

Tests of Large-Diameter Reinforced-Concrete Pipe

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The standard test in general use for concrete pipe of all sizes is the three-edge bearing test. This test is used to determine two values, generally accepted as indicative of the quality and strength of concrete pipe: the load to produce a 0.01-inch crack and the load to produce ultimate failure.

It is common practice to use this test on both plain and reinforced-concrete pipe in sizes ranging from 4 inches to 72 inches in diameter. Relatively few three-edge bearing tests have been performed on pipe larger than 72-inches in diameter. This was partly due to the lack of equipment with sufficient capacity to handle the larger pipe as well as the cost of manufacturing and testing the pipe to destruction.

In addition, there was some feeling that the three-edge bearing test was not applicable to large-diameter pipe. Depending to some degree on the size of the pipe and the amount of steel reinforcement, test results on large pipe did not appear to be consistent with either theory or tests on pipe of smaller sizes. It was found that increasing the steel area beyond a certain amount had little or no effect on either the 0.01-inch-crack load or the ultimate load which the pipe would support.

In the last 10 years the demand for concrete pipe in larger sizes has grown considerably. It is well known that the relationship between the supporting strength of the pipe in the ground and the strength of the same pipe in a three-edge bearing test is an empirical one developed mainly with tests on smaller pipe. The increased demand for large pipe and the lack of available design data pointed up the need for a study of the behavior of large pipe under load.

A number of tests have been run on pipe 84 inches in diameter. The three-edge bearing test was selected as the easiest method of loading the pipe. Various systems for reinforcing the pipes were used including standard types normally used in pipe production.

As a result of these tests, it is believed that the major factor causing the discrepancy between test results and expected theoretical results has been the failure to consider shearing stresses set up in the wall of the pipe. Failure due to shearing stresses occurs before the tension reinforcement has begun to carry its design load, particularly in heavily reinforced pipe. If special reinforcement is provided to take care of shearing stresses, the strength of the tension reinforcement can be used more efficiently. It is possible to greatly increase the crushing strength of large diameter pipe without an increase in the wall thickness.

● THERE are two different methods of determining the load-carrying ability of any structure. One is an analytical method wherein certain safe values of stress are assigned to the materials in the structure. The structure is then proportioned in accordance with known principles of mechanics, so that applied loads will not create stresses in the structure greater than the known safe values. The second method is to build and test a number of individual specimens whose dimensions and materials are consistent with those used in

the actual structure. The second method is the one which has been used most extensively to determine the load-carrying ability of reinforced-concrete pipe.

METHODS OF TESTING

A number of different types of tests have been devised to determine the load-carrying capacity of a rigid pipe. The standard method of testing now generally used for concrete pipe is the three-edge bearing test as described in ASTM Specifications

C4, C118, C14, C75, and C76, as well as AASHTO Designation T33-45. The sand-bearing test also described in these same specifications is sometimes used as an alternate. It is considered by some to be more representative of the loading to which a pipe in the ground is subjected, but this appears to be questionable. In addition, the test is cumbersome and expensive to perform. The three-edge bearing test is a simple, convenient, and rapid method of checking the strength and quality of pipe.

STRENGTH REQUIREMENTS FOR REINFORCED-CONCRETE PIPE

Load-test requirements for concrete and reinforced-concrete pipe have been a subject for discussion and study for many years. One of the earliest and most-complete studies on the load-supporting strength of reinforced-concrete pipe was made in 1907 and 1908 at the University of Illinois. The tests were reported in Engineering Experiment Station Bulletin 22 by A. N. Talbot. Following these tests, railroads began using reinforced-concrete culvert pipe for drainage structures. The pipe was designed in accordance with the formulas from Bulletin 22, but in 1919 it was said that more than 20 different specifications for reinforced-concrete culvert pipe were in existence. In 1919 the Joint Concrete Culvert Committee was formed to simplify and reduce the number of specifications. In a report issued in 1926 the committee specified the steel reinforcing to be used with concrete pipe. This report was the forerunner of the present day ASTM specifications for concrete sewer and culvert pipe.

In the current ASTM specifications there are no references to design stresses for reinforced concrete pipe. Strength requirements are given for three-edge and sand tests together with minimum wall thicknesses and minimum steel areas for each size of pipe. These quantities were determined partly by theory and partly by experience and testing. Two strength requirements are specified, one for a 0.01-inch crack and one for an ultimate.

Strength requirements are specified only for pipe 72 inches and smaller in diameter. Until recently the bulk of the pipe manufactured in this country came within this range of sizes. Strength requirements for

pipe larger than 72 inches have never been specified, because there has never been sufficient test data available to determine what the requirements should be. In addition, there has been some feeling in the concrete-pipe industry that the three-edge bearing test is not applicable to large-diameter pipe. This is probably due to the fact that large pipe when tested in three-edge bearing sometimes fails to develop the strength anticipated, considering the amount of reinforcing steel and the strength of the concrete used in making the pipe.

