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Failure Analysis of a Poly(Vinyl Chloride) Natural Gas Main Pipe From Las Vegas, New Mexico (NBS Failure Analysis No. 105)

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Measurement Engineering Division
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National Bureau of Standards
Washington, D. C. 20234

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Prepared for
Office of Pipeline Safety
National Transportation Safety Board
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

A section of poly(vinyl chloride) (PVC) pipe from a natural gas main pipe was submitted to the Metallurgy Division, National Bureau of Standards by the State Corporation Commission of New Mexico at the request of the Office of Pipeline Safety, National Transportation Safety Board. The latter agency requested an evaluation of the cause of an in-service failure. Gas leakage from a failure crack in the pipe was said to have been the attributable cause of a fatal explosion, on October 21, 1972, in a private residence located at 120 Alamo Street, Las Vegas, New Mexico.

The pipe was received by this laboratory in two pieces, which based on accompanying reports, resulted from accidental breakage in the transverse direction through the site of the original failure crack, during exhumation and removal of the section of the gas pipe from the trench. In addition, one section of pipe contained three longitudinal cracks extending away from this break, and a small portion of the pipe was missing at a point where one of these cracks emanated away from the transverse break. The following excerpts are taken from the accompanying letter of transmittal from a Safety Engineer in the Pipeline Division, State Corporation Commission, State of New Mexico; and purportedly describe a series of events preceeding the explosion, as well as those occurring during and after exhumation of the pipe:

> "At station 7+25 to 8+50, being in the lower portion of the grade, a concentration of water collected during some very heavy rainfall and I am informed that the contractor was attempting to remove this very wet soil and in so doing a piece of their machinery got too deep and struck the pipe."
>
> "On inspection you will note that I have marked the top of the pipe in red. Also, I marked a part of the pipe break in red." (Author's note: The marked portion of the break indicated that it had extended from the top of the pipe in a circumferential direction to about the mid-points of the two sides of the pipe, in its installed configuration.)
>
> "This, I am told by the workmen who removed the section of pipe, was about the limits of the break; the remainder of the break occurred when the pipe was removed from the ditch."
>
> "You will notice at the top of the edge of the coupling a "nick" which was made by an outside force. Also, along the top of the pipe on each section you will note a "scratch" or abrasion showing on each of the sections we are sending you."

This laboratory was requested by the Office of Pipeline Safety to evaluate the pipe for compliance to specifications, because the information quoted above from the letter of transmittal indicated that being struck by construction equipment was the obvious cause of failure. Consequently, the pipe was evaluated for compliance, and some additional observations were made of the fracture surfaces.

Several weeks after the analysis had been completed, and a report of test drafted for the Office of Pipeline Safety, the author was informed by counsel for plaintiff in a lawsuit involved with the explosion that testimony in earlier depositions indicated that the original crack, that is, the one from which leakage occurred, was on the bottom of the pipe in its original orientation. In addition, counsel for plaintiff showed this author several photographs which had been included as exhibits in the earlier depositions. Although all of the photographs were taken after the pipe had been broken in two during removal from the trench, a careful examination of them indicated conclusively to us that the original fracture was a transverse, or circumferential one, and that both sections of pipe received by this laboratory had been further severely damaged at some time after the pipe was broken in two during removal from the trench. This additional damage caused considerable difficulty in attempting to determine the cause of failure, since it was in the critical area of the original failure, and the information supplied in the original letter of transmittal, i.e., that the original crack was on the top of the pipe in the installed configuration, was erroneous. Independently, in this laboratory, and prior to receipt of information that the crack had been at the bottom of the pipe circumference, microscopic examination of the surfaces of the transverse crack had indicated that the point of in-service, fatigue-type failure of the pipe occurred at the bottom, if failure were due to other than external mechanical damage, i.e., being struck by construction equipment.

In reassessing the problem, the original package was carefully examined. The pipe had been wrapped in several layers of brown kraft paper, and mailed as "printed matter". At the time the pipe was received in this laboratory, one end of the package had been opened. However, the unopened end showed evidence of damage, including a hole in the package. Therefore, it seemed apparent that the pipe was most likely damaged in the mails, either as a result of being dropped, or crushed. When received a portion of the pipe was missing, as noted above, and the hole in the package was of sufficient size that the missing material could have fallen out of the package.

