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EFFECTS OF CRACKS IN REINFORCED CONCRETE SANITARY SEWER PIPE

The ultimate strength of reinforced concrete pipe is determined by application of a factor of safety on the 0.01-inch crack design strength. This safety factor ranges between 1.5 for loads up to 2000 $D_{0.01}$ and 1.25 for loads greater than 3000 $D_{0.01}$. Many tests of concrete pipe have proven the conservatism of this safety factor and, in fact, design strengths are generally exceeded. Field surveys have still to produce a single sewer project exhibiting any structural distress which can be attributed to reinforcement corrosion.

Regardless of such information, the attitude of some construction inspectors can be summed up by the statement, "A concrete pipe with a hairline crack has failed and should be rejected." This attitude is usually justified by a concern for structural integrity. This CP Info article shows that such concerns have little basis in fact, as indicated by the results of tests of reinforced concrete pipe installed for a Texas Brazos River Authority sanitary sewer project.

Based on the report "Effects of Cracking in Reinforced Concrete Pipe for Sewers" by Dalton E. Hamilton, P.E., Trinity Engineering Testing Corporation, 3601 Manor Road, Austin, Texas, authorized by Texas Concrete Works, March, 1971.

GENERAL

Do hairline cracks indicate the failure of reinforced concrete pipe? What is the effect of a waste water environment which may be conducive to the development of hydrogen sulfide and possibly sulfuric acid? When these questions were raised on a particular project, Texas Concrete Works authorized Trinity Engineering Testing Corporation to study the conditions and develop data for a complete evaluation.

PROJECT DESCRIPTION

A sanitary sewer line constructed for the Brazos River Authority contained both 30- and 42-inch diameter reinforced concrete pipe with a 2-inch cover over the inner cage reinforcing to provide sacrificial concrete. After installation, inspection revealed a longitudinal hairline crack had developed at the inside crown in both size pipe.

STUDY OBJECTIVES

- Determine the depth of cracks.
- Develop load-strain and load-deflection information during three-edge-bearing tests of a representative pipe section up to the formation of both hairline and 0.01-inch cracks.
- Study the effect of an acid environment on the concrete and reinforcement exposed by cracks.
- Evaluate autogenous healing of cracks.

SAMPLING

Cores, centered on the hairline crack, were cut from the 30-inch diameter pipe in the field. One section of 42-inch diameter pipe was selected at random from stock remaining in the plant yard and tested in three-edge-bearing. Cores were also taken from this pipe, centered on cracks produced during load tests and from uncracked areas.

TESTS

Samples of the cores containing cracks were prepared for testing by sawing along lines parallel to the crack and approximately one inch on each side of the crack. After polishing the saw-cut faces, a coat of epoxy resin was applied to all cut surfaces and the inside and outside surfaces were left uncoated. The cut surfaces were coated to seal the surfaces which are not exposed in their normal position as part of the pipe. *Figure 1* illustrates the method of preparation of the test specimens.

These specimens, additional cores and pipe sections were subjected to the following tests:

- A section of the 42-inch pipe was instrumented with strain gages and loaded in a three-edge-bearing test until hairline cracks were observed.
- After removal of cores, the 42-inch pipe was rotated 45 degrees, and replaced in the three-edge-bearing test stand and loaded until a 0.01-inch crack was produced. Deformations were measured with a dial micrometer. *Figure 2* shows the arrangement of strain gages and dial micrometer.
- Cores from uncracked areas of the 42-inch pipe were utilized for compressive strength tests of the concrete.
- The depth of the cracks in four cores, two each from the 30- and 42-inch pipe, were measured by ultrasonic methods prior to, during and after completion of other tests.
- One core, No. 18, was submerged in water to determine the probability of autogenous healing of the cracked concrete.
- The remaining three cores, one from the 30-inch pipe and two from the 42-inch pipe, were mounted in a chamber and exposed to water vapor for two weeks and to the vapor from a 5 percent sulfuric acid solution for a period of five and one-half months.
- After completion of tests, scrapings from the inside and outside surfaces of the three cores subjected to acid vapor were chemically analyzed.
- Upon completion of all tests, the three cores were split along the crack and the inside crack surfaces and the reinforcing steel visually inspected. Scrapings from the reinforcing steel were also chemically analyzed.

