Experience with Shear Reinforcement in Reinforced Concrete Pipe

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• PRODUCERS of reinforced concrete pipe have realized for many years that an upper limit existed for the strength of large pipe in a three-edge-bearing test. This was reflected in most standard specifications in that standard designs were not included for pipe larger than about 72-in. inside diameter. Until the revision of ASTM C76 Specification for Reinforced Concrete Culvert Pipe, about three years ago, this upper limit had never been too well defined. However the new specification C76-57T, Tentative Specification for Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, definitely fixed the limits for standard designs for the various strength classifications for sizes up to 108-in. diameter. Above these limits, special designs using thicker walls, shear reinforcement or both are generally required.

For example, in Class I which is for a 1200-D ultimate, standard designs are given for pipe up to and including the 108-in. size. However in Class IV, which is for a 3000-D ultimate, standard designs are given only for pipe up to and including 72-in. diameter for wall B. For any larger pipe in this class, special designs are required.

The need for the special designs is created by the particular type of test generally used as an acceptance test for reinforced concrete pipe. This is the three-edge-bearing test. In this test, the pipe is supported on two closely spaced strips of hard wood, rubber, or sand-filled hose. The load is applied along a line bearing located diametrically opposite the center of the support. In effect the pipe is subjected to a concentrated load. This is the standard method of load testing a pipe as described in ASTM, AASHO, Federal and other specifications. Reinforced pipe tested in this manner is checked for the load to produce an 0.01-in. crack and the load to produce ultimate failure. Often, a sand bearing test is also specified. However, it is a cumbersome test, expensive to perform and not often used.

The three-edge-bearing test produces high shearing stresses in the wall of a pipe. The standard reinforcement for a large diameter pipe may be two circular cages of steel, one near the inner surface of the pipe wall and one near the outer. It may also be a single elliptical cage so shaped that the steel is properly located to resist the tensile stresses that develop in the concrete due to bending moments. A combination of circular and elliptical cages may also be used. None of these systems provide any reinforcement for the diagonal tension stresses that are developed as a result of the high shearing stresses in a three-edge-bearing test. Thus the maximum test load that this pipe can carry is limited largely by the resistance of the concrete alone to a diagonal tension failure.

In recent years there has been a steadily increasing demand for higher and higher pipe strengths. This demand has been largely but not entirely in highway work. Interstate highways with flatter grades and long radius curves require the construction of deep cuts and high fills. Concrete pipe culverts under these higher fills often require either special methods of installation such as the imperfect trench method or pipe which will carry the required heavier test loading. When this test loading is beyond the limits of the standard designs given in ASTM or AASHO Specifications, special designs are required.

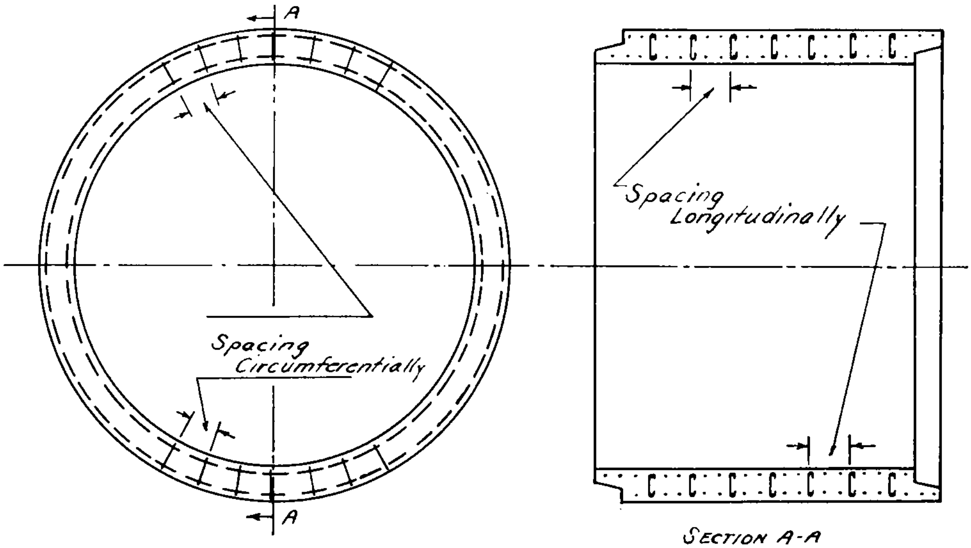

Figure 1. Two circular cages with shear reinforcement.

