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Pacific Gas and Electric Company
Metallurgical Laboratory Test Report
Technical and Ecological Services
3400 Crow Canyon Road
San Ramon, CA 94583

SUBJECT: METALLURGICAL EVALUATION OF CRACKING IN LINE 109 SEAM WELDS

BACKGROUND

Recently cracking was discovered in the longitudinal seam welds from 2 spools removed from line 109. The spools were removed from the line to evaluate and characterize the girth weld defects when the seam weld cracking was discovered. Spool #1 was received from [redacted] of the R&D Department, and Spool #2 was received from [redacted] of TES. No further identification of these spools was provided. However, the spools are believed to be from gas transmission line 109 which was installed in 1935. We were charged with determining the origin of the cracks.

VISUAL EXAMINATION

According to the drawing shown in **Figure 1**, the belled area extends from the fusion line at the girth weld root to a total distance of 3.125-inches away. The first 1.5-inches from the root is a uniform diameter to accommodate the backing ring, and the remaining 1.625-inches is the transition region where the spool tapers down to the nominal 22-inch OD dimension. For Spool #1 the seam weld cracks extended from the girth weld to a distance of 2.8-inches away, which was entirely within the belled region. In Spool #1 there were three discrete cracks; one was 1.6-inch long and the other two were each 0.3-inch long. Macroetching the inside surface of the pipe showed all the cracks were in the seam weld metal. In Spool #2 there were 5 cracks in the seam weld metal. The largest was about 1.9-inches long and the other four were each less than 0.25-inch long. Here also the cracks did not extend beyond the belled region.

For Spool #1 the deepest crack measured was 44.1% of the local wall thickness. For Spool #2 the deepest crack found was adjacent to the girth weld and was 76.5% of the local wall thickness. The crack depth data is itemized in **Table 1** below.

pc: [redacted]

Date: 12/23/96

Tested by: [redacted]

Prepared by [redacted]

Approved b[redacted]

TES 24-Hour Service Line: 8-251-3197 or (510) 866-3197

962116a/mcvc:

Table 1 - Depth Dimensions Of Seam Weld Cracks

Sample ID	Crack Through-Wall Dimension	Local Thickness*	% Of Local Thickness
Spool #1, Location A	0.148-inch	0.370-inch	40.0%
Spool #1, Location B	0.150-inch	0.340-inch	44.1%
Spool #2, Location A	0.116-inch	0.311-inch	37.3%
Spool #2, Location B	0.190-inch	0.314-inch	60.5%
Spool #2, Location C (Nearest The Girth Weld)	0.309-inch	0.404-inch	76.5%

* Includes Local Weld Reinforcement

METALLURGICAL EVALUATION

Macroscopic views of the seam weld cracking in Spool #1 is shown in **Figure 2** and in **Figure 3**. The crack in **Figure 2** is a cross section through the middle of one of the 0.30-inch long cracks. The section plane was about 0.75-inch from the fusion line of the girth weld, as measured from the root. The crack in **Figure 3** is a cross section through the 1.6-inch long crack. This section plane was about 2.25-inches from the fusion line of the girth weld, as measured from the root. Microscopic examination of the cracking revealed that these seam welds were made with two layers deposited from the outside, and that the cracking was confined to the first (root) layer only. The microstructure of the first layer was renormalized, apparently by the heat from deposition of the second layer. The crack propagated in a transgranular manner, and the crack tip was relatively blunt. The crack that was closest to the girth weld (shown in **Figure 2**) followed a trail of oxides/inclusions in the weld metal, as shown in **Figure 4**. A sample of the larger crack was broken open at liquid nitrogen temperature to examine the crack surfaces. There was no evidence of beach marks or other indicators of progressive crack growth on the fracture surface. The fracture surfaces were covered with a uniform layer of corrosion products, as shown in **Figure 5**. No evidence of high temperature oxide scale was found inside any of these cracks, nor did we find any evidence of repair welds made from the inside surface.