Since the end of World War II, there has been a trend toward the use of larger sizes of concrete pipe. Wider use of heavy power equipment has reduced the problem of handling heavy sections of pipe. Increasing costs of labor and form work have placed precast concrete pipe in a better competitive position with monolithic structures. Wider recognition of the great durability and good hydraulic properties have probably had some influence on the trend toward the larger sizes.

Concurrent with the demand for larger and larger pipe came a demand for information on the load-bearing capacity of that pipe. The empirical relationship developed at Iowa State College between the strength of a pipe in a three-edge bearing test and the supporting strength of the same pipe in the ground is well known. To apply it one obviously needs to know the strength of a pipe in a three-edge bearing test. But as previously pointed out, this information is lacking for pipe larger in diameter than 72 inches.

In an effort to throw some light on this problem, the American Concrete Pipe Association, together with the Lewistown Pipe Company at Hillside, Illinois, and later with the Lock Joint Pipe Company of East Orange, New Jersey, decided to run a series of load tests on 84-inch reinforced-concrete pipe. It was considered impractical to try to develop average values for test-load requirements to be included in pipe specifications. Rather, the tests were to study the behavior of the pipe under load when reinforced in different ways. The three-edge bearing test was selected as the method of testing the pipe. Ultimately it is hoped that a design procedure for large-diameter reinforced-concrete pipe can be recommended, but this paper will report only on tests of the pipe.

TYPES OF FAILURE

Reinforced-concrete pipe is generally reinforced either by two circular cages or by one elliptical cage. In testing pipe reinforced in this manner, it has been observed that two different forms of failure usually occur. One is a tension failure of the steel reinforcing at either the top or bottom of the pipe. This type of failure occurs rarely in large-diameter pipe of the proportions generally used in present-day manufacture.

The second type of failure is by a stripping or shearing of the concrete from the tension face at the top and bottom of the pipe. As the pipe is loaded, tension cracks form in the concrete and the reinforcing steel begins to be effective. This steel is originally in the shape of a circle, but the high bending moments at the top and bottom of the pipe cause the steel near the inner face of the pipe wall to tend to move inward, so as to form a chord of the original circle. As the load is increased this action continues until the tendency of the steel to straighten is great enough to strip off the concrete. This is the type of failure usually occurring in the larger pipes.

Experience has shown that the larger the pipe the more susceptible it is to this

type of failure. Forces tending to straighten the steel increase with the pipe size. This type of action does not occur in ordinary reinforced-concrete beams as the direction of the stress in the tension steel is mainly in a straight line along the axis of the steel itself.

A typical example of a pipe loaded to failure in a three-edge bearing test is shown in Figure 1.

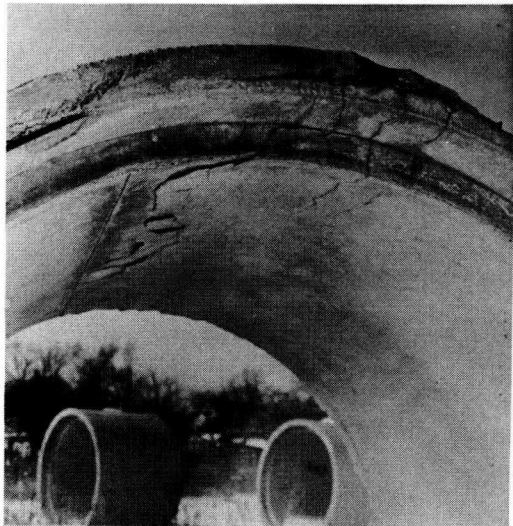


Figure 1. This pipe was tested to failure in a three-edge bearing test.

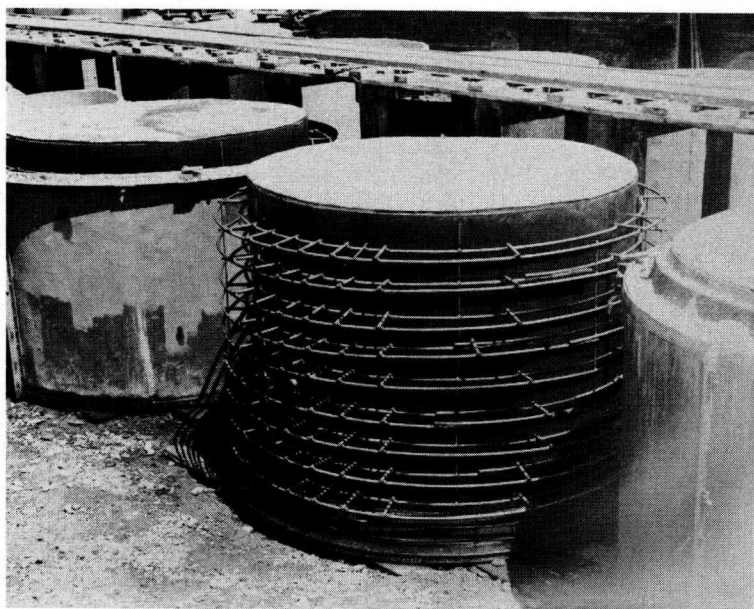


Figure 2. Reinforcing for Pipe A has been placed around the inside form of the pipe.