A special design may be based on an increased wall thickness. This provides more concrete to carry the diagonal tension developed in the three-edge-bearing test. It also will permit a reduction in the amount of tension reinforcement over that used with a standard wall thickness. Generally a manufacturer can without too much difficulty produce a thick-wall pipe by using outside forms of the next larger standard size of pipe, although this may not always be the case. Probably in the smaller pipe sizes, increasing the wall thickness is the best way to extend the upper limit of the pipe strength in a test. For larger diameters, however, increasing the wall thickness may mean a considerable weight increase. This may mean increased delivery costs to the competitive disadvantage of concrete pipe. It may also create some problems in handling the pipe at the installation site although thick-wall pipe as large as 13 ft in inside diameter has been made and installed satisfactorily. In many cases, however, where a special design is required a manufacturer will prefer to use standard equipment. Therefore, to carry the diagonal tension stresses, shear reinforcement must be provided in the pipe wall.

In pipe reinforced with two circular cages, this shear reinforcement is in the form of radial ties between the two cages (Fig. 1). The ties can be inserted singly, but they can also be built in multiple assemblies so that an entire row can be inserted at one time. In pipe reinforced with a single elliptical cage the shear reinforcement is usually made of circular segments welded to the main elliptical cage (Fig. 2).

The use of shear reinforcement was described in 1955 (*1*). Since that date, more than 50 installations have been de-

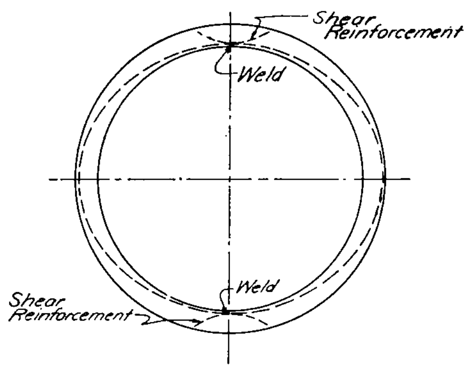

Figure 2. Elliptical steel cage with shear reinforcement.

signed and built using shear reinforcement. No doubt many others have been built that have not come to the attention of the author. At least one state includes provisions in its specifications for this type of pipe. Other states accept such pipe specifically designed for a particular installation. With this background of experience, it is possible to form some conclusions on the use of shear reinforcement in pipe.

There can be no doubt that shear reinforcement properly designed and properly installed provides one means of manufacturing a pipe which will meet a very high test load. It is believed that the action of the shear reinforcement is exactly like that of stirrups in a reinforced concrete beam. The shear steel or stirrups carry the diagonal tension. This makes possible the effective use of greater areas of tension reinforcement. In the pipe however, the shear reinforcement performs the added function of holding the tension steel in its curved shape. Under heavy tension this steel would have a tendency to straighten out, thus spalling off the concrete cover on the inside of the pipe.

It would appear that the design of the shear reinforcement must be largely empirical. As previously noted, reinforced concrete pipe is accepted in part on the basis of its ultimate strength in a three-edge-bearing test. Hence it is the behavior of the shear reinforcement at loads approaching the ultimate that is of particular interest to the designer. The true distribution of stresses in a pipe wall at these loads cannot be evaluated. There will be considerable cracking and crushing of the concrete and relatively large deflections will have occurred. Tension steel may have been stressed beyond its yield strength. The application of the equations for the design of shear reinforcement in a beam will be useful in arriving at a satisfactory design for the size of the shear reinforcement in a pipe. However, experience and judgment are required for the successful application of these formulas.

The shear reinforcement to be effective must be positively anchored to the inside cage of the pipe reinforcement. Usually this anchorage is by hooking or bending the tie or stirrup around this reinforcing. The hook or bend should be through a minimum of 180 deg and should project back into the concrete at least 1 in. beyond the steel to which it is anchored (Fig. 3). This will help insure that the hook will not straighten out under load. Some manufacturers have used sections of welded-wire fabric bent so as to be easily anchored with the use of an auxiliary rod.

Welding of the shear steel to the main reinforcing to obtain the necessary anchorage is probably too expensive to be practical.