Macroscopic views of the cracks found in Spool #2 are shown in **Figure 6** and **Figure 7**. **Figure 6** shows the deepest crack found in the sample. As reported in **Table 1** it was 76.5% of the local wall thickness. The section plane was approximately 0.50-inch from the fusion line of the girth weld, as measured from the root. The macro shows a repair weld was made from the inside surface, and that there are defects associated with the repair. Although when we received the sample the seam weld crown was ground off and was smooth, the bead placement and shape appears to indicate repair welding was also done from the outside surface. **Figure 7** is a cross section of the same crack shown in **Figure 6** except at a location farther from the girth weld (about 1.8-inch from the girth weld). The macros in **Figure 6** and **Figure 7** show that the cracks are not in the repair weld metal but are in the original SAW weld metal, which is now the heat affected zone of the repair weld at the inside surface. The cracks propagated in a transgranular path, and the crack tips were very blunt. No evidence of high temperature oxide scale was found inside any of these cracks. There was no evidence of beach marks or other indicators of cyclic crack growth on the fracture surface.

DISCUSSION

A typical unrepaired seam weld is shown in **Figure 8.** Note that this seam was made with a single pass submerged arc weld. Based on our experience this is typical construction practice. The photomacrographs in **Figure 2** through **Figure 7** show that both of these seam welds differ from this configuration indicating they were repaired. The repairs were done with the manual shielded metal arc process, as evidenced by the coarse ripple structure on the outside surface, and the limited penetration compared to the submerged arc process. The seam weld repairs were completed before the girth weld was made because the repairs at the inside surface were found to be ground smooth to accommodate the backing ring. In considering the cost of manufacturing, it is also likely that the belled regions were made by cold expansion rather than at elevated temperature.

The repairs in Spool #1 were made from the outside surface. The lack of slag or high temperature oxide scale inside the crack indicates the crack was not exposed to elevated temperature for very long, if at all. The absence of beach marks, striations, or other indicators of cyclic crack growth such as progressive oxidation rules out fatigue as the cause. The fact that the cracking followed a trail of oxides/inclusions in the weld metal indicates the crack was related to the solidification of the first layer of the weld metal repair. This trail of oxides/inclusions could then act as a weak path in the material. The absence of slag inside the crack indicates the crack was probably not present before the second weld layer was deposited. One scenario that accounts for all the evidence is that the crack was formed shortly after the second layer of the repair weld was solidified but still hot. We believe the cracks in the spool are fabrication defects that have been present since the line was installed in 1935. The reason for repair of the original submerged arc weld is unknown, but likely to be because of cracking during the cold expansion or "belling" process.

The cracking in Spool #2 propagated in a transgranular path, which tends to support their being created at a low temperature. In a weld a high temperature failure would tend to favor an intergranular or interdendritic path. Also, if the cracking occurred at the temperatures associated with welding, we would have expected to see high temperature oxide scale along the crack surfaces. The crack opening displacement varied along the length of the crack. The COD is greatest adjacent to the girth weld (**Figure 6**) and decreases in size with increasing distance from it (**Figure 7**). The strain associated with the cold expansion or belling operation is uniform until 1.5-inches away from the circumferential joint, at which point it starts decreasing as the pipe transitions back to the 22-inch nominal diameter (see **Figure 1**). The decreasing COD in the cross sections seem to track well with the decreasing strain in the transition. All the evidence points to cracking that occurred at low temperature. Since there was no evidence of beach marks, striations or other indicators of cyclic progression, fatigue is unlikely. The evidence in Spool #2 indicates these cracks were formed during fabrication, most likely during cold expansion. The misalignment of the top and bottom repair welds may indicate that there was a greater degree of cracking elsewhere and those cracks got the most attention during the repair process. For whatever reason the cracks seen here were omitted from the repair process.

CONCLUSIONS

The cracking in spool #1 was located in a manual SMAW repair weld made to the original SAW seam. The original seam weld likely cracked during the cold expansion process. We believe the cracking in the repair weld was caused by the fabrication process, meaning the crack has been present since original construction in 1935. The cause of the cracking is believed to be related to the solidification of the first layer of the repair weld metal, wherein impurities such as oxides and inclusions were concentrated along the last region to solidify. This created a weak local area which cracked probably after deposition of the second layer.

We believe the cracking in Spool #2 was located in the original SAW weld metal and was caused by the cold expansion or belling process during fabrication. This conclusion was arrived at primarily by the presence of large crack opening displacements in the belled area, and the absence of consistent evidence to support any other low temperature failure mechanism. Before the pipe was placed into service an attempt to repair the cracking was made but not all the original weld metal cracks were removed. The reason for this is unknown.