On the basis of the above information, the original draft report of test was rescinded, since much of it was concerned with the determination of the possible cause of damage which occurred after the pipe was removed from the trench, which therefore would be later information now indicated to have been totally unrelated to the condition of the pipe at the time of the accident. Figure 1 shows the pipe in the as received condition, with the broken ends placed together. Point "A" indicates the location of a nick in the outer edge of the coupling. Point "B" locates what initially was shown as being the approximate midpoint of the original crack, and was reported to be in the immediate area of the top of the pipe in its installed configuration. Consequently, terms such as upper, lower, and side, used in this report are in reference to locations on the pipe, with respect to point "B", as they would have been while the

pipe was in service. A longitudinal crack, between points "B" and "C", was one of three such cracks present in this section of the pipe when it was received in this laboratory, which were later found to have been produced after the pipe was exhumed.

Description of Sample

The sample consisted of a section of bell-end pipe into which a section of straight pipe was cemented. In addition to the name of the manufacturer, the pipe was marked with legends containing the following information: 2" SDR21 200PSI WP @ 73°F PVC1120 CS 256-63. This indicated the following: that the pipe had a nominal outside diameter of 2 inches; that the standard thermoplastic pipe dimension ratio, i.e., the ratio of the pipe diameter to the wall thickness, was 21; that it was pressure rated for continuous use for up to 200 pounds per square inch of water pressure at 73°F; that the pipe was produced from a compound based on rigid poly(vinyl chloride) (PVC), Type 1, Grade 1, a normal impact strength and high chemical resistance material, to provide a hydrostatic design stress of 2000 pounds per square inch for water at 73°F; and that the pipe conformed to the specifications and requirements set forth in Commercial Standard No. 256 issued in 1963 by the National Bureau of Standards, Department of Commerce, for Poly(Vinyl Chloride) Plastic Pipe (SDR-PR and Class T). The complete specifications for the basic PVC compounds required to be used in pipe covered by CS 256-63 are included in the Standard by means of a reference to the American Society for Testing and Materials (ASTM), Method D1784-69, Standard Specification for Rigid Poly(Vinyl Chloride) Compounds and Chlorinated Poly(Vinyl Chloride) Compounds, which fully describes them. Although this Standard was issued three or four years after the pipe in question had been installed, precursor Tentative Standards were in effect at the time the Commercial Standard was issued and these contained the same fundamental physical properties requirements for Type 1, Grade 1, PVC as the current issue, although the latter now classifies this type of PVC as "Class 12454-B rigid PVC." In addition to the above legends, each piece was marked with what appeared to be an identification number, such as might be used to identify a lot or batch of material. The bell-end piece was marked, A22E863, and the straight piece, B17A85348.

The overall length of both sections of the pipe was about 160 cm (63 in), with the bell-end section measuring about 77 cm (30 in). The length of the straight pipe was 84 cm (33 in) exclusive of a section about 5.7 cm long (2.5 in) inserted into the bell socket.

The transverse crack in question was in the bell-end section, at the lower half of the pipe, and was located along the bottom of the socket. At about the midpoints of the sides of the pipe the crack curved away from the socket base to point "B", in Figure 2, which was located about 8.25 cm (3.25 in) from the outer end of the bell socket, or approximately 2.3 cm (0.9 in) from the point where the outside diameter of the pipe began to increase to form the bell socket.

Visual Examination

The visual examination was concerned with three areas of potential damage, including longitudinal abrasion marks along the upper surface of the pipe, a nick on the outer edge of the bell socket near the top of the pipe, point "A" in Figure 1, and the transverse crack surfaces.

In the vicinity of the coupling of the bell-end section to the straight section of the pipe, there were a series of shallow abrasion marks. These marks covered an area approximately one inch in width along the top portion of the pipe. Because of the ductility of the plastic, it could not be determined with certainty in which direction the abrasions occurred, with respect to the nick in the end of the bell socket. The nick on the outer edge of the bell socket was near some of the abrasion marks on the straight section of the pipe. Whether there was any connection between these marks and the nick, could not be determined with certainty. The nick which was approximately 0.5 cm (0.19 in) long in the circumferential direction was not very deep. About 10% of the total wall thickness had been removed at the socket entrance. Since the socket appeared to be firmly cemented to the straight section of pipe, the latter of which had been inserted about 5.7 cm (2.25 in) into the socket, it seemed unlikely that the presence of the nick would have any detrimental effect on the strength of the pipe at that point. Microscopic examination of the surface of the nicked area indicated that it was unlikely that it was the result of a brittle fracture, such as one caused by a sharp blow, but rather appeared to have been the result of a scraping action. Except for a few particles of embedded soil, the remainder of the surface was relatively clean. However, there was nothing to indicate a specific time at which this particular damage occurred, other than that it happened sometime after the two pipe sections had been joined together. This was indicated by the fact that the surrounding area was coated with a light grey pipe cement.