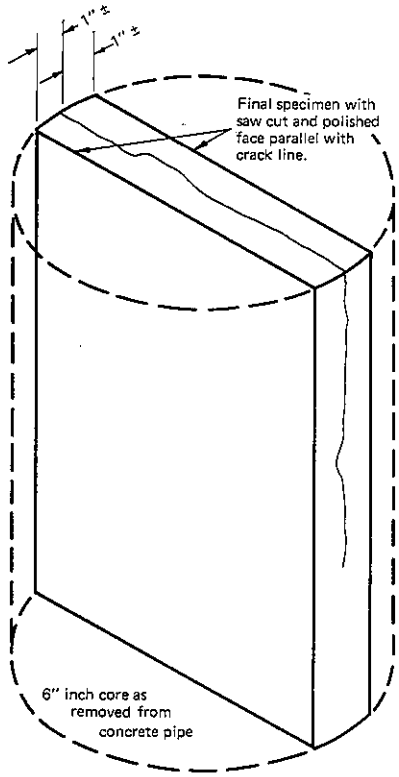

FIGURE 1. CRACKED CORE TEST SPECIMEN.

TEST RESULTS

- The average compressive strength of the concrete utilized in the manufacture of the pipe was found to be 4,940 psi.
- *Figure 3* shows the initial depth of the cracks in the four core specimens before testing, as measured on March 24, 1971, and the reduction in crack depth due to autogenous healing. For sample No. 18, which was submerged in water, the crack depth was measured twice, first after one month and again after completion of the test. The crack depths of the other three specimens exposed to acid vapor were measured after six months.

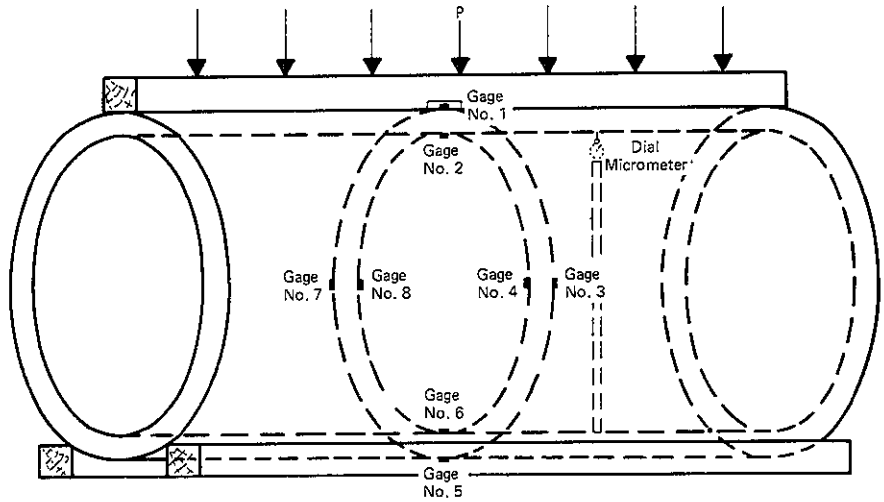

FIGURE 2. TEST STAND AND PIPE INSTRUMENTATION.

TABLE 1. CHEMICAL ANALYSIS OF CRYSTALS FORMED ON ACID EXPOSED SPECIMEN.

	Sample No. 3 30" R.C.P.	Hairline Crack 42" R.C.P.	0.01 Inch Crack 42" R.C.P.	Wet Sand Exposure	Ground Concrete Reference
Calcium, % by wt.	23.0	20.2	22.0	0.6 (20.7)*	25.6
Sulfate, % by wt.	48.7	48.4	52.8	1.4 (48.7)*	0.4
Iron, % by wt.	0.5	1.2	0.4	0.1 (3.9)*	1.8
Magnesium, % by wt.	—	0.7	0.4	0.1 (1.3)*	1.5
Soluble Silica, % by wt.	1.5	0.7	0.2	0.1 (0.1)*	0.1
Insoluble Silica, % by wt.	0.1	0.1	0.1	97.1 (—)*	0.1
Sodium, % by wt.	—	0.6	0.5	0.1 (0.2)*	0.1
Aluminum, % by wt.	—	0.4	0.4	0.1 (0.7)*	0.5
Total % Accountable	73.7	72.2	76.7	99.2 (75.5)	30.0
Chloride, % by wt.	—	—	0.05	—	0.05
Carbonate, % by wt.	—	—	None	—	4.46
Bicarbonate, % by wt.	—	—	3.67	—	24.85