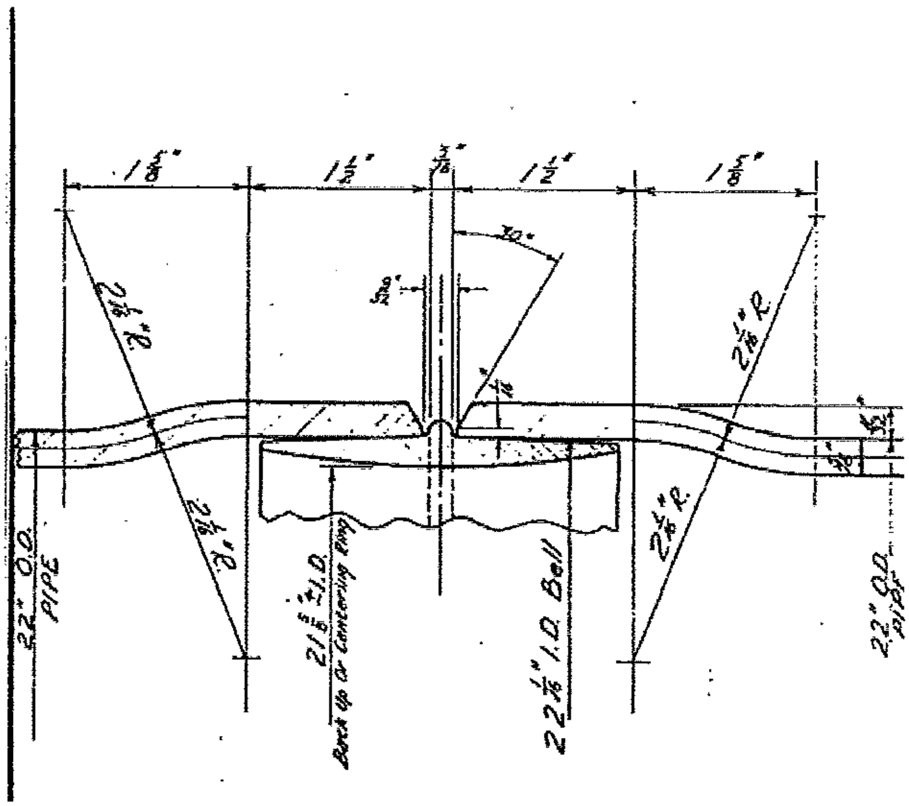

Figure 1 - Typical double-bell chill ring joint configuration.