FIRST SERIES OF TESTS ON 84-INCH PIPE

The first series of tests on 84-inch pipe were intended to show the effectiveness of various methods of reinforcing the pipe in preventing failure due to stripping or shearing of the concrete. The pipe sections were made with standard tongue-and-groove forms. Test sections were of uniform wall thickness and showed no evidence of honeycombing or other defects. Test sections were placed in a testing frame for a standard three-edge test. The load was applied by means of a 100-ton hydraulic jack. Changes in the vertical and horizontal diameter were measured to the nearest $\frac{1}{32}$ inch. While this may seem to be a rather crude method of measuring deflections, it was considered good enough for the purpose of these tests.

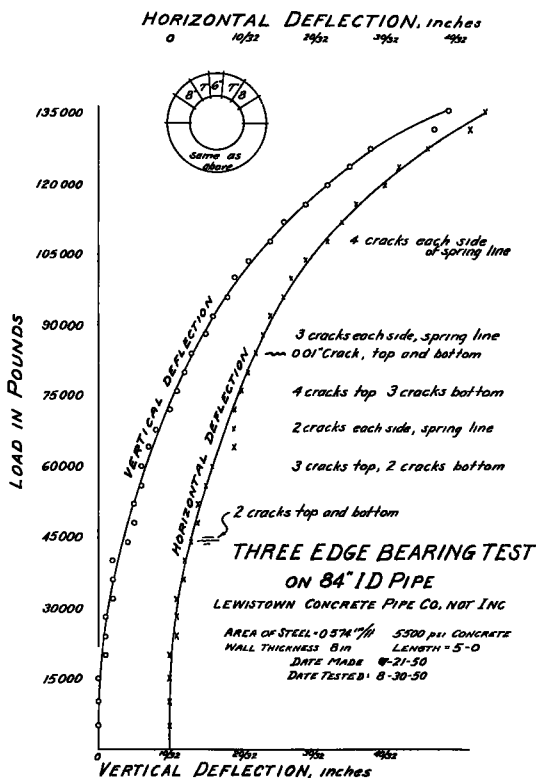


Figure 3. Load-deflection curves for Pipe A.

The first pipe tested, Pipe A, was reinforced with concentric steel hoops spaced on 6-inch centers. The two hoops were welded together with $\frac{1}{2}$ -inch ties at the top and bottom of the pipe. These ties, or

stirrups, are to prevent the tendency of the curved reinforcing bars to straighten as the pipe is loaded.

This system of reinforcing, shown in Figure 2, requires that the pipe be tested with a particular axis vertical. Results of tests on this pipe are shown in Figure 3. The 0.01-inch crack occurred at a load of 84,000 lb. and the ultimate at 135,000 lb. This corresponds to 16,800 and 27,120 lb. per ft., respectively.

It is generally considered that an 84-inch extra-strength reinforced-concrete culvert pipe should have an ultimate strength of 21,000 lb. per ft. This pipe easily meets this requirement despite the fact that the steel area is less than the minimum required by ASTM specifications for that class of pipe.

The reinforcing used in Pipe B, Figure 4, was similar to that already described. The main difference was the equal spacing of $\frac{3}{8}$ -inch ties around the circumference of the pipe, so the pipe could be tested in any position. The results from the test of this pipe are shown in Figure 5 and are seen to correspond fairly closely to the first pipe tested.

Figure 6 shows a different method of tying the steel hoops together with $\frac{3}{8}$ -inch bars. The steel area is slightly greater in this pipe. Results of the tests are shown in Figure 7. The 0.01-inch-crack load and the ultimate load are consistent with the other pipe tested. The deflection in this pipe is considerably less, probably due to the method of tying the hoops together. The steel used in forming the concentric hoops in these three pipes was heavy, cold-drawn steel wire approximately $\frac{5}{16}$ inch in diameter. Its tensile properties were about the same as those of cold-drawn wire mesh.

In Pipe D, reinforced with cold-drawn wire mesh, $\frac{3}{8}$ -inch tie bars hooked into inner and outer cages rather than welded to them, were used. As shown in Figure 8, three ties spaced 12 inches apart were placed on every circumferential bar at the top and bottom of the pipe. When tested, the pipe had a 0.01-inch-crack load of 137,000 lb. or 27,400 lb. per lin. ft. The load was not increased to ultimate failure but was stopped at 160,000 lb. as shown in Figure 9.