A microscopic examination of the transverse crack surfaces disclosed an occluded particle embedded in the pipe wall near the bottom of the pipe. This particle appeared to be a piece of sand and was slightly less than 0.02 cm (0.01 in) in width and appeared to be essentially spherical. Some discoloration in the pipe wall, as well as the presence of other debris was noted in this area.

In order to observe these features more carefully, the straight section of pipe was cut off, in the circumferential direction at a point approximately 6.35 cm (2.5 in) beyond the outer edge of the bell socket. In cutting the pipe, the particle was vibrated loose and was lost, leaving a discrete cavity in the wall of the pipe. The bell-end section of the pipe was also cut off in such a manner as to reveal the internal crack surfaces of the longitudinal cracks, originally believed to have been part of the overall failure of the pipe. The first transverse cut was made at point "C" in Figure 1. Two additional cuts, nearer the socket end of the section, were made in order to open up two shorter longitudinal cracks along the sides of the pipe.

The cavity left by the missing particle was located in the wall of the pipe near the inner surface, nearly diametrically opposite point "B" in Figure 1. The cavity was slightly less than 0.02 cm (0.01 in) in both width and length. Its depth indicated that most of the particle had been embedded in the wall on the socket side of the crack, see Figure 3. Only a shallow matching cavity was observed on the opposite crack surface. The surface of the pipe wall surrounding the cavity, on the socket side, exhibited a brownish discoloration that appeared to be rather typical of discoloration due to thermal degradation of the material in the pipe compound. This discoloration was in contrast to the dark grey color of the pipe. An alternative cause of the discoloration could have been the presence of a foreign material capable of compatible fusion with the PVC pipe compound, but this is an unlikely situation.

Approximately 1 cm (0.4 in) further along the bottom of the pipe, there was another area near the inner wall that was discolored and pitted. However, it could not be determined by microscopic examination if there were any discrete particulate matter within the pits, or whether the discoloration was due to the presence of other foreign matter or to the presence of degraded pipe compound. Immediately adjacent to the shallow cavity formed by the occluded particle on the opposite surface of the crack, there was a small area, extending from the inner surface of the pipe wall to approximately the mid-wall of the pipe, which appeared to be coated with rust. On the surface of the crack containing the particle, a thin reddish-brown line containing some small particles of debris extended for about 1.9 cm (0.75 in) in the circumferential direction along the mid-wall of the pipe, see Figure 3. This line began just opposite the rust-like stain and progressed upward toward the side of the pipe. These small particles although adhering to the surface of the crack did not appear to have been molded into the pipe compound. Further up the side of the pipe another thin line of a lighter brown stain was observed. This stain was about 0.75 cm (0.3 in) in length and was located in an area about one-third of the way through the pipe wall, as measured from the inner pipe surface.

A similar though much lighter brown stain, about 0.63 cm (0.25 in) in length and containing no apparent particulate matter, was noted near the mid-wall on the opposite side of the area containing the occluded particle.

There were several small cavities in the crack surface, in the area of the occluded particle, distributed in a random pattern. A matching pattern of cavities was located on the opposite crack surface. Since these cavities were essentially clean, apparently contained no particulate matter and were not associated with any apparent discoloration of the pipe compound, they were considered to be indicative of the presence of small voids, or bubbles, in the interior of the pipe wall. If it were assumed that the discoloration previously noted in the pipe wall was due to thermal degradation, then the presence of these voids could be explained by related overheating of the pipe compound at a temperature not quite sufficient to result in discoloration of the pipe compound in these areas.

