Some Effects of Fabrication Practices on the Strength Characteristics of Reinforced Concrete Culvert Pipe

Robert C. Deen*   James H. Havens†

*Kentucky Highway Materials Research Laboratory
†Kentucky Highway Materials Research Laboratory
This paper is posted at UKnowledge.
https://uknowledge.uky.edu/ktc_researchreports/1279
MEMO TO: A. O. Neiser  
Assistant State Highway Engineer

The attached report "Some Effects of Fabrication Practices on the Strength Characteristics of Reinforced Concrete Culvert Pipe" by R. C. Deen, Research Engineer Principal, and J. H. Havens, Assistant Director of Research, covers our investigation into the jointing practices of cage reinforcement for culvert pipe.

You will recall that during our performance studies of reinforced concrete pipe culverts in 1960 there were some indications that reinforcing cages had separated at joints. In one instance a steel cage that had been lapped showed separation. Upon checking the pipe specifications that were in effect at that time, we found that lapped joints were well defined but there was no specification requirement for the weld that was permitted in lieu of the 40-diameter lap joint. We made inquiry to the Chairman of ASTM Committee C 13 on concrete pipe that is responsible for specification C 76 (Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe) concerning the specification for the weld. We were advised that the weld was not defined and asked to supply any information that we had or could provide on the subject.

We discussed welding practices being used in plants supplying reinforced concrete pipe in Kentucky and obtained sample splices for laboratory study. It was decided that a research project involving full scale pipe sections manufactured with a variety of jointing details would be the most desirable method for evaluating the joints in the reinforcing cages.

Mr. W. P. Curlin, General Manager of the Kentucky Concrete Pipe Company, offered to fabricate the necessary pipe sections and to make available the testing facilities at the Louisville plant of the company at no cost to the Department of Highways. Mr. Robert Hockensmith, Manager of the Louisville plant, and Mr. Curlin were indeed helpful and...
INTRODUCTION

Underground conduits have been used for hundreds of years for drainage and water supply purposes. With the advent of railway and automobile transportation, the use of underground conduits for drainage purposes beneath the roadways increased greatly. It soon became apparent that there was a definite need for knowledge concerning the manufacture, installation, and field behavior of pipe culverts. Accordingly, in the first half of the century, much attention and research has been directed toward the development and establishment of acceptable techniques and specifications for the manufacture and installation of pipe culverts. This work has been accomplished by many individuals and organizations.

Factors governing the maximum height of fill, and thus the maximum load that may be safely placed over reinforced concrete pipe culverts, are: 1) pipe strength, 2) character of fill material over the pipe, 3) character of the foundation material beneath the pipe, 4) relative settlement of the material over the pipe to that of the material on either side of the pipe, and 5) the method of bedding and installation. In an attempt to provide a method by which one can easily identify a satisfactory pipe with regard to quality and strength, the rather simple and convenient three-edge bearing test has been proposed as ASTM Designation C 76-59T (AASHO M170-57)(See Appendix D). This test method is currently being used in Kentucky as well as in many other areas to evaluate the strength of a reinforced concrete pipe. It has been suggested that this method is applicable to concrete pipe up through the 72-inch inside diameter size.
A criterion for the installation design of concrete pipe culverts has been developed by the Bureau of Public Roads in cooperation with the American Concrete Pipe Association. This criterion was distributed to the various highway agencies on April 4, 1957, as Circular Memorandum 22-40, Bureau of Public Roads (See Appendix A). This memorandum is the basis for specifications adopted in thirteen states, including Kentucky. To provide for an efficient utilization of rigid pipe, the Kentucky Department of Highways issued Amendments 15, 15A and 16 to the 1956 edition of Standard Specifications for Road and Bridge Construction (See Appendix B) as well as Standard Drawings 11.22 and 11.23 (See Appendix C) specifying bedding details, methods of installation and pipe strength required for various heights of fill.

Early experience gained from work on the interstate highway system disclosed a need for additional detailed study and understanding of the theory of design, pipe fabrication practices, and construction or installation practices. Investigations of certain aspects of the theory and installation practices have been reported by the Research Division of the Kentucky Department of Highways*. On November 12, 1959, the Bureau

---

requested the states to furnish annual performance data for the purpose of evaluating the installation criterion. According to the Bureau's Circular Memorandum 32-30, dated October 18, 1962, 34 states are participating in the study and are making annual reports. The present study concerns the fabrication practices and their possible relationship to pipe strength, failure of pipe under embankment loads, and the feasibility of repairing or restoring the structural integrity of in-place pipe that have been damaged during or soon after construction.
THEORETICAL CONSIDERATIONS

The strength of reinforced concrete pipe is commonly stated in terms of D-load strength. By definition, D-load is the load in pounds per linear foot per foot of internal diameter. An advantage of the D-load designation is that all sizes of pipe of a given D-load, installed under similar conditions of bedding and backfilling, will support the same height of fill. Reinforced concrete pipe are tested by the three-edge bearing test and are classified according to the D-load that will produce a 0.01-inch crack or the D-load that will produce ultimate failure. The 0.01-inch crack D-load is the load in pounds per linear foot per foot of internal diameter which the pipe will withstand under the three-edge bearing test without showing cracks in excess of a width of 0.01 inch. The ultimate D-load is the load in pounds per linear foot per foot of internal diameter which the pipe will withstand under the three-edge bearing test before ultimate failure. Minimum permissible D-loads for the five strength classes of reinforced concrete pipe are listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Minimum Permissible D-Loads.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Class</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td>IV</td>
</tr>
<tr>
<td>V</td>
</tr>
</tbody>
</table>
The three-edge bearing test is a severe test inasmuch as the load applied to the conduit is in the form of point loading and inasmuch as there is no side support applied to the conduit as there would be in the case of a field installation where lateral pressure would exist at the sides of the conduit. Under field conditions of loading, the vertical loads applied to the conduit will be distributed over a portion of the conduit rather than concentrated and side pressures will be exerted on the conduit; thus, under field conditions the conduit may sustain loads which are greater than those indicated by the three-edge bearing test. This fact is accounted for in design by use of a load factor, which is the ratio of the strength of a pipe under any stated condition of loading to its strength when tested by the three-edge bearing method. The value of the load factor is greatly dependent upon the method in which the conduit is bedded as well as the nature and density of the backfill material.

It is imperative, therefore, that the installation of the pipe culvert be in full accordance with the design theory and with the plans. If damage occurs to the pipe, and if full faith is credited to the design procedure, the fault must arise from either poorly fabricated pipe, or improper installation techniques, or negligence in adhering strictly to plans.

In the event that a pipe is damaged, whether the cause is apparent or not, the question inevitably arises as to what resources are available as an alternative to complete removal and replacement -- i.e., can the pipe be effectively and satisfactorily repaired in place? With regard to this, Paragraph 30 of ASTM C76-59T (AASHO M 170-60) is cited in full:
"Pipe may be repaired, if necessary, because of occasional imperfections in manufacture or accidental injury during handling and will be acceptable if, in the opinion of the purchaser, the repairs are sound and properly finished and cured and the repaired pipe conforms to the requirements of these specifications."

In a most liberal interpretation, the pipe, even though severely damaged, could be acceptable if repaired and restored sufficiently to meet the requirements of the specification.

The reinforcement steel in a concrete pipe is more or less inactive or passive so long as the pipe is subjected to a uniform radial loading. In this case, the annular shell of the pipe is uniformly in compression. Any unbalance in imposed loads produces tensile stresses in the outer portion of the concrete. Since the concrete is inherently weak in tension but strong in compression, the function of the reinforcement is to provide a tensile reactance to the compression borne by the concrete. Thus a pipe could be fabricated from individual concrete panels with external steel bands in much the same manner as wood-stave barrels (See Fig. 1). It follows then that one or more damaged panels could be replaced and thereby restore the continuity of bearing and compression in the shell.

On the other hand, if the shell were cast monolithically about the steel and were then fractured to such an extent that continuity of compressive bearing in the concrete was lost (See Fig. 2), it follows that routing of the damaged concrete and replacement with new concrete, even though a high degree of bond was not achieved, should restore the
Fig. 1. Pipe Consisting of Compression Panels and External Reinforcement.
Fig. 2. Concrete Pipe with Discontinuity in the Compression Ring.

Fig. 3. Pipe with Compression Ring Patched and Restored.
pipe virtually to its original strength (See Fig. 3). This idea assumes, of course, that the steel is not damaged and that the pipe, when restored, is not critically out-of-round.

Many of the pipe found to be damaged in-place have been deformed considerably — otherwise the concrete shell would have remained intact (See Figs. 4 through 9). Rejecting any thought toward jacking in-place pipe back to roundness, the problem at hand involves the degree of collapse to which remedial treatment might be deemed feasible. For instance, if the pipe is elongated horizontally and if the continuity of the shell is restored, the pipe could never be quite as strong as the original round pipe. If the interior of the pipe is also lined to provide an additional compression ring (preferably reinforced), it should be possible to strengthen the pipe to a degree equal to or greater than its original value (See Fig. 10).

Of equal importance to the strength of the pipe is the continuity of reinforcement steel. It is assumed that the steel in a damaged pipe may have been stressed to or beyond the yield point but that it is capable of again withstanding an equal level of stress unless continuity has been impaired. A broken weld or series of welds would therefore be an obvious detriment to strength unless repaired prior to replacement of concrete in the compression shell. In fact, welds and laps are of considerable interest to this study because of their possible influence upon the original strength of the pipe. In manufacture, where two cages of wire are used, it is the usual practice to place the joints 180 degrees apart. It follows, therefore, that if the welds or laps
Fig. 4. Failure in Bottom of 60-Inch Culvert under a 28-Foot Fill; Station 1619+45L, I-64-3(7)35, Shelby County.

