U. S. Department of Agriculture
Soil Conservation Service
Engineering Division
Design Branch

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DESIGN NOTE NO. 9*

Subject: Use of AWWA C302 Pipe for Principal Spillway Conduit

Purpose of Note: Questions exist as to the relative merits of pressure pipe meeting the specifications AWWA C300, AWWA C301, and AWWA C302 for use as principal spillway (drop inlet) conduit under or through earth dam embankments. If differences in acceptability for this purpose exist, and they do, what are the conditions and requirements of use for each type? It is the purpose of this design note to answer these and related questions.

AWWA C300 is Reinforced Concrete Water Pipe - Steel Cylinder Type - Not Prestressed

AWWA C301 is Reinforced Concrete Water Pipe - Steel Cylinder Type - Prestressed

AWWA C302 is Reinforced Concrete Water Pipe - Noncylinder Type - Not Prestressed

Hereafter in this note these pipe will be referred to as 300, 301, or 302 pipe.

Requirements for Principal Spillway Conduits: The main requirements are now listed and discussed.

Durability - The conduit must be durable because of the high cost of replacement. It must not deteriorate in its environment at the particular site of use. Principal causes of deterioration are: (1) freezing and thawing where water seeps through or can enter cracks in the conduit wall, (2) corrosion of reinforcing steel due to exposure to oxygen and moisture or acid water and (3) chemical attack on the concrete due to excess concentration of acid or alkali. All of these causes of deterioration are augmented by cracks that permit seepage of water through the conduit wall or into the wall.

Accessibility for Maintenance and Repair - Virtually no material available at a practical cost can be expected to last 100 years without some maintenance. Hence it is of major importance that the conduit be of sufficient size to accommodate relatively easy inspection and repair.

Strength to Resist Loads - The conduit must not fail structurally. It must resist all forces both transverse and longitudinal that can come to it by external or internal loading, on firm or yielding foundation, as

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the case may be. It should resist all known loads with a very comfortable margin of safety. There are enough unknowns, particularly due to unpredictable variations in foundation consolidation, to tax any reasonable factor of safety.

It is well established that the load from an earth dam embankment on a compressible foundation produces tensile strain in both the embankment and the foundation in a direction transverse to the embankment centerline. The magnitude of this strain, for almost any dam on a compressible foundation, far exceeds the strain at failure of concrete in tension. (See TR No. 18.)

Hence on a compressible foundation with normal layout of the principal spillway conduit the earth stretches in the longitudinal direction of the pipe and relative to it.

This relative motion extends the pipe joint opening and may induce sufficient longitudinal tensile stress in the pipe to cause transverse cracks. If the pipe does not crack, the maximum tension will exist at or near the middle of the pipe section. The pipe section will crack as soon as its strength in tension is exceeded. If the foundation and embankment were homogeneous and isotropic and no bending stresses were induced in the pipe, the location of the cracks should be symmetrical about the middle of the pipe section. It is doubtful that the idealized "no bending stress" condition exists in most foundations. When bending stress exists it is probably a maximum at a rigid anti-seep collar, or if an anti-seep collar is not on the section of pipe then at or near the middle of the pipe section. It is probable that the point of maximum bending stress has more to do with the location of transverse cracks than any other single factor.

The maximum probable change in direct tension in the pipe per foot of length is usually equal to the total normal inter-granular pressure per foot multiplied by (1) the coefficient of friction between the soil and the pipe or (2) the coefficient of internal friction in the soil, whichever is smaller. These forces are probably a maximum on a conduit under an earth dam embankment at the time of completion of the earth fill and before development of phreatic surface.

From Technical Release No. 5, The Structural Design of Underground Conduits, the total vertical load per foot length of the conduit in pounds is

$$W_c = C_p \gamma b_c^2 = K \gamma b_c H_c \quad \ldots \ldots \ldots \quad (1)$$

where

$C_p$ = a load coefficient (See TR No. 5.)