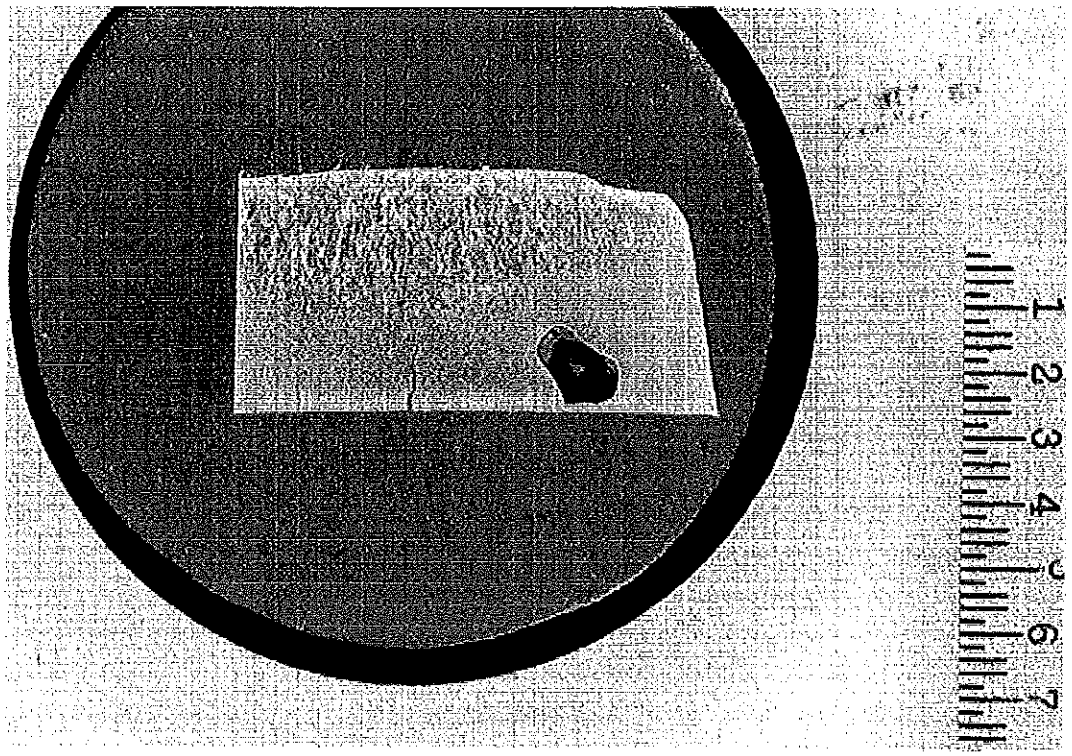

Figure 2 - Cross section through a 0.30-inch long crack in Spool #1. The depth was 0.150-inch or 44.1% of the 0.340-inch local wall thickness. Magnification is 4.0X.

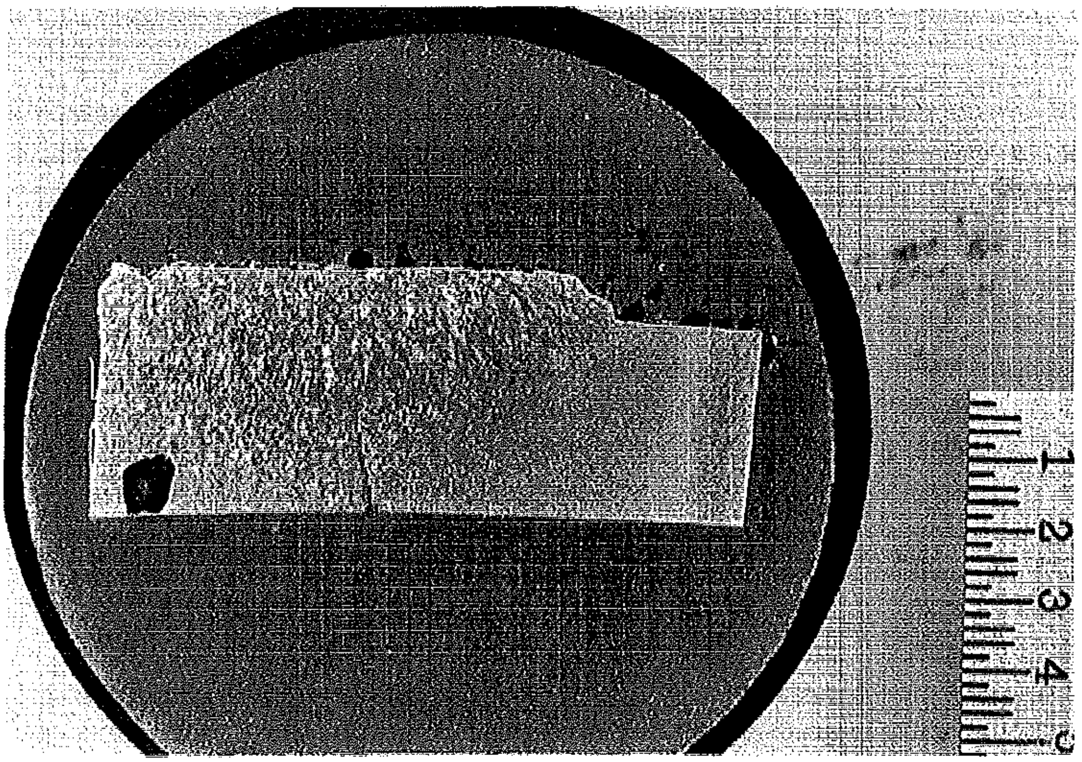

Figure 3 - Cross section through the 1.6-inch long crack in Spool #1. The depth was 0.148-inch or 40.0% of the 0.370-inch local wall thickness. Magnification is 4.3X.