Vertical striae were observed on the surface of the crack extending from the inner surface to approximately the mid-wall of the pipe. This area extended for about 3 cm (1.2 in) in one direction from the occluded particle including the area containing the small cavities, and for about 0.5 cm (0.2 in) in the other direction to the beginning of the thin line containing the particles of apparent debris. These striae are typical indications of a stress crack.

There was an excess of pipe cement on both sides of the crack, extending away from the bell end and also into the straight section of pipe inserted in the socket. However, it did not appear that the cement was present in such quantity that residual solvent would have had a detrimental effect on the strength of the pipe. In fact, the visual evidence available indicated good workmanship in the assembled joint. In addition, assuming that the cementing of this coupling was performed with the pipe sections in the trench, a fairly common installation procedure, then the presence of the excess cement at this location would definitely establish the fact that it was at the bottom of the pipe in its installed configuration.

Compliance Tests

The pipe was tested for compliance with several sections of CS 256-63, for SDR21 pipe, with respect to dimensions, resistance to flattening, and for extrusion quality, as required for new pipe. Since each of the two sections of pipe were marked with different code numbers, as described above, these series of tests were conducted on specimens from each section.

Two specimens approximately 5 - 6.4 cm (2 - 2.5 in) in length were cut from the outer ends of each of the two pipe sections. The ends of the specimens were squared off and smoothly finished. Measurements were then made of the outer diameter and wall thickness. The specimens were not checked for compliance to the requirements for out-of-roundness, since these are applicable only to pipe prior to shipment from the point of manufacture. The specifications were met with the exception that each of two sets of measurements on the straight section of pipe indicated that the minimum wall thickness was 0.003 inch less than that specified although the average wall thickness was within specifications. However, this could be attributed to the uncertainty of the measuring procedures. The type of micrometer specified in the standard for making these measurements was not used. A substitute instrument of less accuracy was used. Consequently, considering these factors, plus the actual application of the pipe, this apparent failure to meet specifications was considered inconsequential with regard to the strength of the pipe.

Following the dimensional measurements, the same specimens were subjected to the resistance to flattening test. This test requires the specimen to be slowly crushed between two parallel plates until the distance between the plates is equal to 40 percent of the measured outside diameter. None of the specimens exhibited any visual evidence of cracking, crazing, or splitting that would have indicated poor quality or the possible onset of degradation due to aging.

Two additional specimens approximately 0.6 cm (0.25 in) in length were removed from the outer ends of each pipe section for use in the extrusion quality test. The test method referenced in CS256-63 is that of the ASTM Method D2152-67, Standard Method of Test for Quality of Extruded Poly(Vinyl Chloride) Pipe by Acetone Immersion. On completion of the test the specimens exhibited no evidence of swelling, flaking or disintegration, indicating that the compound had been properly fused during the molding operation.

It was not possible to check the pipe for notched impact strength, since this test requires the use of flat specimens. The current ASTM Standard for Type 1, Grade 1 PVC requires a minimum notched Izod impact strength of 0.65 foot-pounds per inch of notch. Although there is a current ASTM Specification for bell-end PVC pipe containing requirements for dimensions of the bell socket, with respect to wall thickness, length, and entrance and bottom diameters, CS256-63 requirements were limited to straight pipe. As a result, no attempt was made to determine these dimensions, except on a cursory basis.

On the basis of an infrared spectrographic analysis, the pipe compound was found to be based on a PVC homopolymer.

Conclusions

The presence of the sand-like particle embedded in the pipe wall, and located at the bottom of the pipe, together with the presence of apparently degraded pipe compound, was considered to be the most probable initiation source of a stress crack. Such a stress crack could be initiated by various combinations of external forces, including normal expansion and contraction of the pipe, compaction of surrounding soil, or compressive forces at ground level that would result in the development of tensile stresses on the inner surface of the bottom of the pipe wall.