The high value of the 0.01-inch-crack load is thought to be due to the 6-inch



Figure 4. Reinforcing for Pipe B is shown in position.

spacing of the longitudinal wires in the wire-mesh reinforcing. If this spacing were 8 inches or 12 inches, as is the case

for some styles of mesh, such a high value of the 0.01-inch-crackload probably could not be expected. The area of reinforcing steel in this pipe is that required by ASTM Specification C76 Table 2 for 84-inch pipe.

Pipe E, reinforced as shown in Figure 10, is the same as Pipe D, except for the spacing of the tie bars or stirrups. Three

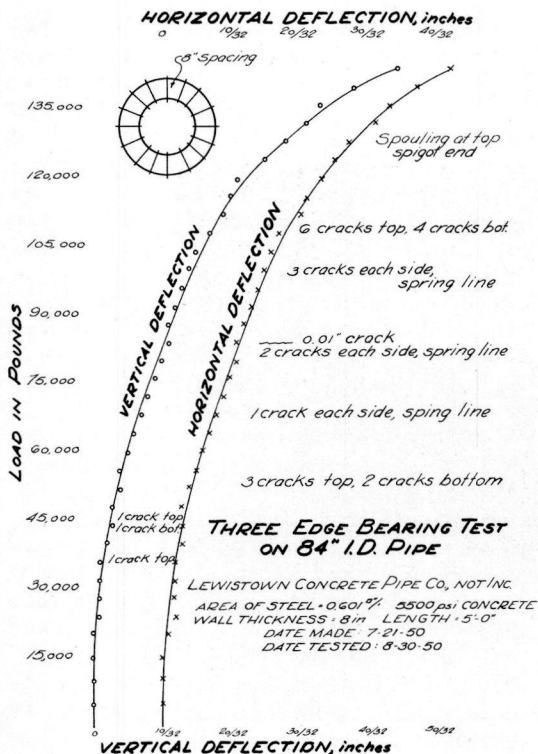


Figure 5. Load-deflection curves for Pipe B.

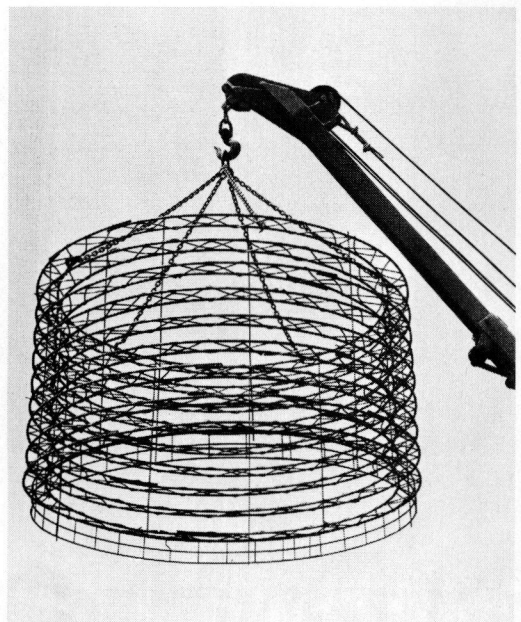


Figure 6. Reinforcing for Pipe C is being lifted into place in the forms.

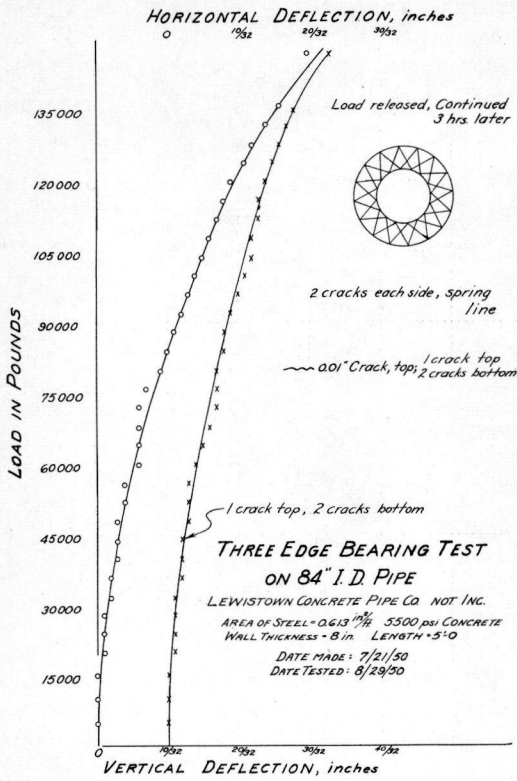


Figure 7. Load-deflection curves for Pipe C.