Fig. 5. Failure in Top of 60-Inch Culvert under a 28-Foot Fill; Station 1619+45L, I-64-3(7)35, Shelby County.
Fig. 6. Failure in Bottom of 54-Inch Culvert Under a 32-Foot Fill; Station 1633+30L, I-64-3(7)35, Shelby County.

Fig. 7. Failure in Top of 54-Inch Culvert Under a 32-Foot Fill; Station 1633+30L, I-64-3(7)35, Shelby County.
Fig. 8. Failure in Bottom of 54-Inch Culvert under a 53-Foot Fill; Station 1087+50, I-75-7(5)160, Grant County.

Fig. 9. Failure in Top of 54-Inch Culvert Under a 53-Foot Fill; Station 1087+50, I-75-7(5)160, Grant County.
Fig. 10. Repaired Pipe with Reinforced, Gunite Liner.
are weak and if the pipe is by chance positioned in the three-edge bearing test or in an embankment so that the joints are located at points of greatest bending and highest stresses, strength could be seriously affected — moreso than if the joints were randomly orientated.

Aside from other factors, such as wall thickness and amount and strength of steel which are more closely related to design, the quality of welds or laps in the steel may largely determine load strengths. In an older specification (AASHO M 41-55, deleted in 1957), the weld was described thus:

"If welded, the member at either a welded splice or intersection shall develop a tensile strength not less than the minimum strength required for the reinforcement."

The current specifications (AASHO M 170-60 and ASTM C 76-59T) specify:

"If the splices are not welded."

and the alternative of welding is not subsequently clarified. AASHO M 32-60, Cold-Drawn Steel Wire for Concrete Reinforcement, covers the requirements for the wire to be used in Welded Steel Wire Fabric for Concrete Reinforcement. AASHO M 55-60 (ASTM A 185-58T), which includes a shear-type test for the quality of welds obtained in the manufacture of the fabric (mesh). Apparently none of the existing specifications covers the particular point about welding the mesh to form the reinforcing cage.

Observations of in-place pipe which were damaged structurally to an extent that the welded joints in the steel cage were exposed (in
the bottom of the pipe) revealed that some welds (lapped about 1-1/2 inches, welded on one side) had broken. Welded joints were then clipped from normal production cages and these were tested in tension (See Appendix E, Table 6). Invariably the splice was weaker than the wire. It was noted, however, that the break usually occurred at the juncture of the wire and fillet where the weld cut into the wire and reduced the cross-section. Also, due to the eccentricity of the pull about the weld, there was bending of the wire at its juncture with the weld. Although these pull-tests were not realistic or representative of the strength of the joint when encased in concrete, it was apparent that the welds were incapable of withstanding the full tension of the wire.
MATERIALS AND APPARATUSES

In an effort to obtain additional information concerning the effects of various pipe-fabrication practices upon pipe performances, the Kentucky Concrete Pipe Company was most cooperative in manufacturing and testing several sections of pipe at the Louisville Plant.

Thirty-three sections of Class III pipe, 50 inches in inside diameter by four feet in length were prepared according to the following schedule:

Series A - Four sections, inner and outer cages of reinforcement lapped at least 40 diameters, laps 180 degrees apart.

Series B - Four sections, inner and outer cages of reinforcement lapped at least 40 diameters, laps 90 degrees apart.

Series C - Four sections, inner and outer cages lapped approximately three inches and fastened with two spot welds, welds placed 180 degrees apart.

Series D - Four sections, inner and outer cages lapped approximately three inches and fastened with two spot welds, welds placed 90 degrees apart.

Series E - Four sections, inner and outer cages lapped approximately three inches and fastened with two spot welds, welds 0 degrees apart.

Series F - Four sections, non-reinforced.

Series G - Three sections, inner and outer cages lapped approximately 1-1/2 inches and fastened with one spot weld, welds spaced 180 degrees apart.

Series H - Three sections, inner and outer cages lapped approximately 1-1/2 inches and fastened with one spot weld, welds spaced 90 degrees apart.

Series J - Three sections, inner and outer cages lapped approximately 1-1/2 inches and fastened with one spot weld, welds placed 0 degrees apart.
The inner cages of reinforcement were made from 3- x 8-inch, No. 0 + s. welded wire fabric. The No. 0 wire (0.3065-inch diameter) was the longitudinal wire in the fabric and was spaced three inches, center-to-center. This is the wire which provides the reinforcement for the concrete pipe. The No. 5 wire (0.2070-inch diameter) was spaced at eight inches. The outer cage of reinforcement was made from 3- x 8-inch, No. 2 + 7, welded wire fabric; the No. 2 wire (0.2625-inch diameter), on 3-inch spacing, provided the reinforcement for the pipe.

The four sections of pipe in Series F were manufactured on November 9, 1960, and the 20 sections in Series A through E were made November 10, 1960. The last nine sections, Series G, H and J, were prepared on November 14, 1960. Test cylinders, 6 x 12 inches, and beams, 3 x 5 x 20 inches, were fabricated from the same concrete used in the pipe.

The wire fabric for the reinforcing steel was taken from rolls and run through a press which shaped the fabric in the approximate form required (See Fig. 11). The fabric was then cut and either tied or welded so as to maintain its shape during handling. For Series A and B the inner cage of reinforcement was lapped approximately 12 inches (See Fig. 12) and the outer cage was lapped approximately 16 inches (See Fig. 13). Both the inner and outer cages used in Series C, D and E were lapped about three inches and were held in shape by two welds (See Fig. 14). For Series G, H and J the laps were approximately 1-1/2 inches and were fastened with a single weld (See Fig. 15). Companion cages were then placed in the mold (See Fig. 16) and made ready for placement of the concrete.
Fig. 11. Wire Fabric from Roll Being Shaped by Running Through a Press.
Fig. 11. Wire fabric from roll being shaped by running through a press.
Fig. 12. Joint of Inner Cages of Reinforcement Used in Series A & B.

Fig. 13. Joint of Outer Cages of Reinforcement used in Series A & B.
Fig. 14. Joint of Inner Cages of Reinforcement used in Series C, D & E.

Fig. 15. Joint of Reinforcement Cages Used in Series G, H, & J.
All sections of pipe used in this investigation were machine-made, tamped pipe (See Fig. 17). In the machine, the relatively dry concrete mix is rammed into the form by two hardwood, metal shod tampers (See Fig. 18) operating at the rate of 500 to 600 times a minute. The core (inside form) of the machine was fixed while the outside form revolved. As the form spins the dry mix is fed into the form and tamped. The machine then lifts the inside core and the pipe (See Fig. 19) is ready to be taken to the curing room. The outside form and base rings are so designed that when the latches are loosened, the weight of the form causes it to drop free from the pipe and permits the form to be reused immediately. The pipe were first cured in a steam-heated room (See Fig. 20) at 100°F to 130°F for 24 hours and then removed to an outside storage area for 28 days.

A Forney testing machine (See Fig. 21) having a capacity of 500,000 pounds, located in the yard of the Louisville Plant of the Kentucky Concrete Pipe Company, was made available for loading the pipe. All of the tests were made in this machine.

Shown in Fig. 22 is a yoke assembly which was used to restrain selected sections of pipe along their horizontal diameters during the three-edge bearing test. Additional details of the yoke assembly are shown in Fig. 23. The four different sizes of tie rods used in this portion of the study were:

1. Uniform diameter of 3/4 inch.
2. Uniform diameter of 3/8 inch.
Fig. 18. Hardwood Tampers.

Fig. 19. Spun Inner Surface of Pipe after Core has been Withdrawn; Pipe Still in Outer Form and on Dolly.
Fig. 21. Rotary Testing Machine.

Fig. 20. Pipe in Cutting Room.
Fig. 23. Details of Yoke Assembly.
3. A 3/4-inch rod with a reduced section, 8.0 inches long x 0.30 inch in diameter, at the middle.

4. A 3/4-inch rod with a reduced section, 2.6 inches long x 0.30 inch in diameter, at the middle.

Selected pipe were tested in three-edge bearing and with horizontal restraint in order to obtain some knowledge of the horizontal reactance to vertical loading.

From the group of pipe which was loaded to failure, a limited number was selected for repair. To effect the repair a cage of reinforcement steel was prepared from 3- x 8-inch, No. 0 + 4, wire fabric and placed in the broken pipe sections before gunite was applied to a thickness of approximately 2-1/2 inches.
RESULTS AND DISCUSSION

The results and discussions pertaining thereto are treated in four principal categories: 1) Reinforced Concrete Pipe, 2) Non-reinforced Concrete Pipe, 3) Repaired Pipe, and 4) Laterally Restrained Pipe.

Reinforced Concrete Pipe

Twenty-five pipe were loaded by the three-edge bearing method in accordance with the ASTM C 76-59T (See Appendix D). Pipe E-2, as will be shown subsequently (Fig. 40), was tested under a two-point bearing condition. In addition to recording the load required to produce a 0.01-inch crack and the ultimate load, provisions were also made to record load and changes in diameters throughout the entire test. The changes in the vertical and horizontal diameters were measured by means of extension dials as shown in Fig. 22. The load-deformation curves obtained from these tests are shown in Figs. 24-31. At the top of each figure are sketches showing the position of the pipe and the relative locations of the laps in the two cages of reinforcement steel during the test. An examination of these load-deformation curves indicates certain characteristics (Fig. 32) which are essentially the same for all pipe regardless of fabrication and(or) placement of the steel or the position of the pipe in the testing machine.

