Evaluation of Concrete Pressure Pipelines and Failure Prevention

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Abstract

Beginning in 1943 more than 28,000 miles of large diameter prestressed concrete pipelines have been placed in service, principally as water transmission mains, operating at pressures as high as 250 psi. Although the pipes have generally performed well, over 500 failures due to exterior corrosion have occurred since 1955. Ruptures are often catastrophic causing considerable damage as well as loss of service. Almost all of these pipelines are buried under varied depths and conditions making internal inspection the most practical method for detection of distress and prevention of bursts.

Analysis of numerous failures has revealed that cracking and/or delamination of the concrete core occurs a considerable time before unstable conditions develop and rupture finally takes place. These indications of incipient failure are discernible by internal inspection. Delaminations are detected by continuous sounding of the lining with a length of small diameter steel pipe. Characteristically the signature cracks appear longitudinally disposed on the side quadrants of the lining and are outlined with surface deposits of carbonate.

To develop a procedure for locating distressed pipe sections before they burst, it is necessary to hypothesize the sequence of events which will likely take place before rupture. Almost invariably prestressed cylinder pipes fail by virtue of corrosion and breakage of the prestressing wires on the exterior. Experience has shown that the corrosion usually originates in a local area of the pipe where the coating is deficient: possibly damaged, separated from the core, cracked, chemically altered, porous, or otherwise failing to protect the wire. In a buried mortar coated prestressed pipe the result of corrosion is usually embrittlement and strength reduction of the wire rather than failure through dissolution and loss of section.

When wires are embrittled and break suddenly in the corroding area, the stress is transferred to the coating which separates from the core exposing adjacent wraps to corrosion. The release of tension in the core causes additional wires at the edge of the distressed area to break. As the corrosion and breakage of wires proceeds, the compression in the concrete core is gradually relieved. Since the internal pressure acts against the steel cylinder, once the core compression is entirely released, the lining remains without stress and does not go into tension. The development of longitudinal lining cracks depends on the pipe design and combination of internal pressure and external load. As wires break and the cylinder expands, the pressure is reduced momentarily on the exterior of the lining which can cause a longitudinal crack to develop on the interior. Transient pressures in the pipeline can have the same effect if the lining and cylinder have separated. Rupture finally occurs when sufficient contiguous prestressing wires are broken so that the force of the internal pressure exceeds the yield point of the cylinder which then further expands and bursts.

Cracks indicative of distress in embedded cylinder pipes are usually located on the side quadrant, longitudinally disposed, and continuous over their length. They are invariably associated with

hollows and often with intersecting circumferential cracks. Although distress conditions are obvious in some pipes circumferential cracks and cracks in the invert and crown by themselves may not indicate distress conditions unless associated with significant hollows. These cracks can originate from transient stresses which occur during manufacture, installation, or testing without affecting the integrity or durability of the pipe. The presence of wrappers or saddles at outlets, restrained or beveled ends, fittings and other specials can result in cracking and may be misleading unless construction details are known. Structural analysis of the pipe prior to internal inspection is recommended to assess the likelihood of cracks or lining separation due to causes other than corrosion and broken prestress wires. Results of the internal survey should be reviewed in the light of the pipe's design, construction, history, and service conditions. There are a number of causes of cracks and hollows which must be considered before it is determined that the observed conditions represent broken wires resulting from corrosion or trauma.

While lining hollows without cracks can result from broken prestress wires particularly in low head pipes, they can also develop where drying shrinkage occurs in excess of the concrete creep resulting from the prestress. Neither the past nor the present design procedures take into account that the inelastic volume changes of the outer core are restrained by the cylinder, but the lining is free to shrink. If a prestressed cylinder pipe which is designed to have a relatively low amount of prestress in relation to the thickness of the core is stored for an extended period of time, the lining may shrink completely away from the cylinder. Lining hollows then may develop, particularly toward the spigot end where the concrete compression is reduced because of the prestress discontinuity. It is not unusual to find hollow areas in heavy wall pipe or in pipelines that have been empty for some time and dried out. Even in low head lines that have been dewatered for only a short time, the spigot ends outboard of the spigot crack have been found to be consistently hollow in places.

The location of separations of the lining from the cylinder by sounding and by development of longitudinal lining cracks presents an opportunity for detecting distressed pipe sections before they rupture. Although the time period between the development of the separation or appearance of a lining crack and rupture of the pipe is indeterminate due to the variables involved, experience has indicated that it can be as long as one to two years or more. To date, more than 80 sections of prestressed pipe in a condition of incipient rupture have been found by internal inspection and have been removed or repaired as required before they burst.

While much of the technique of internal inspection applies equally to lined cylinder pipes as well as embedded cylinder pipes, there are differences that should be borne in mind. The lack of an outer core in the lined cylinder pipes mutes the sound of the hollow to a certain extent particularly toward the pipe ends. At the same time cracks in the core are likely to evidence heavy deposits of carbonate on the surface and indicate distress more clearly because of the cement rich layer on the interior which develops because of segregation during centrifugal casting.

The prestressed concrete cylinder pipe is a composite structure with many variables in design and fabrication which can affect susceptibility to internal cracking and lining separations. Furthermore, it is usually buried at different depths, in varying trench widths, and under different environmental conditions along the length of the line. All these variables may affect the position and extent of cracking on the interior. For these reasons, it is recommended that the first inspection of a pipeline include personnel experienced in the design, fabrication, installation, and inspection of the pipe who are knowledgeable in what cracking may occur normally without adversely affecting performance.

In order to confirm the findings of the internal inspection it is necessary to excavate the pipes that appear to be in distress and inspect the exterior. In some instances it may be found that the distress has not affected the water tight integrity of the pipes. In these cases it may be that some of the recently developed repair techniques are more economical than replacement. It is equally important to analyze the cause of the distress to establish whether it is singular to a section of pipe or likely to be endemic throughout the pipeline.

In summary, experience and analysis have shown that interior inspections of pipelines are effective in locating distressed prestress pipe sections and preventing unanticipated service interruptions. When the inspections are carried out at regular intervals, distressed pipe sections can be removed or repaired prior to failure at considerable cost savings. More important, timely pipe replacement or rehabilitation avoids the possibility of property damage or personal injury coincident with catastrophic pipe rupture.

If you have any questions, please contact **Dr. C.Vipulanandan**