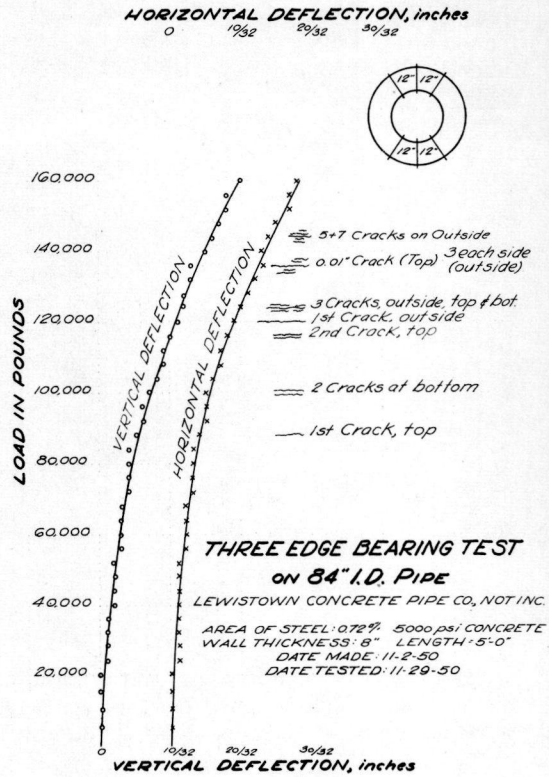


Figure 9. Load-deflection curves for Pipe D.

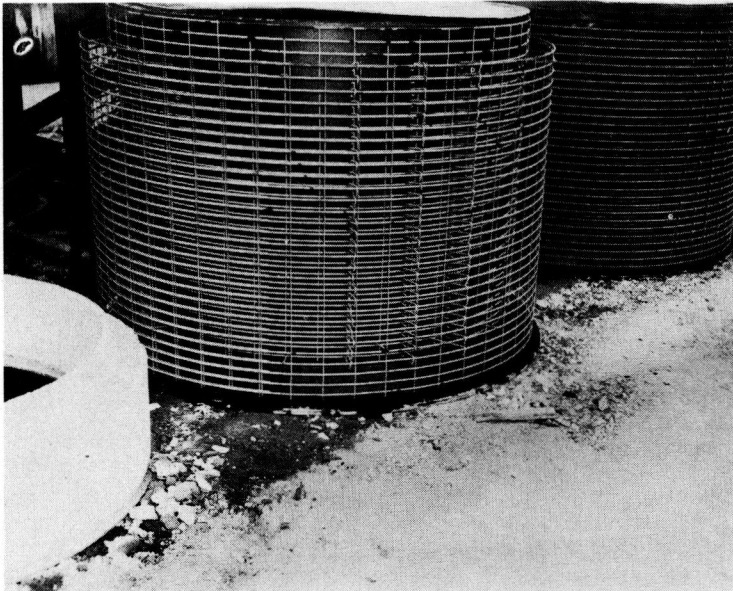


Figure 8. Pipe D was reinforced with wire mesh. Hooked tie bars provide shear reinforcing.

ties spaced alternately 12 inches and 6 inches apart were placed on every circumferential bar at the top and bottom of the pipe. Figure 11 shows that the test results correspond closely with those of Pipe D, as would be expected.

Failure occurred by a separation of the inner cage from the curved bar of the trusses and the stripping off of the concrete at the top of the pipe. Load-deflection curves are shown in Figure 14. The results of this series of tests is given

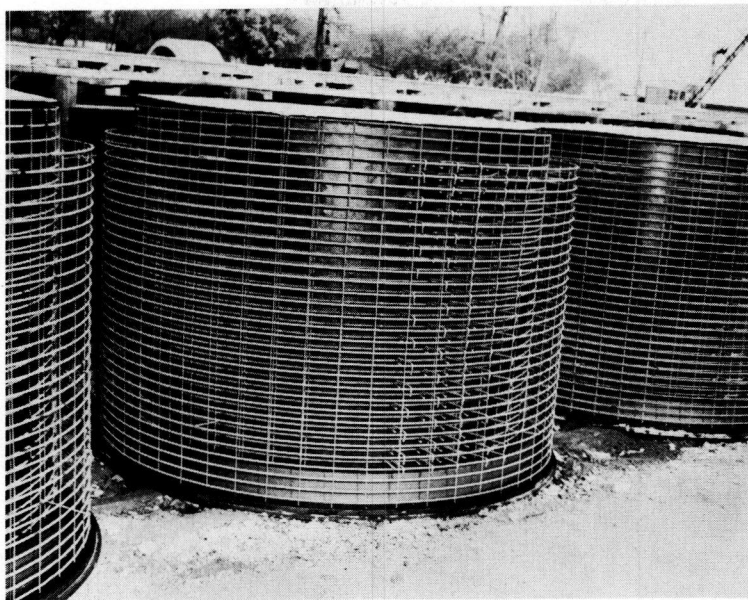


Figure 10. Pipe E reinforced as shown differed from Pipe D only in the spacing of the tie bars.