The sheer steel spacing should not be too great. Certainly it should not be greater than the pipe wall thickness in the section of high shear except possibly where its use is mainly to provide an additional safety factor. Somewhat better results can be obtained with closer spacing but the cost increases at a rapid rate. The shear steel should cover an angle of at least 60 deg at the top and bottom of the pipe. When installed the pipe should be so placed that the shear reinforcement is centered about the vertical centerline of the pipe.

The effect of shear reinforcement on the 0.01-in. crack strength of reinforced concrete pipe is somewhat controversial. Some tests have shown exceptionally high cracking strengths when shear reinforcement was used. In other tests, cracking strengths have been surprisingly low relative to the ultimate strengths obtained. The formation of the 0.01-in. crack is dependent on the crack pattern which develops in the concrete. The crack pattern and spacing will depend on the bond between the tension steel and the concrete and apparently also to some extent on the location and spacing of the shear reinforcement. Pipe reinforced for shear has always been designed with large areas of tension steel. Often this is made up using two layers of welded-wire fabric rather than a single layer of heavy fabric. Better bond would be expected with the two-layer cage and hence a better cracking strength than with the single heavy

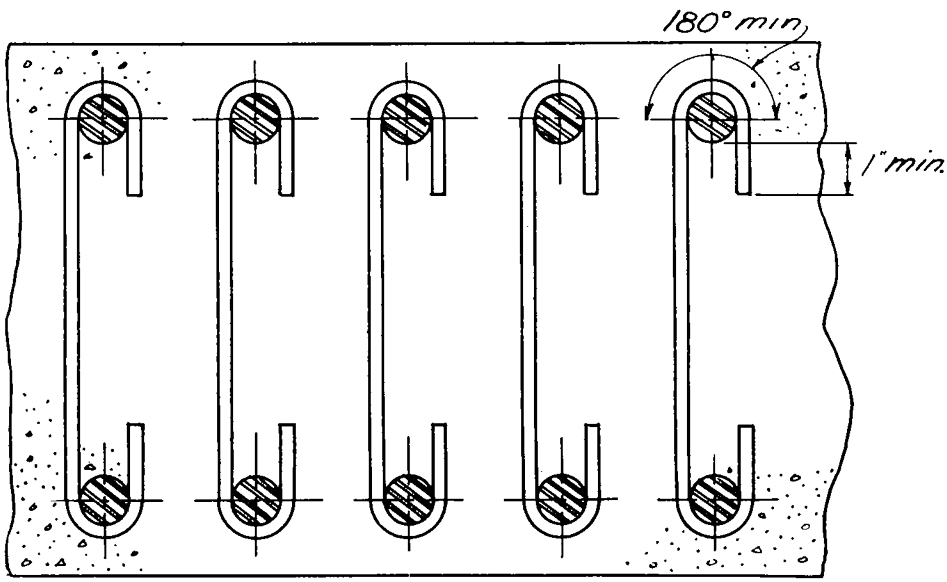

Figure 3. Cross-section through pipe wall.

cage. However, tests have shown that if a staggered pattern of placing the shear steel is used, a better crack pattern results even with a single heavy cage.

There are two opposing schools of thought concerning the practical value of reinforcing pipe for shear. One feels that such designs are practical and competitive. The other feels that where high fills are encountered which might require this type of pipe, more emphasis should be placed on special methods of installation which could use pipe of a lower crushing strength. It is further argued that shear reinforcement is of value only in a three-edge-bearing test and would not be equally effective in the field.

Experience to date is certainly proof of the value of the imperfect trench method of installation. Beyond a doubt it is practical and permits the use of standard pipe under very high fills. Where this method of installation can be used and where there is sufficient understanding of what is involved in this method of construction, its use certainly should be strongly encouraged. There are some installations, however, where this method of construction cannot be used. The pipe for such an installation will have to have a high crushing strength and should be built with shear reinforcement. The effectiveness of shear reinforcement in the field has neither been proven nor disproven. All installations of this type of pipe with which the author is closely familiar have performed in excellent fashion. These are nearly all installations under very heavy fills. The method of bedding the pipe on some of these installations has not been particularly good. This would seem to show that shear reinforcement is effective in the field. However, research is needed to indicate its true value. Certainly it provides protection against poor bedding practices. Its continued use is further evidence that it is a workable means of manufacturing high strength pipe in the large sizes.

REFERENCE

1. HENDRICKSON, J. G., JR., "Tests of Large-Diameter Concrete Pipe." HRB Bull. 102, pp. 1-11 (1955).