$\gamma$ = average weight of the embankment material above the top of the conduit in lbs. per cubic foot

$b_c$ = the outside width of the conduit in feet

$H_c$ = height of the earth fill above the top of the conduit in feet

K = another different load coefficient

For positive projecting conduits in the incomplete projection condition, the condition usually encountered in our earth dam operations, a reasonable average value for K is 2.0. Then

$$W_c = 2\gamma b_c H_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The total load acting upward on the bottom of the conduit is approximately equal to the load on top and the loads on the two sides is approximately equal to one-sixth of the load on top. Then the total normal load on the conduit per foot of length is approximately

$$W_{NT} = 4.33\gamma b_c H_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The coefficient of friction between earth and concrete for wet unsaturated clay is about 0.2, and for dry clay is about 0.5. For remolded clay the coefficient of internal friction varies from about 0.25 to 0.50. Other materials and conditions would indicate different values.

The change in total longitudinal stress in the pipe in pounds per foot length of pipe is

$$\Delta S = 4.33C_f \gamma b_c H_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where

$C_f$ = the appropriate friction coefficient

$\Delta S$ = the change in stress in pounds per foot length of pipe

The force tending to pull a section of pipe apart is

$$F = \Delta S \cdot \frac{L}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where

F = total tensile force in the section of pipe in lbs.

L = length of section of pipe in feet

Assume that the concrete has no strength in tension, then

$$F = A_s f_s \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where

$A_s$ = the cross sectional area of the longitudinal steel in the pipe in square inches

$f_s$ = the unit stress in the longitudinal steel in pounds per square inch

Combination of equations (4), (5), and (6) gives

$$A_s f_s = 4.33 C_f \gamma b_c H_c \cdot \frac{L}{2}$$

$$= 2.17 C_f \gamma b_c H_c L \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

Evidence in the form of partial cracking at the top or bottom of the pipe shows that, in the average foundation subject to consolidation, bending stresses are also induced in the conduit from differential settlement due to irregularities in the foundation or to the effect of rigid anti-seep collars under the conduit. The forces which produce such bending are highly indeterminate. Available evidence indicates that rigid anti-seep collar projections below the bottom of the conduit may be a principal cause of induced bending in the conduit.

Ability of 300, 301, and 302 Pipe to Meet Above Requirements: All three types of pipe can be adequately designed to resist the lateral loads and the joint rotation and extension capacity are equal because all types can be provided with the same steel joint rings and "O" ring gasket.

The major strength difference in the three types of pipe is found in the absence or presence of a steel cylinder. The 300 and 301 pipe are manufactured with a steel cylinder of not less than 16 gage, U.S. Standard, welded to the joint rings to make a watertight assembly. The 302 pipe does not contain such a cylinder. The presence of the cylinder makes a large difference in the amount of longitudinal steel in the 300 and 301 pipe as compared to 302 pipe.

Table 1

Cross-Sectional Area of Longitudinal Steel*

| Nominal Diameter Inches | Type of Pipe | | | | |
|---|---|---|---|---|---|
| | 300 | | | 301 | 302 |
| | Cylinder | Re Bars | Total | Cylinder | Re Bars |
| 18 | 3.8 | 1.2 | 5.0 | 3.8 | 1.2 |
| 24 | 5.0 | 1.2 | 6.2 | 5.1 | 1.2 |
| 30 | 6.1 | 1.2 | 7.3 | 6.4 | 1.2 |
| 36 | 7.3 | 1.2 | 8.5 | 7.6 | 1.2 |
| 42 | 8.4 | 1.2 | 9.6 | 8.9 | 1.2 |
| 48 | 9.6 | 1.2 | 10.8 | 10.2 | 1.2 |

*Approximate minimum requirements for 16-foot long sections of pipe. There is no minimum requirement for "Re Bar" steel for the 300 pipe; the values shown are seldom exceeded by any appreciable amount. The cross-sectional area for the cylinder steel is based on the use of 16 gage, U. S. Standard, a minimum gage commonly used in the industry.