TABLE 1
LOAD TESTS ON 34-INCH REINFORCED-CONCRETE PIPE

Pipe	Steel Area sq. in. per lin. ft.	ASTM 0.01 in. crack lb. per lin. ft.	Ultimate Load lb. per lin. ft.
A	0.574	16,800	27,120
B	0.601	16,800	28,800
C	0.613	15,900	29,400
D	0.720	27,200	32,000 (No failure)
E	0.720	28,800	32,000 (No failure)
F	1.33	--	38,400

Pipe F was reinforced by a method which provided both shear reinforcing and an increased steel area in the region of high bending moments. Welded trusses of $\frac{7}{8}$ -inch round bars similar to that shown in Figure 12 were placed on 6-inch centers inside wire-mesh cages, as shown in Figure 13. The trusses were not fastened to the mesh other than for wires used to hold the assembly together. The wire mesh was the same as that used for Pipes D and E. This pipe was tested to failure without any crack as great as 0.01 inch being observed.

in Table 1.

As a result of these tests, it was felt that the type of reinforcing used in Pipe F showed considerable promise as a method of producing a high-strength pipe without too great an increase in the amount of steel reinforcing required. The additional reinforcing steel required for greater strength could be provided by the truss, which does not need to extend around the entire circumference of the pipe. It was, therefore, planned to run a second series of tests on pipe reinforced in this manner.

SECOND SERIES OF TESTS ON 84-INCH PIPE

Nine additional pipes were cast for test purposes. Each pipe was 5 feet long with an 8-inch wall. Standard tongue-and-groove forms were used in casting the pipe.

Three pipes were standard ASTM C76 Table 2 pipe for control specimens. The reinforcing consisted of two wire-mesh cages, each providing a steel area of 0.731

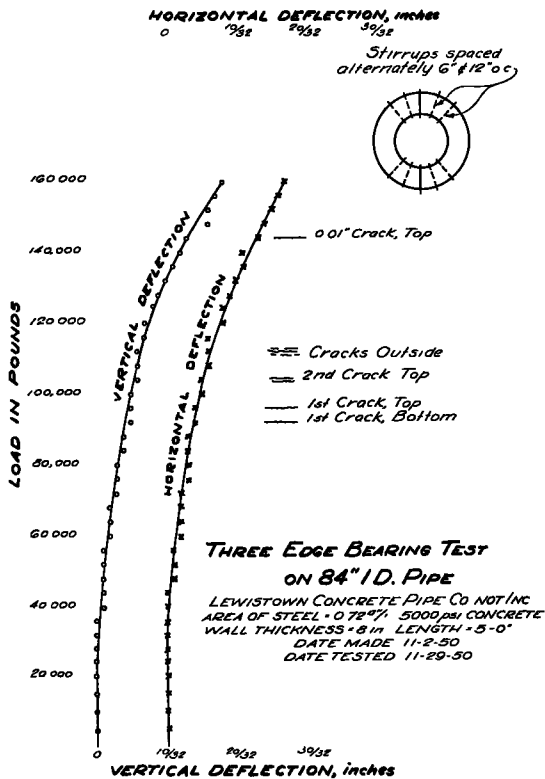


Figure 11. Load-deflection curves for Pipe E.

sq. in. per foot of pipe. These pipes are referred to as Design 1.

In Design 2, the same wire-mesh cages were used. In addition, welded trusses made up of $\frac{3}{8}$ -inch bars were placed on 6-inch centers at the top and bottom of the pipe.

Design 3 pipes were constructed with two lighter wire-mesh cages, each providing a steel area of 0.52 sq. in. per linear foot. Trusses were located on 2-inch

TABLE 2
LOAD TESTS ON 84-INCH REINFORCED-CONCRETE PIPE
(In Pounds per Lineal Foot)

DESIGN NO 1				
Pipe No	Age (days)	ASTM 0 01 in crack	Ultimate Load	
1	34	14,000	23,200	
2	30	14,000	21,400	
3	41	16,000	20,000	
DESIGN NO. 2				
4	33	18,000	38,100	
5	34	22,000	35,050	
6	36	20,000	33,980	
DESIGN NO 3				
7	32	28,000	44,400	
8	36	26,000	43,950	
9	39	30,000	45,750	

centers to provide a total tension steel area in the top and bottom of the pipe of 1.18 sq. in. per ft. At the springline, the outer cage was doubled up to provide a tensile steel area of 1.04 sq. in. per ft.

Details of these designs are shown in Figure 15.

Standard test cylinders cured with the pipe indicated a concrete compressive strength in excess of 5,000 psi. at the time the pipe was tested.

The pipes were tested in three-edge bearing, and the results are summarized in Table 2.

