assures that no large defects can exist after a hydrostatic test to a reasonably high-pressure level.

Grooving corrosion is also a phenomenon that results from the sulfide-inclusion problem. The sulfide layers appear to make the material immediately adjacent to the bondline more susceptible to corrosion than the surrounding material. As a result, when corrosion (external or internal) occurs in an area that includes the bondline, the corrosion rate will be higher in the bondline region than in the parent material. The frequent result of such corrosion is the creation of a long, sharp V-notch along and centered on the bondline. In no case should such corrosion be treated or evaluated as one would treat or evaluate pitting corrosion in the parent pipe. The resulting anomaly is equivalent to a sharp crack in a relatively brittle material with a depth of penetration that is difficult if not impossible to accurately measure. It is worth noting that high-frequency-welded ERW pipe may be susceptible to hook cracks or grooving corrosion or both. However with the advent of the use of materials with even lower sulfur contents from the 1980s onward, one can expect that these problems will be less extensive than is likely in the case of the older low-frequency and d.c.-welded materials.

HOW TO DETERMINE IF AN ERW SEAM INTEGRITY ASSESSMENT IS NECESSARY

Review of the Segment

The first item on the agenda should be a thorough review of the segment at issue. The list of parameters to consider includes:

- Diameter
- Wall thickness
- Grade
- Age
- Manufacturer
- MOP
- Hydrostatic-test history
- Service ruptures or leaks
- In-line-inspection history
- Coating type

Cathodic-protection history
Typical operating pressure cycles
Type of product transported
Classification of seam type (low-frequency a.c.-welded ERW, d.c-welded ERW, electric flash welded).

The roles that those parameters play in the determination of the need for integrity assessment are discussed below roughly in order of their importance. An example of a decision-making format for determining whether or not an ERW seam-integrity assessment plan is necessary is shown in Figure 1. Because it can be anticipated that an operator's plan for integrity assessments of ERW pipe will be audited by the Office of Pipeline Safety and/or state regulators, the plan should include every ERW or flash-welded segment affecting an HCA. In many cases, it may be sufficient to note that the segment was considered but eliminated with no need for further analysis because

- It is comprised of a newer, high-quality material having none of the potentially problematic characteristics that occasionally affect the older materials,
- The operating pressure level is so low that the risk of a seam rupture is negligible, and
- The track record of the segment embodies no evidence of any seam-related problems.

Service-Incident History

The first thing that should be considered when one is trying to decide whether or not a special seam-integrity assessment is needed for a segment of ERW pipe is the history of service leaks or ruptures that resulted from seam-related problems. The incidents should be categorized as follows.

Service Incidents Involving an ERW Seam in Line Number XX

		Pipe Data							
Mile Post or Survey Station	**Date of Incident**	**Diameter**	**Wall Thickness**	**Grade**	**Manufacturer**	**Year Installed**	**Pressure at Failure**	**Leak or Rupture**	**Cause of Failure**

Causes of failure typically would be:

(1) Bondline defect

(2) Hook crack with no fatigue crack growth

(3) Hook crack with fatigue crack growth

(4) Offset skelp edges with no fatigue crack growth

(5) Offset skelp edges with fatigue crack growth

(6) Selective seam (grooving) corrosion

(7) Other (describe)

(8) Unknown.

If either a fatigue-related failure or a selective seam-corrosion (grooving corrosion) failure has occurred in the segment and that failure (or failures) occurred after the segment had been tested to a pressure level of at least 1.25 times the MOP, a seam-integrity-assessment plan should be developed. The reassessment interval should be based on the crack growth rates or corrosion rates that can be inferred from past failures or from similar circumstances on other pipelines. If any of these types of failures have occurred, further analyses should be made of the times of previous tests in relation to the times of the previous failure to see whether or not the failures were of a time-dependent nature. To be excluded from a seam-integrity-assessment plan, a segment must either have no recorded seam-related service failure, or any seam-related service failure must be entirely explainable as a non-time-dependent event (e.g., the failure occurred because the pipeline was accidentally overpressured by an amount approaching or exceeding 1.25 times the MOP).

Service-Pressure History

First and foremost, the maximum operating pressure (MOP) should be considered in terms of percent of the specified minimum yield strength (SMYS). Is it relatively high (50 to 72 percent of SMYS), intermediate (30 to 49 percent of SMYS), or low (less than 30 percent of SMYS)? Also, what does the pressure spectrum look like over a 30-day period? A 1-year period? Has the type of operation changed so that today's pressure cycles are more aggressive than before? Aggressiveness of pressure cycles can be crudely categorized for particular environments as follows:

Annual Pressure (Hoop Stress) Cycle Spectrum
(Number of Cycles in Each Stress Group*)

Range, % SMYS	Very Aggressive	Aggressive	Moderate	Light
65 to 72	20	10	2	0
55 to 65	40	20	4	0
45 to 55	100	50	10	0
35 to 45	500	250	50	50
25 to 35	1000	500	100	100
20 to 25	2000	1000	200	200

If fatigue failures have occurred or if the pressure spectrum falls into the aggressive or very aggressive category, a seam-integrity-assessment plan should be developed. The reassessment interval should be based on crack growth rates that can be inferred from past failures or from similar circumstances on other pipelines. To be excluded from a seam-integrity-assessment plan, a segment must have exhibited no failure involving fatigue crack growth and its pressure cycle aggressiveness must be shown by analysis to be incapable of causing the margin of safety demonstrated by its last hydrostatic test to be eroded within twice the expected life of the pipeline.