It is evident from Table 1 that 300 and 301 pipe have much greater resistance to both direct tension and tension due to induced bending than does 302 pipe.

When bending and shear are induced in the conduit from differential settlement under a section of pipe the interaction of the pipe and cradle in longitudinal bending is open to question. If the pipe and cradle were to interact as a monolithic beam, the structure would have considerable strength in bending against forces producing tension in the bottom element and addition of longitudinal steel in the cradle would provide added resistance to bending. The addition to longitudinal steel in the cradle is not effective in providing resistance to bending against forces which produce tension in the top element, such as those induced over rigid anti-seep collars. Because the interaction between pipe and cradle is questionable, and the forces producing bending are highly indeterminate, the use of additional longitudinal reinforcement in the cradle does not solve the problem.

Watertightness - The 300 and 301 pipe have a higher level of reliability as to watertightness under pressure mainly because of their process of manufacture in which the cylinder and ring assembly is pressure tested before the concrete cover is added. There have been some minor problems with 302 pipe under internal pressure test due to seepage apparently around the joint ring. The leakage in these cases has been very low but any leakage should be avoided.

The Evidence: Our recorded experience, summarized in Table 2 as well as our spot observations clearly demonstrate the superiority of 300 and 301 pipe over 302 pipe. Table 2 does not tell all of the story. The circumferential cracks in 16-foot lengths of 301 pipe did not exceed one-sixtyfourth of an inch whereas the circumferential cracks in 12-foot lengths of 302 pipe ranged from one-sixteenth to one-quarter inch. In the small sample of 3 dams with 300 pipe there were no cracks evident on the inside of the conduit.

Table 2

Cracking Experience*

| Type of Pipe | 300 | 301 | 302 |
|---|---|---|---|
| Number of Structures | 3 | 28 | 32 |
| Number of structures with cracks having a width equal to or less than 1/16 inch | | | |
| full circle transverse cracks | 0 | 3 | 18 |
| partial transverse cracks | 0 | 8 | 11 |
| Number of structures with cracks having a width greater than 1/16 inch | | | |
| full circle transverse cracks | 0 | 0 | 13 |
| partial transverse cracks | 0 | 0 | 1 |

*From "Summary of Field Reports and Analysis of Data on Surveys of Principal Spillway Pipe Conduits" by Design Section, SCS, April 22, 1964, pages 29-35.

Recommendations:

1. AWWA C302 pipe should be used only on foundations of sound unweathered rock with a reinforced concrete cradle.

2. Construction plans should include 302 pipe as an alternate only when the conditions of recommendation number 1 above are satisfied.

3. Equation (7) should be used as a guide to estimate the gage of cylinder required for conduits of 300 or 301 pipe under high embankments on compressible foundations. As a guide a value of 0.25 for $C_f$ is recommended.

Example - Calculate the gage requirement for a 301 pipe conduit 36 inches in diameter with standard reinforced concrete cradle under an 80-foot high embankment. Outside diameter of the pipe is 44 inches. The moist weight of the embankment will be 110. lbs. per cubic foot. The conduit sections will be 16 feet long. The allowable stress in the steel cylinder will be taken as 20,000. lbs. per square inch. (The minimum yield strength for cylinder pipe under the specifications is 27,000 psi.)

$$A_s f_s = 2.17 C_f \gamma b_c H_c L$$

$$A_s = \frac{(2.17)(0.25)(110)(80)(16)(3.67)}{20,000}$$

$$= 14.0 \text{ square inches}$$

$$A_s = \pi \text{ (mean diameter of cylinder)(thickness)} = \pi D_m t$$

$$t = \frac{A_s}{\pi D_m} = \frac{14.0}{38.5\pi} = 0.12 \text{ inch}$$

Use steel cylinder of 10 gage, U. S. Standard.