The load-deformation curves are essentially linear up to the occurrence of the 0.01-inch crack. There seems to be a very slight
Fig. 24. Load-Deformation Curves for Series A.
Fig. 25. Load-Deformation Curves for Series B.
Fig. 26. Load-Deformation Curves for Series C.
Fig. 27. Load-Deformation Curves for Series D.
Fig. 28. Load-Deformation Curves for Series E.
Fig. 29. Load-Deformation Curves for Series G.
Fig. 30. Load-Deformation Curves for Series H.
Fig. 31. Load-Deformation Curves for Series J.
Fig. 32. Typical Load-Deformation Curves.
tendency for the deformation to increase, with little attendant increase in load, when the first crack appears -- at something less than 0.1 percent change in vertical diameter and a load of 13 to 18 kips. This tendency for the curve to flatten seems to be more pronounced after the 0.01-inch crack appeared -- apparently, there was a slight redistribution of stress from concrete to steel. The 0.01-inch crack typically occurred at a strain of 0.1 to 0.2 percent and at a load of 18 to 25 kips. The slopes of the curves become flatter as the ultimate load (40 to 45 kips) is reached at strains of 0.6 to 1.5 percent. The pipe in Series A and B (steel lapped 40 diameters and tied) appear to have reached the ultimate load at smaller deformations, 0.6 to 1.0 percent, and therefore gave steeper curves than pipe in which the steel was welded.

Soon after the ultimate load was reached, the concrete at the top and/or bottom began to shear (See Figs. 4 through 9, 33 and 34). There was a slight decrease in the load at this point and thereafter the load remained rather constant to strains of 2.7 to 6 percent. At deformations of this magnitude the steel started to break in the outer cage about midway up the sidewalls (See Fig. 35). Very soon after the steel began to fail, the load decreased rapidly as the stresses transferred to the inside portion of the wall and caused compressive failure of the concrete (See Figs. 8 and 36).

It may be noted from the load-deformation graphs that pipe that had not been loaded sufficiently to break the steel recovered approximately 50 percent of the strain upon unloading and that those in which the steel had been broken regained only about 15 percent of the strain.

Other pertinent data from these tests are summarized in Table 2.
Fig. 33. Shear-Type Failure in Top of Pipe.

Fig. 34. Shear-Type Failure in Top of Pipe.
Fig. 35. Broken Steel in Outer Cage of Reinforcement.

Fig. 36. Compressive Failure of Inner Portion of Concrete Wall.
Table 2. Summary of Test Results on Pipe Tested in Three-Edge Bearing

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>0.01-in. Crack Load (kips)</th>
<th>0.01-in. Crack U-Load (lbs/sq.ft.)</th>
<th>Ultimate Load (kips)</th>
<th>Ultimate U-Load (lbs/sq.ft.)</th>
<th>Date Manufactured</th>
<th>Date Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>23</td>
<td>1278</td>
<td>37</td>
<td>2056</td>
<td>11-10-60</td>
<td>12-8-60</td>
</tr>
<tr>
<td>A-4</td>
<td>--</td>
<td>--</td>
<td>46</td>
<td>2556</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>B-1</td>
<td>28</td>
<td>1556</td>
<td>44</td>
<td>2444</td>
<td>11-10-60</td>
<td>12-8-60</td>
</tr>
<tr>
<td>B-2</td>
<td>--</td>
<td>--</td>
<td>47</td>
<td>2611</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>B-3</td>
<td>30</td>
<td>1667</td>
<td>46</td>
<td>2556</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>B-4</td>
<td>--</td>
<td>--</td>
<td>47</td>
<td>2611</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>C-1</td>
<td>28</td>
<td>1556</td>
<td>47</td>
<td>2611</td>
<td>11-10-60</td>
<td>12-8-60</td>
</tr>
<tr>
<td>C-2</td>
<td>27</td>
<td>1500</td>
<td>47</td>
<td>2611</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>C-3</td>
<td>20</td>
<td>1111</td>
<td>43</td>
<td>2389</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>C-4</td>
<td>25</td>
<td>1399</td>
<td>44</td>
<td>2444</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>D-1</td>
<td>32</td>
<td>1778</td>
<td>45</td>
<td>2500</td>
<td>11-10-60</td>
<td>12-8-60</td>
</tr>
<tr>
<td>D-2</td>
<td>24</td>
<td>1333</td>
<td>41</td>
<td>2278</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>D-3</td>
<td>26</td>
<td>1444</td>
<td>48</td>
<td>2667</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>D-4</td>
<td>25</td>
<td>1389</td>
<td>46</td>
<td>2556</td>
<td>11-10-60</td>
<td>5-11-61</td>
</tr>
<tr>
<td>E-2</td>
<td>--</td>
<td>--</td>
<td>43</td>
<td>2389</td>
<td>11-10-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>E-3</td>
<td>24</td>
<td>1333</td>
<td>46</td>
<td>2556</td>
<td>11-10-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>E-4</td>
<td>--</td>
<td>--</td>
<td>44</td>
<td>2444</td>
<td>11-10-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>G-1</td>
<td>29</td>
<td>1611</td>
<td>50</td>
<td>2778</td>
<td>11-14-60</td>
<td>12-8-60</td>
</tr>
<tr>
<td>G-2</td>
<td>--</td>
<td>--</td>
<td>43</td>
<td>2389</td>
<td>11-14-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>G-3</td>
<td>20</td>
<td>1111</td>
<td>47</td>
<td>2611</td>
<td>11-14-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>H-1</td>
<td>25</td>
<td>1389</td>
<td>43</td>
<td>2389</td>
<td>11-14-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>H-2</td>
<td>--</td>
<td>--</td>
<td>43</td>
<td>2389</td>
<td>11-14-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>H-3</td>
<td>--</td>
<td>--</td>
<td>45</td>
<td>2500</td>
<td>11-14-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>J-1</td>
<td>21</td>
<td>1167</td>
<td>41</td>
<td>2278</td>
<td>11-10-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>J-2</td>
<td>21</td>
<td>1167</td>
<td>47</td>
<td>2611</td>
<td>11-10-60</td>
<td>5-25-61</td>
</tr>
<tr>
<td>J-3</td>
<td>21</td>
<td>1167</td>
<td>43</td>
<td>2389</td>
<td>11-10-60</td>
<td>5-25-61</td>
</tr>
</tbody>
</table>
Non-Reinforced Concrete Pipe

Four pipe (Series F) fabricated with no reinforcing steel were broke in the three-edge bearing test (See Fig. 37). The results of these tests are summarized in Table 3.

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>Ultimate Load (kips)</th>
<th>D-Load</th>
<th>Date Manufactured</th>
<th>Date Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-1</td>
<td>16.5</td>
<td>919</td>
<td>11-9-60</td>
<td>12-8-60</td>
</tr>
<tr>
<td>F-2</td>
<td>26.0</td>
<td>1440</td>
<td>11-9-60</td>
<td>7-18-61</td>
</tr>
<tr>
<td>F-3*</td>
<td>23.0</td>
<td>1280</td>
<td>11-9-60</td>
<td>7-18-61</td>
</tr>
<tr>
<td>F-4</td>
<td>22.0</td>
<td>1220</td>
<td>11-9-60</td>
<td>7-18-61</td>
</tr>
</tbody>
</table>

* Maximum vertical deflection less than 1/8 inch.

Fig. 37. Non-Reinforced Concrete Pipe Under Test.
Repaired Pipe

Three pipe -- C-3, E-2 and J-2 -- were used for this portion of the study. These pipe were first loaded in the three-edge bearing, as described previously, in order to obtain damaged pipe. The results of these loading tests were given in Figs. 26, 28 and 31 -- which indicate the extent of structural damage before repair was attempted. To effect the repair, a cage of reinforcement was placed in the damaged pipe and gunite was applied. After repairs had been completed, the pipe were again loaded by the three-edge bearing method.

The cages of reinforcing steel used in the repair work were fabricated from 3- x 8-inch, No. 0 to 4, wire fabric. The cages for Pipe C-3 and Pipe J-2 were prepared from a single section of the wire fabric; the joints were lapped approximately three inches and were joined by a single weld on each strand of wire. The cages were positioned in the damaged pipe and a clearance of about one inch was maintained between the wire and the wall of the pipe by clipping and bending portions of the No. 4 wire. The cage of Pipe E-2 consisted of two semi-circular sections of wire fabric lapped approximately three inches and spliced together with two spot welds on each strand of wire. The clearance between the wire and the pipe wall was maintained with one-inch mortar cubes.

The proportioning of the material used to prepare the gunite was three parts sand, two parts cement, and water as needed to obtain the desired consistency. The total quantity of materials used for repair of the three pipe included seven bags of portland cement and 30 gallons of water. Approximately 300 pounds of material was lost through rebound.
The gunite was applied to a thickness ranging between 2-1/4 inches and 3-1/2 inches. The gunite was applied first to the sides of the pipe, then to the top and finally to the bottom after removing rebound material with compressed air (See Figs. 38 and 39). Gunite work was done on June 13, 1961, by a Department of Highways' maintenance crew.

Special provision was made to prevent Pipe E-2 from rebounding or recovering its circular shape after it had been loaded beyond its ultimate strength. At the conclusion of the initial loading test, the yoke assembly pictured in Fig. 23 was placed on the pipe to hold it in its collapsed shape until it could be repaired and retested. Figures 40 and 41 show Pipe E-2 after it had been repaired and at the time of retesting.

The load-deformation curves for the gunite-repaired pipe are shown in Figs. 42 to 44. It is noted that this type of repair is more than adequate to restore structural integrity to the pipe. Table 4 summarizes some data obtained in this portion of the study. Figures 45 and 46 show a repaired pipe before and after the loading test.

Table 4. Summary of Test Results on Repaired Pipe

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>Ultimate Load (kips)</th>
<th>Ultimate Load (lbs/sq ft.)</th>
<th>Date of Manuf.</th>
<th>Date of Initial Testing</th>
<th>Date of Repaired</th>
<th>Date of Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-3</td>
<td>90</td>
<td>5000</td>
<td>11-10-60</td>
<td>5-11-61</td>
<td>6-13-61</td>
<td>7-18-61</td>
</tr>
<tr>
<td>E-2</td>
<td>112*</td>
<td>6222</td>
<td>11-10-60</td>
<td>5-25-61</td>
<td>6-13-61</td>
<td>7-18-61</td>
</tr>
<tr>
<td>J-2</td>
<td>94</td>
<td>5222</td>
<td>11-14-60</td>
<td>5-25-61</td>
<td>6-13-61</td>
<td>7-18-61</td>
</tr>
</tbody>
</table>

* Yoked to prevent rebound.
Fig. 38. Gunite Repair of Damaged Pipe.