Test-Pressure History

The test-pressure history of each segment should be reviewed and the following information should be compiled.

* These numbers may need adjustment based on actual experience in a particular pipeline since the crack growth rates may vary. These results apply to a 16-inch OD by 0.250-inch w.t. X52 pipeline for a particular set of crack-growth parameters. Also, the operator who wishes to assess a given spectrum using these example ranges might consider its equivalence to one of these spectra by means of Miner's Rule. For example,

$\frac{n_2}{40} + \frac{n_2}{40} + \frac{n_3}{100} + \cdots + \frac{n_6}{2000} = X$ where n_1, n_2, etc. are the numbers of cycles in the spectrum in each of the above ranges. If X is less than 1, the spectrum is less aggressive than the "very-aggressive" spectrum and should be comparable to the particular less-aggressive spectrum where X becomes close to 1.

Test Pressure History of Line XX

			Maximum Test Pressure				
Segment No.	**Test No.**	**Date of Test**	**% SMYS**	**% MOP**	**No. of Seam-Related Test Failures**	**Did Pressure Reversals Occur? Yes/No**	**Were the Causes of the Seam-Related Test Failures Determined? Yes/No**

If the test was conducted after the pipeline had been in service, special note should be taken of any seam failures (leaks or ruptures) that occurred well below 1.25 times the MOP or below the level of a prior test. These may be the result of fatigue-enlarged defects or selective seam corrosion.

The causes of all test breaks or leaks should be determined in any new test and studied, if known, in the case of prior tests. The expected causes will be the same as those discussed previously under service-incident history. Failures that occur at the highest pressure that the pipe has ever experienced are often associated with manufacturing defects. Large numbers of failures often lead to "pressure reversals" where defects fail at lower levels than they were subjected to during a prior pressurization. If enough pressure reversals occur, the likelihood of a reversal of a given size can be predicted.

If the investigations of test failures indicate the presence of time-dependent defect growth (i.e., fatigue or selective seam corrosion), a seam-integrity-assessment plan should be developed. The reassessment interval should be based on crack growth rates or corrosion rates that can be inferred from past failures or from similar circumstances on other pipelines. If hook cracks or offset skelp edges are revealed by test breaks but no evidence of fatigue is found, the nature of pressure cycles on the system should be reviewed to see if fatigue could become a problem. To be excluded from a seam-integrity-assessment plan, a segment should exhibit no test breaks when tested to a pressure level of 1.25 times MOP. Other scenarios that may warrant exclusion could be those in which test breaks occurred but only at test pressure levels well in excess of 1.25 times the MOP and in which large pressure reversals are extremely unlikely.

Age of the Pipeline

As seen in Table 1, the performance of ERW pipe materials improved steadily between 1940 and 1970. This trend is believed to be a consequence of technological improvements in the manufacturing process. While the age of a pipeline segment alone cannot be used to determine whether or not it should be subjected to a seam-integrity inspection, the pipeline operator should consider whether or not a combination of age-related factors and other factors points to the need for a seam-integrity assessment. For example, a 1940s-vintage pipeline may warrant such an assessment if it is subjected to aggressive pressure cycles or if it is found to be significantly affected by corrosion-caused metal loss.

Corrosion

If either external or internal corrosion is found on an ERW segment, the potential exists for selective-seam corrosion. Selective-seam corrosion will occur if an area of metal loss overlays the bondline region and if the bondline region is susceptible. One can expect that an ERW seam made prior to about 1980 will be at least somewhat susceptible to selective-seam corrosion, although susceptibility to selective-seam corrosion varies widely from one material to another.

A pipeline with a known selective-seam-corrosion problem is clearly a candidate for a seam-integrity assessment. A bare pipeline, a pipeline with poor coating, or an extensively disbonded coating could be a candidate, though it may be possible to establish with electrical-survey measurements and excavations whether or not external selective-seam corrosion is likely. To be able to exclude a segment from a seam-integrity-assessment plan, the operator should have a high degree of confidence that no selective-seam corrosion is occurring. Transporting only non-corrosive products assures that no internal corrosion can affect the seams. The absence of internal corrosion can be verified by a metal-loss inspection without the need for a seam-specific assessment. Even if some internal corrosion is occurring, the operator may be able to ascertain that all seams are in non-affected orientations. From the standpoint of external corrosion, it is possible that the responses required by metal-loss inspection will be adequate to demonstrate with a high degree of certainty that no selective-seam corrosion is occurring. Also, pipelines laid with the seams in the top quadrant of the pipe may be less susceptible to external selective seam corrosion than those where no preference was given to the clock position of the seams.