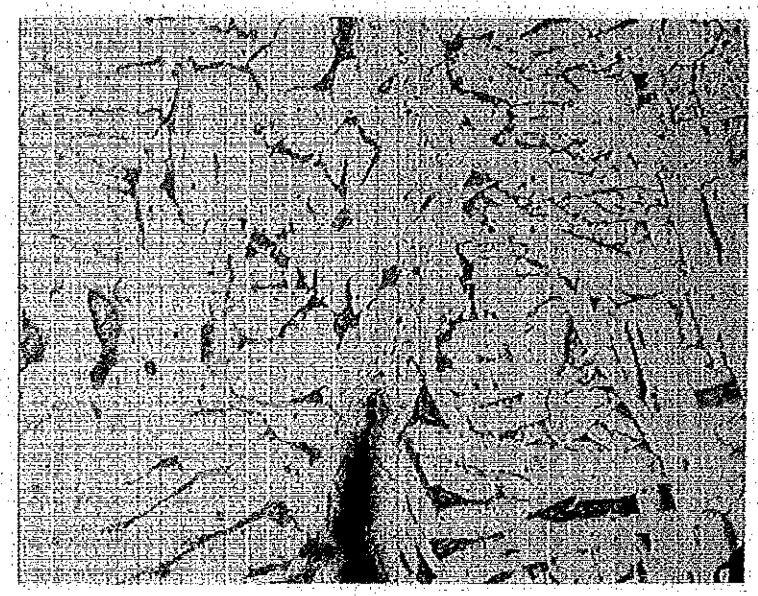

Figure 4 - Photomicrograph of the crack tip in Spool #1 showing that the crack followed a trail of oxides/inclusions in the renormalized weld metal. Magnification is 500X.

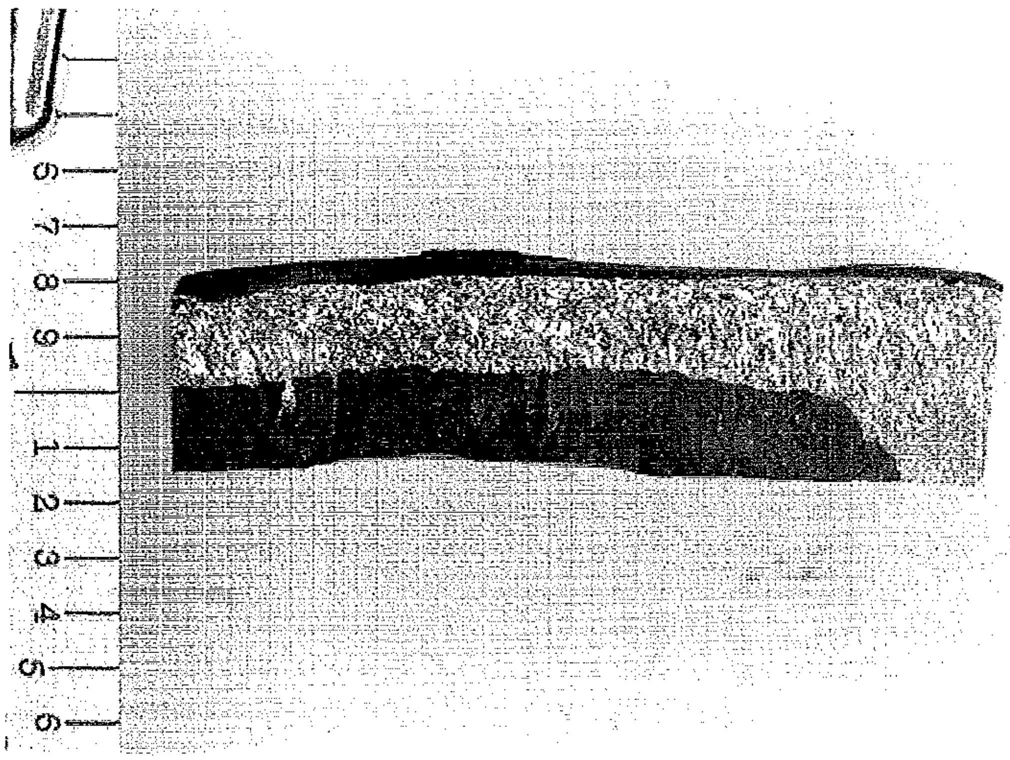

Figure 5 - Fracture surface of the 1.6-inch long crack shown in **Figure 3.** No evidence of in service progression was detected. Magnification is 3.4X.