Fig. 39. Close-up of Gunite Repair.
Fig. 40. Repaired Pipe E-2.

Fig. 41. Repaired Pipe E-2 after Retesting.
Figure 4.2: Load-Deflection Curve for Repeated Pipe C-5.

Position of Pipe During Loading

First Crack Observed inside Top
First Crack Observed inside Bottom
Flanging of Gunite

Pipe C-5

Reinforcement Steel
Gunite
Fig. 43. Load-Deformation Curve for Repaired Pipe E-2.
Fig. 44. Load-Deformation Curve for Repaired Pipe J-2.
Fig. 45. Repaired Pipe before Testing.

Fig. 46. Repaired Pipe after Testing.
Laterally Restrained Pipe

To determine the effects of lateral resistant (lateral resistance) on the load-carrying capacity of pipe, Pipe A-2, A-3 and E-1 were laterally restrained by the yoke assembly shown in Figs. 23 and 24 and were then loaded. The load-deformation curves resulting from these tests are pictured in Figs. 47 to 49.

Even though the lateral restraint was applied by a rather critical, two-point bearing, the load-carrying capacity was increased 150 to 260 percent. When the 3/8-inch diameter tie rods, or the tie rods having the reduced sections, were used, this increase was 150 to 180 percent, and when the 3/4-inch diameter tie rods were used in the yoke assembly, the increase in ultimate load was 230 to 260 percent.

The over-all slope of the load-deformation curves was somewhat steeper when the lateral restraint was applied than when the pipe was not restrained. The first crack observed in these restrained pipe was at a load of approximately 20 kips and a strain of less than 0.1 percent; the 0.01-inch crack occurred at loads of 25 to 30 kips and strains of 0.1 to 0.15 percent. Table 5 summarizes some of the data obtained from these tests.

The ultimate load data summarized in Table 5, as well as those contained in Tables 2 and 3, are presented in graphical form in Fig. 50. The sums of the areas of steel in the internal reinforcement and in yoke-assembly tie rods have been plotted as a function of the ultimate loads obtained in the bearing tests. A similarity is noted here in the linear relationships apparent in these data and in those presented by the
Fig. 47. Test Results for Pipe A-2:
1) Restrained by four, 0.30-inch diameter, 2.6-inch long, reduced-section tie rods; loaded to failure of the reduced section and then unloaded; and
2) Restrained by four, 3/4-inch uniform-diameter tie rods and loaded to ultimate.

Both sets of the tie rods elongated (yielded); the elongation was concentrated in the reduced section in the first test condition; the uniform rods elongated uniformly throughout their full length.
Fig. 48. Test Results for Pipe A-3:
1) Restrained by four, 0.30-inch diameter, 8-inch long, reduced-section tie rods; loaded to ultimate and then unloaded;
2) Restrained by four, 3/4-inch uniform-diameter tie rods; loaded to ultimate and then unloaded; and
3) Loaded to ultimate without lateral restraint.
Fig. 49. Test Results for Pipe E-1:
1) Restrained by four, 3/8-inch uniform-diameter tie rods; loaded to ultimate and then unloaded; and
2) Restrained by four, 3/4-inch uniform-diameter tie rods; loaded to ultimate.
Fig. 50. Relationship Between Ultimate Load and Total Area of Steel (Internal Reinforcement Plus External Tie Rods).
Table 5. Summary of Test Results on Laterally Restrained Pipe

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>0.01-inch Crack Load (kips)</th>
<th>D-Load (lbs/sq.ft.)</th>
<th>Ultimate Load (kips)</th>
<th>D-Load (lbs/sq.ft.)</th>
<th>Date Manuf.</th>
<th>Date Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2</td>
<td>25</td>
<td>1389</td>
<td>74</td>
<td>4111</td>
<td>11-10-60</td>
<td>5-9-61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>105</td>
<td>5833</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-3</td>
<td>25</td>
<td>1389</td>
<td>68</td>
<td>3778</td>
<td>11-10-60</td>
<td>5-9-61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>104</td>
<td>5778</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-1</td>
<td>30</td>
<td>1667</td>
<td>61</td>
<td>3389</td>
<td>11-10-60</td>
<td>12-20-60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>93</td>
<td>5167</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1. Tie rods having reduced sections 2.6 inches in length, 0.30 inch in diameter.
2. 3/4-inch uniform diameter tie rods.
3. Tie rods having reduced sections eight inches in length, 0.30 inch in diameter.
4. No lateral restraint.
5. 3/8-inch uniform diameter tie rods.

American Concrete Pipe Association - that is, the additional area of steel contained in the yoke-assembly tie rods increases the load-carrying capacity of the pipe in much the same manner as if this steel had been included in the internal reinforcement. It is also interesting to note that the ultimate load sustained by the non-reinforced concrete pipe (20 to 25 kips) was on the order of the load required to produce the 0.01-inch crack in the reinforced pipe.

* "D-Load Design and Tests of Concrete Pipe - 1956," Technical Memorandum, American Concrete Pipe Association, October 1, 1957.
The restraint offered by the tie rods of the yoke assembly may be, in a manner, considered to represent the reactance provided by the earth pressure around a culvert in a field installation. Since it has been suggested above that the total cross-sectional area of the tie rods can be equated to a similar increase in the area of internal reinforcement, it may be inferred that lateral earth pressures on the pipe culvert can also be related to an equivalent area of internal reinforcing steel -- that is, the resistance of the soil to lateral deformations is analogous to diametrical reinforcement and to circular reinforcement. Thus, compaction of backfill contributes to the load-carrying capacity of a pipe in much the same way as internal reinforcing steel.
SUMMARY OF SIGNIFICANT FINDINGS

The principal findings regarding the fabrication and location of joints in the reinforcing steel are summarized as follows:

1. The 0.01-inch crack strength and the ultimate strength were not significantly affected by the three methods used to fabricate the joints in the reinforcing cages. The data indicate that there is very little difference in the over-all performance of pipe prepared with: 1) lapped-and-tied joints (Figs. 12 and 13), 2) double-welded joints (Fig. 14), and 3) single-welded joints (Fig. 15).

2. With regard to the relative positions of the joints in the outer and inner cages of reinforcement, there appears to be no measurable difference in the performance of pipe in which the joints are spaced: 1) zero degrees apart, 2) 90 degrees apart, and 3) 180 degrees apart.

3. The load-carrying capacities of the pipe fabricated for this investigation were not significantly affected by the location of the joints in the three-edge bearing tests. Pipe oriented with their joints in the most critical location (points of maximum bending, i.e., four cardinal points) performed as satisfactorily as those pipe in which the joints were located in more favorable positions.

The findings from other phases of study are summarized as follows:

1. The ultimate loads withstood by non-reinforced concrete pipe were approximately equal to the load required to produce the 0.01-inch crack in the reinforced pipe.

- 23 -
2. The repairs, which were made on structurally damaged pipe, with reinforced-gunite inner liners, sufficed to restore original load-carrying capacity to the pipe.

3. Steel in tie rods used to provide lateral resistant (horizontal reactance to vertical loading) appeared to increase the load-carrying capacity of pipe to the same extent that an equal amount of internal reinforcement would have provided.

The findings thus outlined have already proven to be of value and suggest additional areas of study. Committee C-13 of ASTM approved the following revision to C 76 in 1962 (AASHO Committee on Materials subsequently approved a revision of M 170 to conform to ASTM C 76-62T):

"When splices are welded and are not lapped to the minimum requirements above, pull tests of representative specimens shall develop at least 75 percent of the minimum specified strength of the steel."

The apparent relationships between the action of external, horizontal tie steel and the action of internal reinforcing steel may engender further study and lead, perhaps, to more meaningful relationships between passive earth-pressures and the ability of D-strength pipe to withstand fill loads.
APPENDIX A

Design and Installation Criteria For
Reinforced Concrete Pipe Culverts
CIRCULAR MEMORANDUM

TO: Regional and District Engineers

FROM: G. M. Williams, Assistant Commissioner for Engineering

SUBJECT: Reinforced Concrete Pipe Culverts

The purpose of this memorandum is to set forth a criteria for the design and installation of reinforced concrete pipe culverts under various heights of fills and various methods of bedding.

Improper methods of installation operate to restrict the field of usefulness of reinforced concrete pipe culverts by failure to utilize the inherent load carrying capacity. The need for proper culvert installation is apparent not only from the standpoint of maintaining the structural integrity of the culvert itself but also to prevent or minimize to the extent possible settlements in the road surfaces which occur adjacent to culvert installation. Proper specifications therefore must provide methods for the installation of reinforced concrete pipe culverts which will make possible their efficient utilization.

The following criteria for the design and installation of concrete pipe culverts has been developed in cooperation with the American Concrete Pipe Association and in connection therewith an attempt has been made to simplify the prevailing methods of computing the necessary pipe strengths for the various classes of bedding commonly used.

Specifications covering the installation of reinforced concrete pipe culverts conforming to this criteria are recommended and will be considered satisfactory for use on Federal-aid projects.

This criteria, although prepared primarily for reinforced concrete pipe culverts, is applicable to any type of rigid pipe. This memorandum supersedes the memorandum on the subject “Installation of Pipe Culverts,” dated June 5, 1935.

GENERAL

1.1—These criteria cover the design and installation of circular or slightly elliptical reinforced concrete pipe culverts.

1.2—Pipe shall be (a) round pipe reinforced by two lines of circular reinforcement; (b) round pipe reinforced by one line of elliptical reinforcement; (c) elliptical pipe reinforced with one line of circular reinforcement.