SUMMARY

It appears possible to separate ERW pipe segments into three categories based on attributes of the segments and the findings of integrity assessments for metal loss. The categories are:

(1) Clear-cut evidence exists that shows that time-dependent deterioration of seam anomalies is occurring. Category-1 segments will require a special seam-integrity-assessment plan.

(2) No direct evidence of ERW seam deterioration exists, but conditions of operation and attributes of the segment suggest that seam deterioration is likely. For pipeline segments in this category, studies of the attributes, the operations, and the results of other integrity assessments should be made to determine whether or not a special seam-integrity-assessment plan is necessary.

(3) On the basis of the attributes of the segment, the operating conditions, the history of the segment, and all evidence generated by other integrity assessments, it is reasonably clear with a high degree of certainty that no time-dependent seam deterioration is occurring. No special seam-integrity-assessment plan is needed for segments in this category.

The various types of data outlined in this document should be gathered and assessed to establish the appropriate category for each ERW pipeline segment. Detailed analyses as suggested herein can be used to determine whether or not those segments that fall into Category 2 will require a special seam-integrity-assessment plan.

TABLE 1. SEAM FAILURES DURING HYDROSTATIC TESTS ON ERW LINE PIPE (INCLUDES SOME DC WELDED AND SOME FLASH WELDED)

Case No.	Diameter, inches	Wall Thickness, inch	Grade	Year of Manufacture	Test Stress Level, percent SMYS	Miles Tested	Number of Failures	Test Failures per Mile
1	20	0.375	B	1943	99	67	434	6.48
2	20	0.312	B	1943	101	548	267	0.49
3	6-5/8	0.188	B	1946	73	71	45	0.63
4	6-5/8	0.188	B	1946	73	104	5	0.05
5	8-5/8	0.203	B	1946	90	63	2	0.03
6	6-5/8	0.188	B	1947	82	62	25	0.40
7	12-3/4	0.250	X42	1950	90	75	29	0.39
8	12-3/4	0.250	X42	1950	90	34	39	1.15
9	12-3/4	0.250	X42	1950	91	14	1	0.07
10	12-3/4	0.250	X42	1950	90	24	8	0.33
11	12-3/4	0.250	X42	1950	90	61	2	0.03
12	12-3/4	0.250	X42	1951	91	40	37	0.93
13	14	0.250	X52	1952	108	75	43	0.57
14	16	0.281	X52	1952	109	69	19	0.28
15	24	0.312	X52	1952	106	180	8	0.04
16	8-5/8	0.203	X42	1954	90	90	6	0.07
17	8-5/8	0.203	X42	1954	91	102	0	0
18	12-3/4	0.250	X52	1955	91	26	0	0
19	12-3/4	0.219	X52	1955	91	30	6	0.20
20	12-3/4	0.219	X42	1955	91	38	2	0.05
21	10-3/4	0.250	X46	1955	91	13	0	0
22	10-3/4	0.203	X46	1955	89	157	2	0.01
23	12-3/4	0.250	X52	1955	60	195	17	0.09
24	30	0.375	X52	1957	113	344	28	0.08
25	8-5/8	0.250	X42	1957	79	90	5	0.06
26	24	0.312	X52	1959	81	373	0	0
27	24	0.312	X52	1959	81	214	0	0
28	20	0.250	X52	1959	85	99	2	0.02
29	18	0.250	X52	1959	76	148	0	0
30	16	0.250	X52	1959	69	67	7	0.120
31	8-5/8	0.188	B	1959	72	176	2	0.01

Case No.	Diameter, inches	Wall Thickness, inch	Grade	Year of Manufacture	Test Stress Level, percent SMYS	Miles Tested	Number of Failures	Test Failures per Mile
32	6-5/8	0.218	B	1959	48	100	1	0.01
33	16	0.219	B	1959	74	112	5	0.04
34	8-5/8	0.2196	X52	1960	94	332	123	0.38
35	8-5/8	0.219	X52	1960	94	182	12	0.07
36	8-5/8	0.219	X52	1960	94	172	54	0.31
37	8-5/8	0.219	X52	1960	94	181	98	0.54
38	6-5/8	0.188	X52	1964	70	89	3	0.03
39	8-5/8	0.188	X52	1964	90	138	10	0.07
40	16	0.312	X52	1968	90	162	1	<0.01
41	8-5/8	0.219	X52	1968	76	106	0	0
42	12-3/4	0.250	X52	1968	91	113	1	<0.01
43	16	0.312	X52	1970	90	174	0	0
44	16	0.271	X60	1971	90	94	0	0

Long Seam Susceptibility Criteria For Baseline Assessment