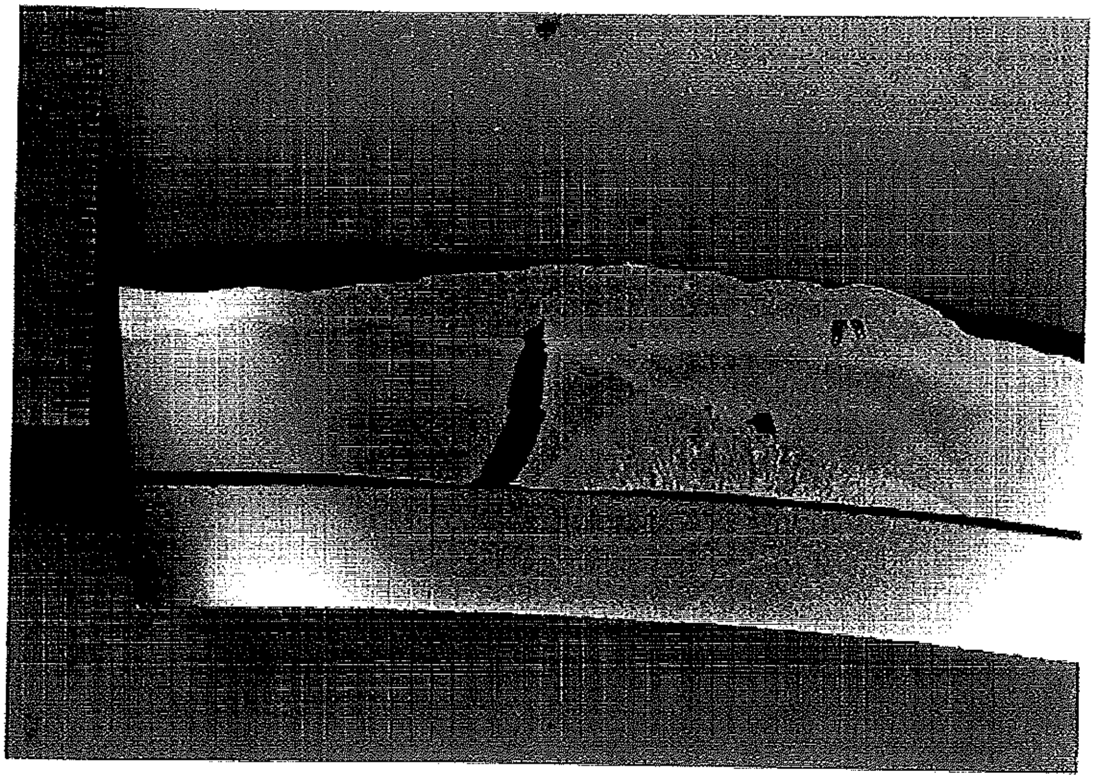

Figure 6 - Cross section through the deepest crack found in Spool #2. It was 0.309-inch deep, or 76.5% of the 0.404-inch local wall thickness. Note the large crack opening displacement. The girth weld can be seen at the OD surface. A weld repair was made from the inside surface. Magnification is 3.3X