DESIGN

2.1—FACTORS AFFECTING STRENGTH

The strength required for a given rigid pipe depends upon its size, the height, character, and weight of the fill over the culvert, the character of the foundation, the depth, and width of trench (if any) in which the pipe is installed, and the method of bedding and installation.

2.2—STRENGTH OF PIPE

The strength requirements for reinforced concrete pipe are given in Table I. A more accurate determination may be obtained from Chart II. The strength is expressed in "D" loads, i.e., the minimum ultimate loads per linear foot required to be sustained by the pipe divided by the nominal diameter of the pipe in feet. Both Table I and Chart II have been computed on the basis of a safety factor of 1.33. The strength of the pipe shall be measured by the three-edge bearing method as specified in ASTM C-76. If required by the engineer, three-edge bearing tests shall also be made as specified in A.S.T.M. C-76 to determine the strength of the pipe at the first 1/100-inch crack. If so required, the 1/100-inch crack load shall be used with a safety factor of 1, i.e., the required 1/100-inch crack strengths shall be at least equal to the D values given in Table I, divided by 1.33. Similarly, if Chart II is used, the "D" values given on the lines in the upper left corner of the chart may be divided by 1.33 and taken as the minimum permissible cracking loads. The pipe shall meet the requirements for both the ultimate and cracking tests or the cracking test may be substituted for the ultimate test as the engineer may direct.

Table I and Chart II have been computed for strengths of pipe up to 6,000 D. For height of fill requiring greater strength, special designs shall be made.

2.2.1—Explanations of Table I

"D Value"

"D Value" is a term commonly used by pipe culvert designers to designate the strength measured by 3-edge bearing test per linear foot
TABLE 1—GIVING MINIMUM ALLOWABLE ULTIMATE "D" VALUE OF CONCRETE PIPE IN 1,000-
POUND UNITS FOR VARIOUS CLASSES OF BEDDING AND HEIGHTS OF OVERFILL.
SAFETY FACTOR ASSUMED 1.33:

All "D" values have been computed for a 60-inch pipe. In general, they are accurate enough for any pipe size now in use except for the trench condition. Here the values given in the table are too large for smaller pipes and too small for larger sizes. For more accurate determinations, use Chart II.

<table>
<thead>
<tr>
<th>H</th>
<th>CLASS A BEDDING</th>
<th>CLASS B BEDDING</th>
<th>CLASS B1 BEDDING</th>
<th>CLASS C BEDDING</th>
<th>CLASS C1 BEDDING</th>
<th>CLASS D BEDDING</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p=0 p=1 Trench</td>
<td>p=0 p=0.7 Trench</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.0 1.0 1.0</td>
<td>1.0 1.2 1.1</td>
<td>—</td>
<td>1.2 1.4 1.3</td>
<td>—</td>
<td>1.9 2.4 2.1</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>1.0 1.3 1.1</td>
<td>1.4 1.8 1.6</td>
<td>—</td>
<td>1.7 2.3 1.8</td>
<td>—</td>
<td>2.7 3.8 2.9</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>1.3 1.7 1.3</td>
<td>1.9 2.4 1.9</td>
<td>1.3</td>
<td>2.2 3.0 2.3</td>
<td>1.5</td>
<td>3.6 5.0 3.5</td>
<td>20</td>
</tr>
<tr>
<td>25</td>
<td>1.6 2.1 1.5</td>
<td>2.4 3.0 2.2</td>
<td>1.5</td>
<td>2.8 3.8 2.6</td>
<td>1.8</td>
<td>4.4 4.1</td>
<td>25</td>
</tr>
<tr>
<td>30</td>
<td>1.9 2.5 1.7</td>
<td>2.8 3.6 2.5</td>
<td>1.7</td>
<td>3.3 4.5 2.9</td>
<td>2.1</td>
<td>5.3 4.6</td>
<td>30</td>
</tr>
<tr>
<td>35</td>
<td>2.2 2.9 1.8</td>
<td>3.3 4.2 2.7</td>
<td>2.0</td>
<td>3.9 5.3 3.2</td>
<td>2.4</td>
<td>— 5.0</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>2.6 3.3 2.0</td>
<td>3.8 4.8 2.9</td>
<td>2.2</td>
<td>4.5 6.0 3.4</td>
<td>2.7</td>
<td>— 5.4</td>
<td>40</td>
</tr>
<tr>
<td>45</td>
<td>2.9 3.7 2.1</td>
<td>4.3 5.4 3.1</td>
<td>2.5</td>
<td>5.1 3.6</td>
<td>3.0</td>
<td>— 5.7</td>
<td>45</td>
</tr>
<tr>
<td>50</td>
<td>3.2 4.2 2.2</td>
<td>4.8 6.0 3.2</td>
<td>2.8</td>
<td>5.7 3.8</td>
<td>3.3</td>
<td>— 5.9</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>3.9 5.0 2.3</td>
<td>5.8 3.4</td>
<td>3.3</td>
<td>— 4.1</td>
<td>3.9</td>
<td>— —</td>
<td>60</td>
</tr>
<tr>
<td>70</td>
<td>4.3 5.8 2.4</td>
<td>— 3.6</td>
<td>3.8</td>
<td>— 4.3</td>
<td>4.5</td>
<td>— —</td>
<td>70</td>
</tr>
<tr>
<td>80</td>
<td>5.2 2.5</td>
<td>— 3.7</td>
<td>4.3</td>
<td>— 4.4</td>
<td>5.1</td>
<td>— —</td>
<td>80</td>
</tr>
<tr>
<td>90</td>
<td>5.8 2.6</td>
<td>— 3.8</td>
<td>4.8</td>
<td>— 4.5</td>
<td>5.7</td>
<td>— —</td>
<td>90</td>
</tr>
<tr>
<td>100</td>
<td>— 2.6</td>
<td>— 3.8</td>
<td>5.3</td>
<td>— 4.6</td>
<td>—</td>
<td>— —</td>
<td>100</td>
</tr>
</tbody>
</table>

NOTE: For depths of overfill less than 2 feet, where the nominal pipe diameter is less than 5 feet, add 50 per cent to the "D" values given in the table for H ≤ 10 to provide for live load and impact. Otherwise, for overfills less than 10 feet, use the "D" value given for H = 10.
of pipe per foot of internal diameter. Thus, a 3,000 D pipe of 2-foot diameter is able to support a 3-edge bearing load of 6,000 pounds per linear foot of pipe.

Class of Bedding

The classes of bedding relate to six different methods used in installing the pipe. The methods are described in detail under “Installation.” In outline, they are as follows:

Class A Bedding

The pipe is supported on a continuous concrete cradle.

Class B Bedding

The pipe is bedded by the most careful methods, but no concrete cradle is used.

Class B, Bedding

The pipe is bedded as described under Class B and, in addition, the imperfect ditch method is used above it.

In specifying B, bedding, the stability of the pavement above the pipe must be considered and provided for by an adequate compacted cover of earth.

Class C Bedding

The pipe is installed with ordinary care.

Class C, Bedding

The pipe is bedded as described under Class C and, in addition, the imperfect ditch method is used above it. In specifying C, bedding, the stability of the pavement above the pipe must be considered and provided for by an adequate compacted cover of earth.

Class D Bedding

The pipe is installed without any great care in compacting the earth around it.

2.2.2—Height of Fill

The height of fill is given in the first vertical column on the left of the table. The heights are in feet measured from the top of the pipe.

2.2.3—Projection Ratio

The projection ratio is designated as “p” and is defined as the ratio of the distance of the original ground surface below the outside top of pipe to the outside diameter of pipe.

2.2.4

Class B and C Beddings require that “p” be 0.7 or less and 0.9 or less, respectively, so the table does not show values above these limits.

2.2.5

The columns marked “trench” assume that the pipe is installed wholly within a trench and that there is no fill over the natural ground surface. Where the sides of the trench are not vertical, its width shall be assumed as that at the level of the top of pipe. The trench is assumed to be 1.35 times the outside diameter of the pipe. Where the actual trench exceeds this width, the required “D” value may be obtained by multiplying the table value by the width of trench divided by 1.35 except that the required value shall not exceed the value for p = 1.

2.2.6

This settlement ratio is determined by an equation which involves the deflection of the conduit, the settlement of the flow line of the conduit, the settlement of the embankment subgrade adjacent to
the conduit, and the deformation of the filling material adjacent to the conduit within the height which the conduit extends above the natural ground surface. The settlement ratio is designated by the symbol "r_{se}". The value r_{se} = 0.7 has been assumed. For other values of r_{se} and for more accurate results in general, Chart II should be used in place of Table I.

Where the projection ratio, p, or the type of bedding shown in the table does not correspond with field conditions, interpolated values may be used. Thus, if the original ground surface is halfway between top of pipe and final ground elevation, the required "D'' value may be taken as the average of p = 0 and "Trench" columns.

2.2.8
Weight of earth has been assumed 120 pounds per cubic foot.

2.3.1—Explanation of Chart II

This is a combination of four diagrams, viz:

*Upper right,* giving load factor, "Ll,” in terms of the projection ratio, "p,” and the bedding class as defined in these specifications.

The load factor is defined as the ratio of the strength of a pipe under any stated condition of loading to its strength when tested in the three-edge bearing test. The principal variables are the projection ratio and the class of bedding, although the size of pipe and fill height have some effect. The value of "q” representing the latter variables has been taken as 0.18.

*Upper left,* giving the safe uniform load \( \frac{W_e}{B_{se}} \) for a given strength of pipe and load factor.

*Lower left,* giving "C_e" in terms of \( \frac{W_e}{B_{se}} \) and \( B_{se} \).

These constants are taken from “Soil Engineering,” by M. G. Spangler, page 422; formula (25-7) giving \( W_e = C_e w B_{se}^2 \), where \( w = \) weight of earth per cubic foot.