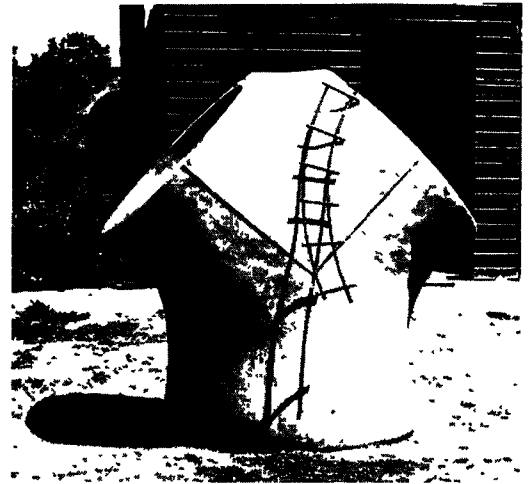


Figure 12. A single truss similar to those placed between circular wire-mesh cages in Pipe F.

In each of the pipes of Design 1, a shear failure similar to that shown in Figure 1 occurred at the ultimate load.

Of the three pipes of Design 2, two failed in shear. The third, although badly cracked, continued to take on load until a compression failure of the concrete occurred at the springline, on one side.

Two pipes in Design 3 failed through excessive elongation and, eventually, the rupture of the outside cage at a point just beyond the ends of the trusses. Failure of the concrete in compression was indicated by spalling on the inside of the pipe at this point. In the third pipe, failure at the ultimate load occurred when the concrete on the inside of the pipe began to crush, indicating excessive elongation of the steel in the outer cage. As before, the outer cage wire ruptured just beyond the ends of the trusses, but the inner cage wires and truss bars also ruptured directly below the top bearing block.

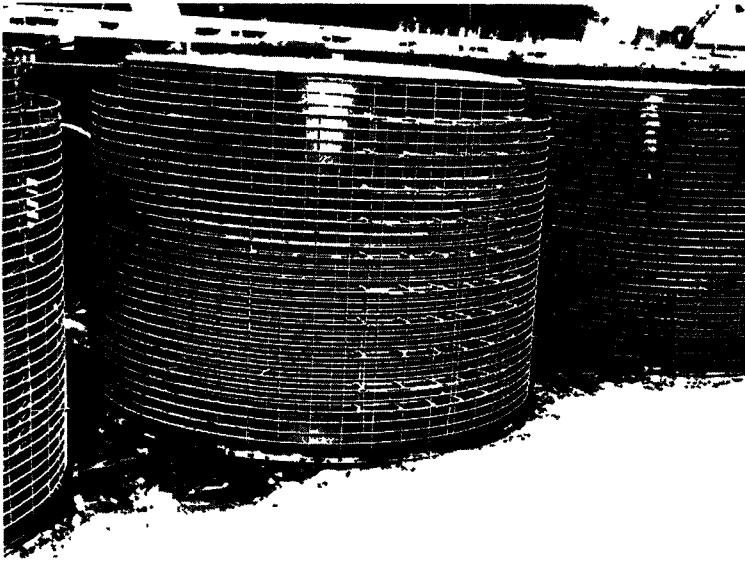


Figure 13. Reinforcing for Pipe F is shown prior to placing the outside form in position.

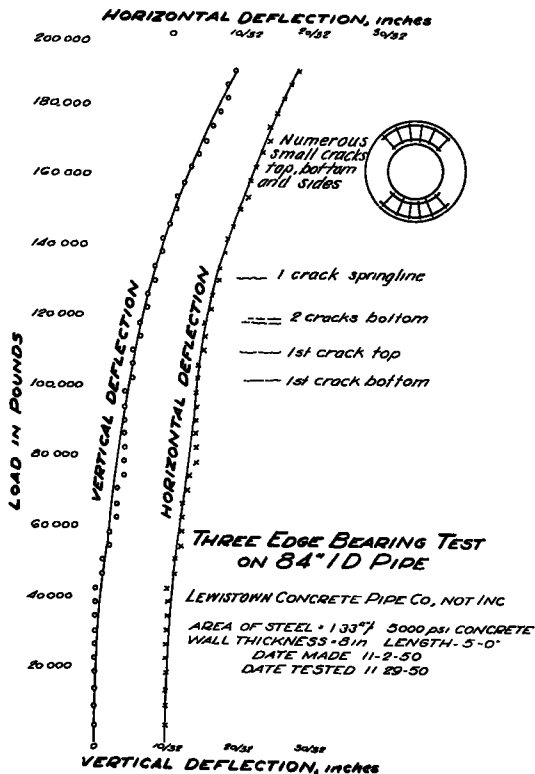


Figure 14. Load-deflection curves for Pipe F.

The top of this pipe after it had been removed from the testing machine is shown in Figure 16.