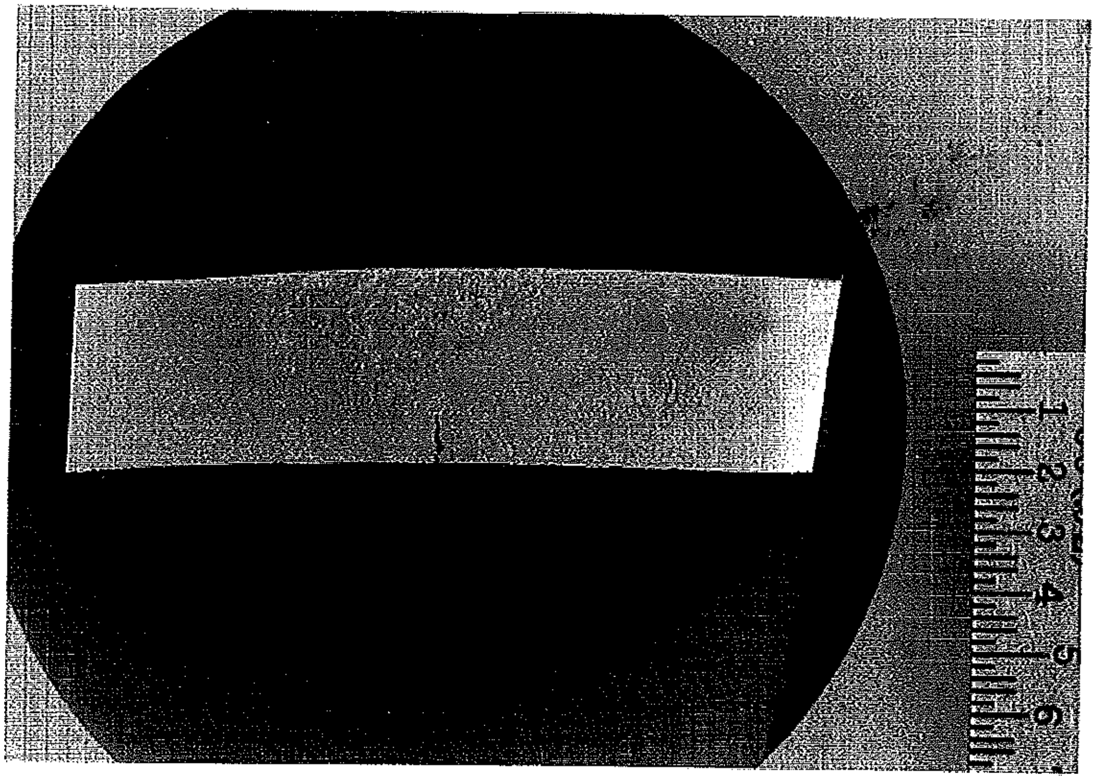

Figure 7 - Same crack as shown in **Figure 6**, except in the transition region of the belled area. The COD is noticeably smaller than that shown in **Figure 6**. Magnification is 3.7X.

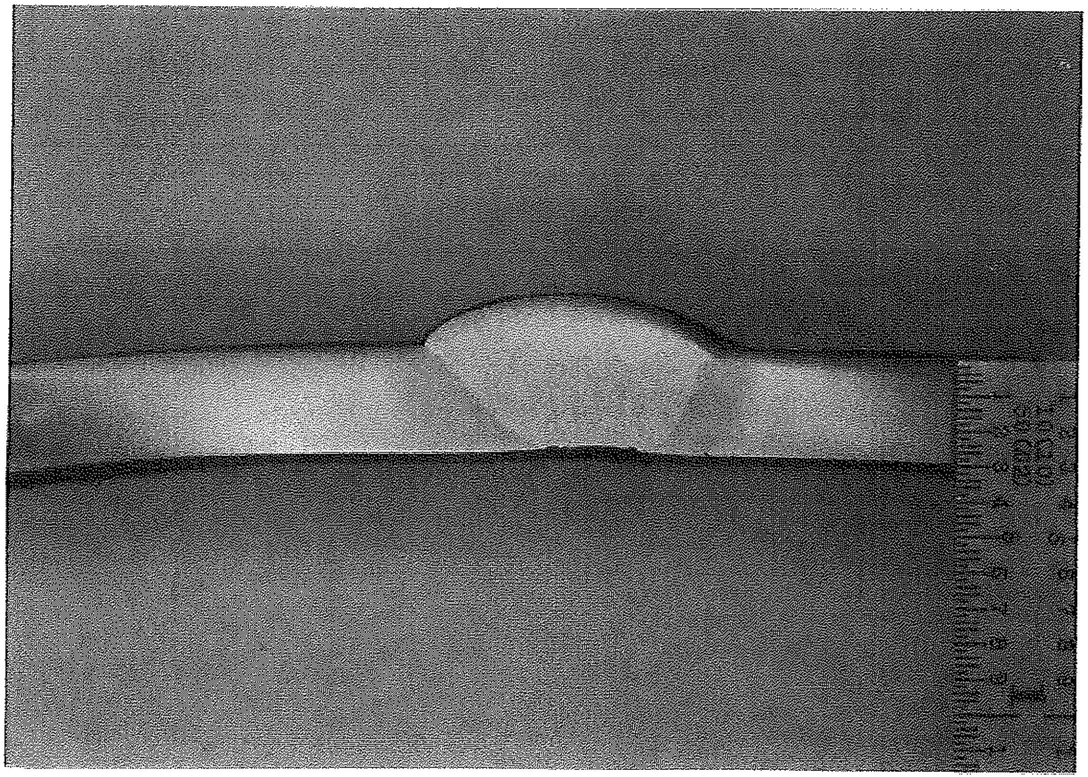

Figure 8 - Typical Line 109 seam weld. The seam is usually made with a single pass submerged arc weld. Magnification is 2.1X.