*Lower right,* giving the value of \( \frac{H}{B_{se}} \) in terms of \( C_e \) and \( r_{se} \). The diagram was obtained by plotting values of equations (25-9) and (25-10) in Spangler’s book, pages 422 and 423. As used here, \( C_e \) is a constant, \( H = \) allowable height of fill over the top of the conduit, \( B_{se} = \) outside diameter of culvert, \( p = \) projection ratio as defined above (Section 2.2.3), and \( r_{se} = \) settlement ratio as defined above (Section 2.2.6). The following values for \( r_{se} \) are suggested (See “Soil Engineering,” by M. G. Spangler, page 422).

Rigid culvert on foundation of rock or unyielding soil + 1.0.
Rigid culvert on foundation of ordinary soil + 0.5 to 0.8.
Rigid culvert on foundation of material that yields with respect to adjacent ground + 0.0 to 0.3.

2.3.2
The chart may be used to determine the necessary pipe strengths for the trench condition by using curve OT in the lower right hand diagram. The rest of the chart may be used as bedding conditions A, B, C, and D, except that wherever B, is given, substitute \( B_o \), the width of the trench. Also change the "D” values given in the upper left hand chart by the factor \( \frac{B_o}{B} \).

2.3.3
For the \( B_1 \) and \( C \) conditions assume \( p = 1.0 \). Ordinarily \( r_{se} \) may be taken at -0.6.

2.4—MINIMUM HEIGHT OF FILL
The minimum height of fill between the top of a rigid pipe culvert and the finished grade of the roadway shall be 1.75 feet for unpaved road and those paved with a flexible type of pavement. For roads paved with Portland cement concrete, the minimum height of fill shall be 1.25 feet.

INSTALLATION

3.1—CONSTRUCTION MACHINERY
Movement of construction machinery over a culvert shall be at the contractor’s risk. Any pipe injured thereby shall be repaired or replaced at the option of the engineer and at the expense of the contractor.

3.2—TEMPORARY STREAM FLOW
The contractor shall provide, as may be necessary, for the temporary diversion of water in order to permit the installation of the culvert in the dry.

3.3—FILL MATERIAL
Fill material within a nominal pipe diameter distance at the sides of the culvert and one foot over the top shall be of soil which can be readily compacted. It shall not contain stones which will be
3.4—CAMBER

The invert grade of culvert shall be cambered by an amount sufficient to prevent the development of a sag or back slope in the flow line as the foundation soil settles under the weight of the embankment. The amount of camber shall be determined by the engineer, based upon consideration of the flow line gradient, the height of fill, the compressive characteristics of the supporting soil, and the depth of the supporting soil stratum to ledge rock. In no case shall the camber be sufficient to produce an adverse grade after settlement has occurred.

3.5—LAYING PIPE

Pipe laying shall begin at the downstream end of the culvert with the bell or groove end of the first pipe section upstream. When bell and spigot pipes are used, bell holes shall be dug in the pipe subgrade to accommodate the bells. They shall be deep enough to insure that the bell does not bear on the bottom of the hole and they shall not be excessively wide in the longitudinal direction of the culvert. When the pipes are laid, the barrel of each pipe shall be in contact with the quadrant shaped bedding throughout its full length exclusive of the bell.

3.5.1

When elliptical pipe with circular reinforcement or circular pipe with elliptical reinforcement is used, the pipe shall be installed in such a position that the manufacturer's marks designating the "top" or "bottom" of the pipe shall be not more than 5° from the vertical plane through the longitudinal axis of the pipe.

3.5.2—Multiple Pipe Culverts

Where multiple lines of pipe are used, they shall be spaced far enough apart to permit thorough tamping of the earth between the pipe. To this end, the adjacent sides of the pipe shall be at least one-half the nominal pipe diameter apart or three feet, whichever is less.

3.6—JOINTING PIPE

Pipe joint design may be of the bell and spigot type or the tongue and groove type unless one type is specified by the engineer.

3.6.1

Joints shall be made with (a) Portland cement mortar, (b) Portland cement grout, (c) rubber gaskets, (d) oakum, or (e) a combination of these materials unless one type or combination is specified by the engineer.

3.6.1 (a) Mortar Joints

The mixture shall be one part Portland cement and two parts sand by volume. The quantity of water in the mixture shall be sufficient to produce a stiff, workable mortar but shall in no case exceed five and one-half (5 1/2) gallons of water per sack of cement. The sand shall conform to the Specification M45-42 and the cement shall conform to Specification M85-55 of the American Association of State Highway Officials.

If ordered by the engineer, air entraining Portland cement conforming to Specification A.A.S.H.O. M-134-55 or an admixture conforming to A.A.S.H.O. M-149-54 shall be used.

The pipe ends shall be thoroughly cleaned and wetted with water before the joint is made. Stiff mortar shall then be placed in the lower half of the bell or groove of the pipe section already laid. Next, mortar shall be applied to the upper half of the spigot or tongue of the pipe section being laid. Then the spigot or tongue end of this pipe shall be inserted in the bell or groove end of the pipe already laid, the joint pulled up tight, taking care to see that the inner surfaces of the abutting pipe sections are flush and even.

3.6.1 (b) Grout Joints

The grout shall consist of Portland cement conforming to M85-55 of the American Association of State Highway Officials mixed to the proper consistency with not more than 5 gallons of water per sack of cement.

The grout shall be poured or pumped into the joint space and retained by molds or runners around the pipe in a manner acceptable to the engineer.

3.6.1 (c) Rubber Gasket Joints—Tongue and Groove Pipe

Rubber Gaskets—The gasket shall be a continuous rubber ring which fits snugly in the annular space between the beveled surface of the tongue and the groove ends of the pipes to form a flexible water-tight seal under all conditions of service. The gaskets shall have smooth surfaces free from all imperfections. The gaskets shall meet the physical test requirements specified in "Methods of Physical Test
3.6.1 (d) Oakum Joint—Bell and Spigot Pipe
Exterior Seal—The bell and spigot pipe shall be calked with oakum and sealed with a hot poured joint compound. Oakum shall be made from hemp (Canabis Sativa) line, or Benares Sunn Fiber, or from a combination of these fibers. The oakum shall be thoroughly corded and finished and practically free from lumps, dirt, and extraneous matter. The fibers shall be thoroughly impregnated with hot asphaltic cement. The sealer shall be Atlas JC-60 hot poured sewer joint compound or the approved equivalent.

3.7—FINISHING
After the joint is made, the inside surface of the pipe and the annular space between the ends of the pipe shall be cleaned. The joint shall then be filled with mortar, and finished smooth and even with the inside surface of the pipe. For pipes 30 inches or less in diameter, the filling of the joints shall be done before the grout or mortar in the joints has set. For pipes over 30 inches in diameter, this operation shall be postponed until the earth fill has been completed. It will probably be necessary to re-clean the joints before applying the mortar.

3.8—ROCK OR OTHER INCOMPRESSIBLE FOUNDATION
Where ledge rock, rocky, or gravelly soil, hard pan, or other unyielding foundation material is encountered at a culvert site, the pipe shall be bedded in accordance with the requirements of one of the classes of bedding, but with the following additions: The hard unyielding material shall be excavated below the elevation of the bottom of the concrete cradle (Class A bedding) or the bottom of the pipe or pipe bell (Class B, B1, C, and C1 beddings) for a depth of at least 12 inches or \( \frac{1}{4} \) inch for each foot of fill over the top of the pipe, whichever is greater, but not more than \( \frac{1}{2} \) the nominal diameter of the pipe. For Class D bedding, the depth shall be 8 inches. The width of the excavation shall be one foot greater than the outside diameter of the pipe and shall be refilled with selected fine compressible material, such as silty clay or loam and lightly compacted and shaped as required for the specified class of bedding. A typical Class B bedding on rock foundation is illustrated in Figure 4.

3.9—METHODS OF BEDDING
The contact between a culvert pipe and the foundation on which it rests is the pipe bedding. It has an important influence on the supporting strength of the pipe. The class of bedding to be employed shall be determined by the engineer and specified on the road plans. Six classes of pipe beddings are as follows:

3.9.1—Class A—Concrete Cradle Bedding
In this class of bedding, the lower part of the pipe exterior shall be bedded in a continuous cradle constructed of 2,000-pound concrete or better, having a minimum thickness under the pipe of one-fourth \( (\frac{1}{4}) \) the nominal inside diameter and extending up the sides of the pipe for a height equal to one-fourth \( (\frac{1}{4}) \) of the outside diameter. The cradle shall have a width at least equal to the outside diameter of the barrel of the pipe plus 8 inches and it shall be constructed monolithically without horizontal construction joints. A typical Class A bedding is illustrated in Figure 1.

3.9.2—Class B Bedding
This class of bedding is applicable only when the projection ratio is not greater than 0.7. The pipe shall be carefully bedded on fine granular materials over an earth foundation, accurately shaped by means of a template to fit the lower part of the pipe exterior for at least 15 percent of its overall height. Compaction of soil material shall then be rammed and tamped in layers not more than 6 inches thick, around the pipe for the remainder of the lower 30 percent of its height. Backfilling to the top of the pipe shall then be completed as specified under "Backfilling." A typical Class B bedding is illustrated in Fig. 2.

3.9.3—Class B1, Bedding
In this type of installation, sometimes called the imperfect ditch method, the pipe culvert shall first be installed in accordance with the requirements of Class B bedding. Then the fill shall be compacted at each side of the pipe for a lateral distance equal to twice the outside diameter or 12 feet, whichever is less, and carried up to an elevation equal to the outside diameter of the pipe plus one foot, above the top of the pipe. Next, a trench equal in width to the outside diameter of the pipe shall be dug in the fill directly over the culvert, down to an elevation one foot above the top of the pipe. Care shall be exercised to keep the sides of this trench as nearly vertical as possible. After the
trench is excavated, it shall be refilled with loose, highly compressible soil material. Straw, hay, cornstalks, leaves, brush, or sawdust may be used to fill the lower one-fourth ($\frac{1}{4}$) to one-third ($\frac{1}{3}$) of the trench in order to insure high compressibility of this backfill. After the backfill is completed, the balance of the fill shall be constructed by normal methods up to the finished grade of embankment. Typical Class B1 bedding installation is illustrated in Figure 5.