(*) Percent present in non-silica portion of residue

Sampled on October 7, 1971

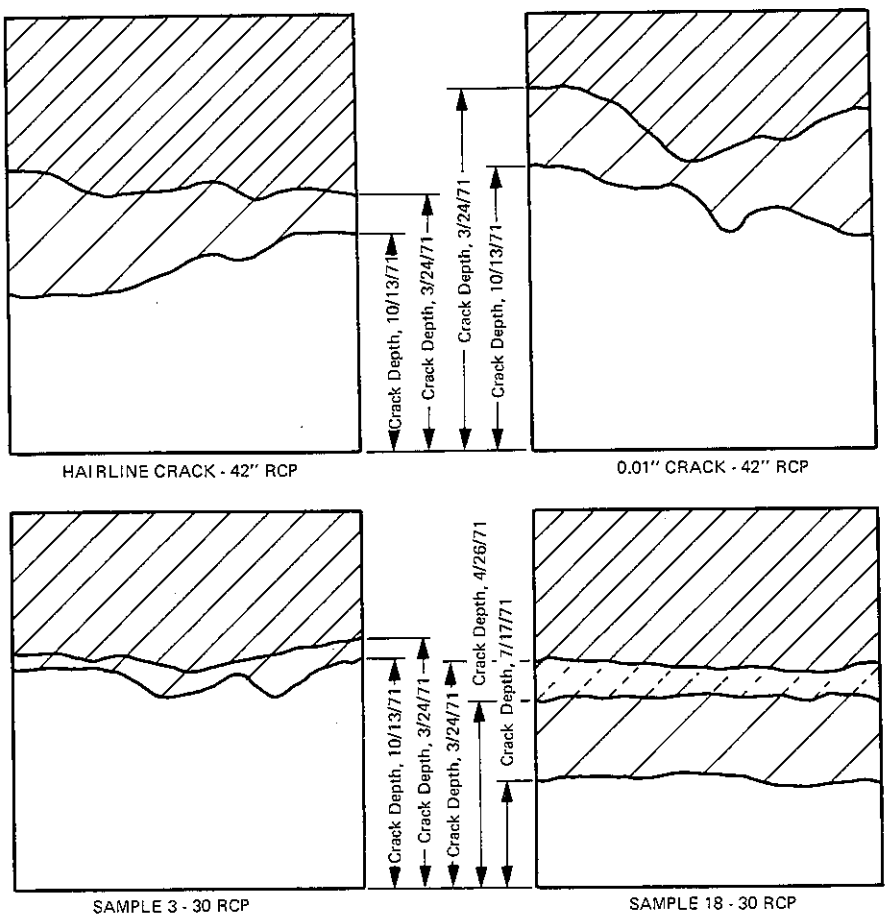

FIGURE 3. CRACK DEPTHS.

- The chemical analyses of the crystals formed on the exposed surfaces of the three specimens subjected to an acid vapor are given in *Table 1*. There was no indication of acid attack on the inside surfaces of the cracks.
- Reinforcing steel in the three specimens subjected to acid vapor exhibited no detrimental effect either by visual inspection or by chemical analysis, as indicated in *Table 2*.

TABLE 2. CHEMICAL ANALYSIS OF SCRAPINGS OF THE REINFORCING STEEL.

ANALYSIS	RESULTS
Calcium, % by wt.	27.6
Sulfate, % by wt.	1.0
Soluble Silica, % by wt.	0.5
Iron	1.9
Insoluble Material	23.7