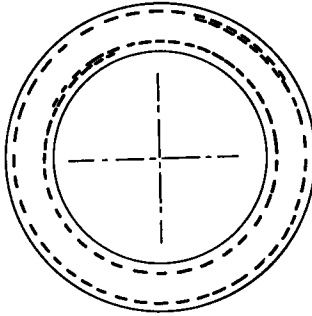
CONCLUSIONS AND COMMENTS

These tests on 84-inch reinforced-concrete pipe indicate that some type of reinforcement to prevent what has been called a shear failure is desirable in the larger sizes if the full strength of the pipe is to be developed. It should be pointed out that this fact has been recognized by many others prior to these tests. Some reinforced-concrete rings with stirrups to prevent shear failure were tested at the University of Illinois in 1908. Pipe reinforced to prevent a shear failure was tested at Iowa State College in 1925. The diameters of the specimens used in these tests were 48 and 36 inches respectively.

A method of preventing a shear failure in pipe reinforced with elliptical cages was patented by Elmer L. Johnson, of Colton, California, around 1935. In 1948 Howard F. Peckworth, after observing failures and working entirely on a theoretical basis, discovered an original method of providing shear reinforcement in large pipe. The designs of the first series of pipe reported on in this paper were developed, built, and tested by J. E. Miller, of Hillside, Illinois, and the writer.

There is some indication that the shear reinforcement used in these tests does more than increase the ultimate strength of the pipe. Pipe reinforced for shear tended to develop numerous fine cracks in the concrete on the tension face of the pipe rather than one or two wide cracks. This has the effect of increasing the load which the pipe will support before developing a 0.01-inch crack.

but stronger pipe can be offset by lower installation costs is not yet known. The type of shear reinforcing which now appears to be most usable is the hooked tie bar, such as was used in pipes D and E. A few manufacturers have used this type of reinforcing and report that once a workman develops a systematic method of installing them, the ties can be placed quite rapidly.

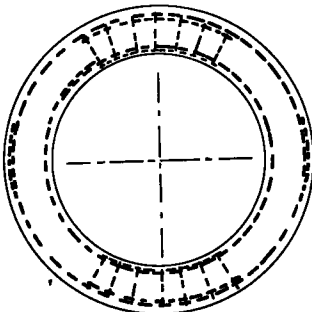
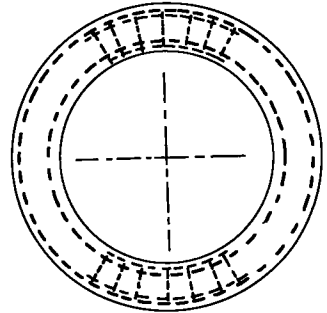


DESIGN NO. 1

Control Specimen - C76-II 84" x 8" Wall x 5'-0"
 2 Lines, each 0.731 in² per lin. ft
 Outside Cage (17"± lap) 58" x 27'-0", 2" x 12",
 4/0 x 6
 Inside Cage (17"± lap) 58" x 24'-0", 2" x 12",
 4/0 x 6
 Lap at upper quarter points

DESIGN NO. 2

84" x 8" Wall x 5'-0" - Two lines, each 0.731 in²
 per ft plus trusses at 6' centers
 Outside and Inside Cage same as Design No. 1
 Trusses 60° arc top and bottom
 Tension steel top and bottom
 Cage - 0.73
 Truss - 0.22
 0.95 in²/lin. ft



DESIGN NO. 3

84" x 8" Wall x 5'-0" - Two lines each 0.52 in²
 per ft plus trusses at 2' centers
 Outside Cage (5'-9"± lap at each springline)
 2-58" x 18'-6", 2" x 12", 2/0 x 5
 Inside Cage (17"± lap at quarter points)
 58" x 24'-0", 2" x 12", 2/0 x 5
 Trusses top and bottom 60° arc
 Tension steel top and bottom 1.18 in² per ft

Figure 15. Reinforcing for Designs 1, 2, and 3 are shown. All truss bars were 3/8-inch-diameter bars.

There can be little doubt that providing shear reinforcement of the type used in these tests will increase the cost of the pipe. Whether this increased cost can be offset by the more-efficient use of the main reinforcing steel or whether a more costly

An added advantage of the ties or trusses is that they form the entire system of reinforcing into a rigid unit. The steel is less likely to be displaced from its proper location during pouring and vibrating.

It appears that shear reinforcing is im-

portant in pipe of large diameter, particularly if the pipe is heavily reinforced. However, the types of shear reinforcing described in this paper have some drawbacks. It is certainly possible that better

methods may be developed. It is hoped that these tests will focus attention on a phase of pipe design and manufacture where improvements beneficial to both consumer and producer are possible.



Figure 16. This is the top of a Design 3 pipe after being tested to failure. Stripping or shearing of the concrete did not occur.

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