3.9.4—Class C Bedding

In this class of bedding, the pipe shall be bedded with "ordinary" care in a soil foundation shaped to fit the lower part of the pipe exterior with reasonable closeness for at least 10 percent of its overall height. The remainder of pipe shall be surrounded by material placed by hand tools to fill completely all spaces under and adjacent to the pipe. Backfilling to the top of the pipe shall then be completed as specified under "Back filling." A typical Class C bedding is illustrated in Figure 3.

3.9.5—Class C Bedding

The pipe shall first be installed in accordance with Class C bedding. The imperfect ditch method shall then be used as described under Class B1 bedding.

3.9.6—Class D Bedding

In this class of bedding, no special care is required in shaping the bed or backfilling except the fill must be in contact with the pipe at all points and shall be constructed by methods as prescribed for other road embankments.
equal to two times its outside diameter, or 12 feet, whichever is less. Special compaction specified in this paragraph will not be required for “D” bedding. Back fill at the sides of the pipe may be compacted by rolling or operating heavy equipment longitudinally parallel with the culvert, provided care is taken to avoid displacement or injury of the pipe. All damage to the pipe shall be repaired by the contractor at his own expense, at the option of the engineer and to his satisfaction.

In all back filling operations, care shall be exercised and it shall be the contractor's responsibility to see that the pipes are not damaged by the lateral forces imposed during compaction of the back fill; especially in the case of circular pipe with elliptical reinforcement or elliptical pipe with circular reinforcement, it may be necessary to install timber struts at the horizontal diameter of the pipe sections, to be left in place until the fill over the pipe is completed.

---

### 3.10 BACK FILLING

Back filling material in a trench and up to the elevation of the top of the pipe shall be selected fine compatible soil material. It shall be compacted at near optimum moisture content, in layers not exceeding six (6) inches in compacted thickness, by hand, pneumatic tampers, or other means approved by the engineer. Care shall be exercised to thoroughly compact the back fill under the haunches of the pipe and to insure that the back fill soil is in intimate contact with the side of the pipe. The back fill shall be brought up evenly on both sides of the pipe for its full length. When the pipe is not installed in a trench, the back fill soil shall be compacted for a width on each side of the pipe.
APPENDIX B

Kentucky Department of Highways
Standard Specifications
Pertaining to
Reinforced Concrete Pipe Culverts
Section 8. CULVERT PIPE
CLASSIFICATION. Pipe covered by this specification shall be reinforced concrete culvert pipe, bituminous coated corrugated metal culvert pipe, bituminous coated corrugated metal culvert pipe-arches, vitrified clay culvert pipe, and cast iron culvert pipe.

7.8.1 REINFORCED CONCRETE PIPE
A. Description. These specifications cover reinforced concrete pipe, circular and elliptical, intended to be used for construction of culverts. The pipe shall be designated according to the following three classes: Class III, Class IV, and Class V, based on D-load strengths.

B. Requirements. Reinforced circular or circular reinforced elliptical concrete pipe shall conform to the current requirements of the Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe, ASTM Designation: C 76 for each respective class and type of pipe specified. Basis of acceptance may be any of the three methods of testing specified in ASTM C 76 as determined by the Engineer.

Elliptically reinforced elliptical pipe shall conform to all requirements of ASTM C 76 except those provisions applying particularly to round pipe or elliptical pipe with circular reinforcement.

7.8.2 BITUMINOUS COATED CORRUGATED METAL PIPE
A. General. Bituminous coated corrugated metal pipe shall conform to the following requirements:

1. Materials. The corrugated metal pipe shall conform to the requirements of the Standard Specifications for Corrugated Metal Culvert Pipe, A.A.S.H.O. Designation: M 38. The bituminous material used for coating shall be an asphalt of such grade and character that, after being applied to the pipe, the coating will comply with the tests hereinafter described.

The inlet and outlet of all pipe fabricated of 16 or 14-gage sheets shall be reinforced in a manner approved by the Engineer. No end finish will be required when headwalls are used.

2. Coating. The pipe and connecting bands shall be coated uniformly with bituminous material, inside and outside, to a minimum thickness of 0.05 inch, measured on the crests of the corrugations. Additional bituminous material shall then be applied in such a manner that a smooth pavement will be formed in the invert (bottom of the pipe when installed) filling the corrugations for one-fourth of the circumference of the pipe. The pavement, except where the upper edges intersect the corrugations, shall have a minimum thickness of one-eighth inch above the crests of the corrugations.
Section 11. PIPE CULVERTS
(Amendment No. 15a)

Pages 331 through 333 inclusive, delete the entire Section 11 and substitute as follows:

5.11.1 DESCRIPTION
This work shall consist of furnishing and installing pipe culverts in accordance with plans and these specifications. Pipe culverts shall consist materially of: (1) reinforced concrete, (2) bituminous coated and paved corrugated metal, (3) vitrified clay, or (4) cast iron. Vitrified clay and cast iron pipe are to be used only when specified on the plans or in the proposals. Pipe culverts shall be circular, elliptical, or arch-shaped as indicated on the plans, proposals, or in special provisions. All pipe culverts shall conform to the dimensions, fabrication, material, and strength requirements provided for each type and class of pipe. Each culvert shall be bedded and back-filled as provided herein and shall conform in all respects the line and grade shown on the plans or as given by the Engineer. Where specified, concrete anchors of the class of concrete and of the dimensions shown on plans shall be constructed on pipe culverts.

The pipe shall be of the type and class named in the proposal and indicated on the plans. Where alternate types of pipe are shown, the Bidder shall state in his proposal, the type of pipe he proposes to use for each size of pipe called for on the plans or in the proposal.

5.11.2 MATERIALS
All culvert pipe used shall conform to the requirements for that particular type and class as shown in Article 7.8.0. Any section of pipe that is defective, broken, or cracked when delivered on the project or when being laid, shall be rejected.

Cement and sand for mortar shall conform to the requirements of Article 7.1.2 and 7.3.3, respectively.

5.11.3 CONSTRUCTION
A. General. No pipe shall be laid until the proposed location has been approved and staked by the Engineer. Soundings for foundation design shall be taken by the Engineer at the inlet and outlet of each culvert and at intervals not greater than twenty feet along the grade line of the bottom of the pipe, and to depths of 0.50 inch per foot of embankment height over the top of the pipe or one foot, whichever is greater. The maximum depth to which these soundings must be taken is 0.75 ft. Wherever ledge rock, gravel, hardpan, or other unyielding soil is encountered within the limits given, the foundation shall be prepared in accordance with Paragraph E, "Rock Foundation." The pipe shall be cambered whenever specified by the Engineer. Pipe shall never be laid in cuts until the rough grading has been completed. The type and method of bedding shall be standard except as may otherwise be specified on the plans.

In case a firm foundation is not encountered at the grade established by the Engineer, the unstable material shall be removed and replaced with suitable material to a width and depth and in a manner that will provide a uniform and firm foundation.

In all operations such as placing the pipe, joining, bedding and backfilling, care shall be exercised; and it shall be the Contractor's responsibility to see that the pipes are not damaged during the unloading or placement on the bed, during compaction of the backfill, by the movement of excessively heavy equipment over the fill, or by any other forces that may cause damage to the pipe. Any pipe culvert which is not in true alignment and grade or which shows undue settlement after laying, or is otherwise damaged, shall be taken up and replaced without extra compensation.

Backfill construction, as hereinafter specified, shall include both the placing and compacting of backfill material in excavated trenches and the construction of the embankment adjacent to the structure to limits specified as necessary to obtain required cover over the structure before normal embankment construction is begun.

B. Standard Bedding—Positive Projection. These pipe shall be bedded in accordance with the following requirements for Standard Bedding—Positive Projection:

A uniform foundation and a uniform or cambered grade throughout the full length of the culvert site shall be
prepared by smoothing and compacting the original ground and filling and compacting with a suitable compressive soil to an elevation above the bottom of the pipe equal to 0.3 of the outside height of the pipe. Any rock encountered shall be excavated and replaced with compacted soil in accordance with Paragraph E, "Rock Foundation." The width of the prepared foundation on each side of the pipe shall be equal to twice the outside width of the pipe or to 12 feet on each side, whichever is less. The foundation material shall be free of stone retained on a 3-inch diameter ring, frozen clods, chunks of highly plastic clay, or any other material objectionable to the Engineer. Within this prepared foundation, a shallow rectangular trench shall be excavated to a width equal to the outside width of the pipe plus an additional 0.3 of the width of the pipe on each side or 12 inches on each side, whichever is greater, and to an elevation above the bottom of the pipe equal to 0.15 of its outside height. Within this trench and along the established line, a groove shall be excavated to conform with lower contours of the pipe and to a depth of at least 0.15 of its over-all height, plus 2 inches, and with recesses for any bells or hubs involved. The pipe shall then be bedded on a peripheral layer of sand 2 inches in thickness. Natural sand, crushed stone or slag sand, or Size No. 11 aggregate may be used for the 2-inch sand bedding. Compactable soil, free from any foreign matter mentioned above, placed in 6-inch layers, loose depth, shall then be rammed and tamped around the pipe to 0.3 of its height. The compacted layers shall be brought up evenly on both sides of the pipe throughout its entire length.