The presence of the stain, apparently rust, adjacent to the location of the occluded particle, and the presence of debris in the reddish-brown line adjacent to the particle, strongly suggest that there was a stress crack in the inner wall of the pipe extending from the inner surface to approximately the mid-wall of the pipe, and that it was undoubtedly present for some extended period of time. The crack was located in such a position that it probably would not have been observed in a cursory visual examination of the interior of the bell socket of the pipe. The absence of any pipe cement inside the crack indicates that it developed sometime after the two sections of pipe had been assembled. Voids in the area of the stress crack could reasonably be expected to result in additional weakening of the pipe wall. Other stained areas observed on the surfaces of the cracks seemed to indicate the possible presence of degraded pipe compound. All of these factors could result in a gross weakening of the pipe wall near the base of the bell socket, particularly in the area along the bottom of the pipe in its installed configuration. Absence of similar debris and rust stains, on the crack surfaces, between the mid-wall and the outer wall indicated that failure in this area occurred at a later period in time, probably as a result of some applied external force which caused the crack to propagate to the outer wall. The relatively smooth fracture

surfaces in this area, as opposed to striated surfaces in the stress crack area, suggested the possibility of a brittle fracture which may have occurred rather suddenly.

This analysis indicates that the strength of the pipe was reduced by the presence of a stress crack along the inner surface of the bottom of the pipe. The stress crack appeared to have been caused by flaws introduced into the pipe during the molding process. Subsequent external forces of undetermined origin caused failure of the pipe wall and the resultant gas leak.

Figure 1. Illustration of the fracture area on the pipe, as received. "A" shows location of a nick on the outer edge of the bell socket; "B", the apparent terminal point of an accidental fracture; and "C", the terminus of a longitudinal crack on the outer surface of the pipe due to subsequent damage in shipment.

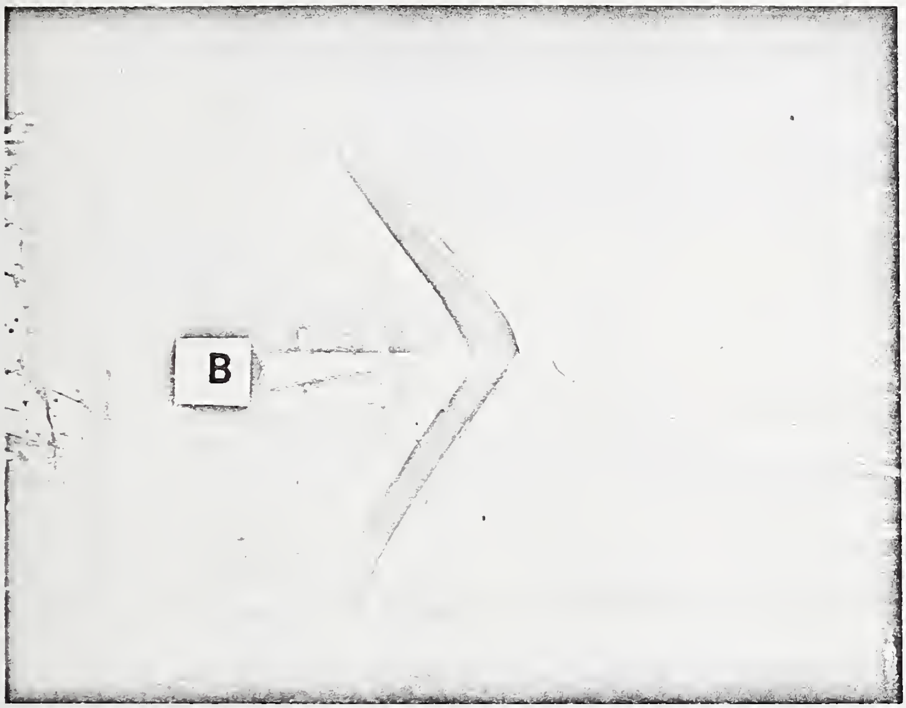

Figure 2. Illustration of the upper part of the pipe, in the vicinity of point "B".

Figure 3. Illustration of crack surface on socket side near bottom of pipe. Arrow shows location of cavity in which the occluded particle had been embedded. The dark line near the mid wall of the socket is that containing rust-like particles and stains.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A natural gas leak from a poly(vinyl chloride) (PVC) gas main was considered to be the attributable cause of a fatal explosion in a private residence in Las Vegas, New Mexico. An analysis of the pipe was conducted in an effort to determine the possible cause of failure. The results indicated that failure occurred as a result of weakening of the pipe due to the presence of a stress crack initiated by an occluded particle, which had apparently been molded into the pipe wall during its fabrication.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Failure analysis; Gas pipe; Natural gas pipe; Plastic gas pipe; Poly(vinyl chloride) gas pipe

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