Sampled on November 19, 1971

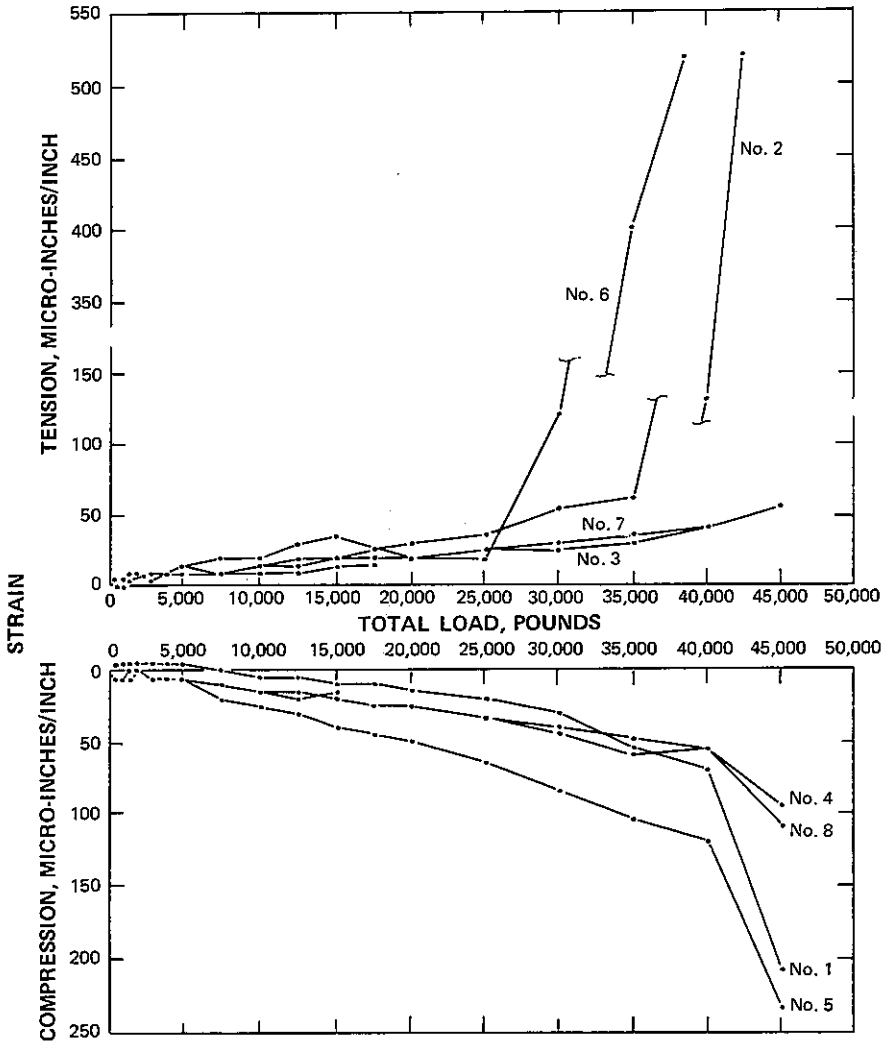

FIGURE 4. LOAD-STRAIN CURVES, FIRST TEST.

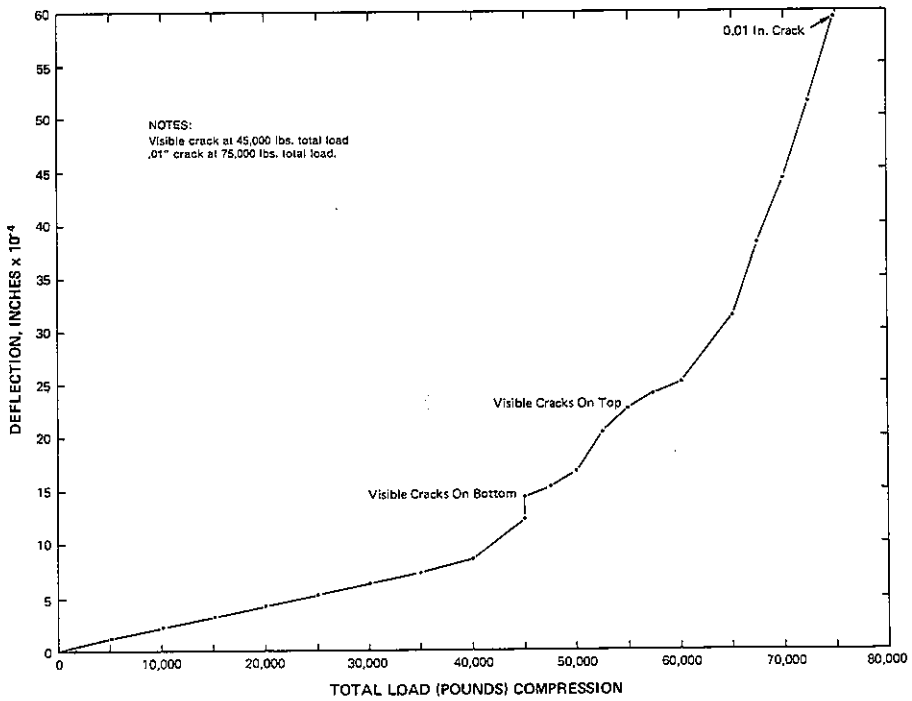

FIGURE 5. LOAD-DEFLECTION CURVE, SECOND TEST.

- The load-strain curves resulting from the first load test are shown in *Figure 4,* and the load-deflection curve from the second load test is plotted in *Figure 5.*

FINDINGS

- Autogenous healing of the sample submerged in water progressed at a fairly uniform rate during the test period. Autogenous healing also occurred in the samples subjected to the acid vapor environment, although at a decreased rate compared to the sample submerged in water.
- Surfaces of the specimens exposed to acid vapor showed some evidence of acid attack, but the inside surfaces of the cracks and the reinforcing steel were not detrimentally affected.
- The load-strain and load-deflection curves indicate that the reinforcing steel becomes structurally effective only after the concrete cracks and thus enables the pipe to sustain greater loads than those which produce hairline cracks.

CONCLUSIONS

- A reinforced concrete pipe will continue to have structural integrity when loaded beyond the loading required to produce a hairline crack and even a 0.01-inch crack.
- There is little or no probability of deterioration of either the reinforcing steel or of the concrete surfaces exposed by a hairline crack, even when sulfuric acid is present.
- Concrete pipe has a high probability of incurring autogenous healing of cracks if any moisture is present either on the inside or outside of the pipe.