Backfill shall then be raised to the original ground level using selected soil compacted at near optimum moisture content in layers not to exceed 6 inches compacted thickness. Tamping shall be by hand tampers, pneumatic tampers, or other means as approved by the Engineer. Care shall be exercised to thoroughly compact the backfill under the haunches of the pipe to insure that the backfill is in intimate contact with the sides of the pipe. Backfill shall be placed and compacted on each side of the pipe to the dimensions and slopes as shown on the Standard Drawings and to a height of at least 2 feet above the top of the pipe on all installations except for those at grade, in which case 1 foot will be allowed to subgrade elevation throughout the entire length of the pipe.

The density of the backfill shall be at least equal to that required in the adjacent embankment. After backfilling is complete, the remainder of the embankment may be constructed by normal methods to the finished grade line as specified in Article 2.5.0, "Embankment."

The Contractor, if he so elects, may construct a portion of the embankment, prior to installing the pipe culvert, to at least 12 inches above the elevation of the top of the pipe, excavate the trench, and install the pipe in accordance with requirements hereinafter specified for "Negative Projection." Payment for structure excavation will not be allowed for that portion of the excavated trench above the original ground.

C. Standard Bedding—Negative Projection. All pipe laid at a grade wherein the top of the pipe is at least 12 inches below the original ground level or constructed earthfill foundation shall be bedded in accordance with the following requirements for Standard Bedding—Negative Projection:

A trench shall be excavated and shall be equal to the outside width of the pipe plus 0.3 of the outside width of the pipe on each side or 12 inches on each side, whichever is greater. Walls of the trench shall be as nearly vertical as possible. If rock or other unyielding material is encountered, it shall be excavated and the foundation prepared as required under Paragraph E, "Rock Foundation." Otherwise, the foundation and lower 0.3 bedding of pipe shall be the same as that specified under Paragraph B. The remaining portion of the trench shall be backfilled with selected fine compactible soil.

Dry, free-flowing Natural Sand, Crushed Limestone Size No. 10, or Crushed Slag Size No. 10, lightly compacted, will be permitted in lieu of soil as backfill material to the top of the pipe, provided that the remaining portion of the trench above the pipe is backfilled with selected fine compactible soil. A minimum of 2 feet of backfill shall be required above the top of the pipe on all installations except for those at grade, in which case 1 foot will be allowed to subgrade elevation. If complete backfilling of the trench does not cover the pipe to the specified depth above the top of the pipe, additional fill shall be placed and compacted to the dimensions and slopes shown on the Standard Drawing and to the elevation required to pro-
vide the minimum allowable cover over the pipe. The density of the backfill shall be equal to that required for the adjacent embankment.

After backfilling has been completed in accordance with the Standard Drawings, the remainder of the embankment may be constructed by normal methods to the finished grade as specified in Article 2.5.0, “Embankment.”

D. Bedding—B. High Fill. Where the required height of fill above the top of the pipe exceeds the limits allowed by Standard Bedding, pipe shall be bedded in accordance with the following requirements for bedding—B. High Fill:

The lower 0.3 of the pipe shall be bedded as specified under Paragraph B or Paragraph C, depending upon the projection of the pipe, but with the following additions:

1. The backfill shall extend upward to an elevation above the top of the pipe equal to the overall height of the pipe plus 12 inches as applicable to either positive or negative projections;

2. A trench equal in width and depth to the overall width and height, respectively, of the pipe shall be dug into the backfill directly over the pipe throughout its full length, with the walls of the trench kept as nearly vertical as possible;

3. After the excavation of the trench is completed, the lower one-third shall be filled with loose straw or hay and the remaining portion shall be filled with soil, lightly compacted;

4. Immediately following the backfilling of the imperfect trench, the remainder of the backfill shall be constructed to an elevation of 2 feet above the trench.

All backfilling shall be done as specified in Paragraph B and C as applicable to conditions under which the pipe is installed. The backfill above the original ground shall be constructed of earth to the dimensions and slopes shown on the Standard Drawings and compacted to the density required for the adjacent embankment.

After the backfilling has been completed in accordance with the Standard Drawings, the remainder of the embankment may be constructed in accordance with Article 2.5.0, “Embankment.”

E. Rock Foundation. Ledge rock, gravelly soil, hardpan, or other unyielding material, when encountered within the sounding limits described in Paragraph A, shall be excavated as hereinafter specified prior to the preparation of the beddings outlined in Paragraphs B, C, or D.

Any hard or unyielding material shall be excavated below the bottom of the pipe to a depth equal to 4 inches per foot of fill over the pipe except that the depth shall be at least 12 inches but shall never exceed ¾ the height of the pipe. The excavated width shall be as shown on the Standard Drawing. The trench shall be refilled and compacted to an elevation of 0.15 of the over-all height above the bottom of the pipe with selected fine compressible material such as silty loam or silty clay. This material shall be firmly compacted and shaped according to the requirements of Paragraph B or C. The lower 0.3 of the pipe shall be bedded within the width of the trench but as otherwise specified under Paragraph B.

Backfill shall be constructed as specified under the applicable portions of Paragraphs B, C, or D depending upon the projection of the pipe and the height of fill, and shall be in accordance with the Standard Drawings. The remainder of the embankment shall then be completed in accordance with Article 2.5.0, “Embankment.”

F. Concrete, Cast Iron and Clay Pipe. Laying of concrete, cast iron, or clay pipe shall begin at the downstream end of the culvert with the bell or groove end laid upgrade and with the successive spigot ends fully extended into each adjoining hub. The barrel shall be true to the line and grade given.

Elliptical concrete pipe with the circular-reinforcement and circular concrete pipe with elliptical reinforcement shall be installed in such a position that the manufacturer’s mark designating the “top” or “bottom” shall not be more than 5 degrees from the vertical plane throughout the longitudinal axis of the pipe.

I. Joints. Joints shall be made with (a) portland cement mortar, (b) portland cement grout, (c) rubber gaskets, (d) oakum, (e) bituminous mastic joint sealing compound, or (f) a combination of these materials unless one type is specified on the plans, except that only one type of jointing material shall be used throughout any single structure. Joints for cast iron pipe culverts shall be made with rubber gaskets or oakum unless otherwise specifically provided.

a. Mortar Joints. The mixture shall be one part portland cement conforming to Article 7.1.2 and two parts sand conforming to Article 7.3.3. The quantity of water
in the mixture shall be sufficient to produce a stiff, workable mortar, but shall not exceed $\frac{3}{4}$ gallons of water per sack of cement. If ordered by the Engineer or specified on the plans, an air-entering portland cement conforming to Article 7.1.4 or an admixture conforming to Article 7.30.1 shall be used.

The ends of the pipe shall be thoroughly cleaned and wetted with water before joints are made. Stiff mortar shall then be placed in the lower half of the bell or groove section which has been laid. Mortar shall then be applied to the upper half of the spigot or tongue of the pipe being laid. The spigot or tongue shall then be inserted in the bell or groove of the pipe already laid, the joint being pulled tight, with care being taken to see that the inner surfaces of the abutting pipe sections are flush and even. After a section of pipe is laid, and before the succeeding section is laid, the lower portion of the hub of the preceding section shall be plastered thoroughly on the inside with mortar to such a depth as to insure a smooth joint between the abutting sections. The remainder of the joint shall then be filled flush with mortar. The inside of the joint shall then be finished and wiped smooth around the full circumference. After the initial set, the mortar shall be protected from air and sun with a thoroughly wetted earth or burlap cover.

b. Grout Joints. The grout shall consist of portland cement conforming to Article 7.1.2, mixed to a proper consistency with not more than 5 gallons of water per sack of cement. Grout shall be poured or pumped into the joint space and retained by molds or runners around the pipe in a manner acceptable to the Engineer. After the initial set of the grout, the molds or runners shall be removed and the inside of the joint shall be finished and wiped smooth. Any portion of the joint which was not filled with grout during the initial pouring or pumping shall be filled to insure a continuous joint throughout the entire circumference of the pipe. After initial set, the grout shall be protected from the air and sun with a thoroughly wetted earth cover or burlap cover.

c. Rubber Gasket Joints—Tongue and Groove Pipe. The rubber gaskets shall be a continuous ring which fits snugly in the annular space between the leveled surface of the tongue and the groove ends of the pipes to form a flexible water-tight seal under all conditions of services. All gaskets shall have smooth surfaces free from imperfections, and when tested in accordance with the applicable requirements of the "Federal Test Method Standards No. 601," shall meet the following requirements.

- Tensile strength shall be not less than 2,300 p.s.i.
- Elongation at rupture shall be such that 2-inch gauge marks will stretch at least 10 inches.
- Hardness shall be between 40 and 65 as measured by the Shore Durometer.
- Permanent set shall not exceed 20 per cent of the original length.

d. Oakum Joints—Bell and Spigot Pipe. The bell and spigot pipe shall be caulked with oakum and sealed with a hot poured joint compound. Oakum shall be made from hemp (canabis sativa) lime, or Benares Sunn Fiber, or from a combination of these fibers. The oakum shall be thoroughly cored and finished and practically free from lumps, dirt and extraneous matter. The fibers shall be thoroughly impregnated with hot asphalt cement. The sealer shall be an approved hot-poured sewer joint compound.

e. Bituminous Mastic Joints. The bituminous mastic joint-sealing material shall be a smooth, uniform mixture of bituminous cement, solvent, and mineral filler. The mineral filler shall consist essentially of short fiber asbestos. The mixture shall be readily applicable by means of a trowel or caulking gun without pulling or drawing, and shall not sag or flow when applied to metal, concrete or vitrified clay surfaces.

The compound shall be capable of withstanding freezing and shall not exhibit any tendency to separate or otherwise deteriorate while in storage.

When applied to a tinned panel or glass plate, in a layer $\frac{1}{16}$ to $\frac{1}{8}$ inch thick, and cured at room temperature for 24 hours, the compound shall set to a tough, plastic coating and shall not shrink, crack, or loosen from the surface.

In addition, the material shall meet the following requirements:

<table>
<thead>
<tr>
<th>Grease Cone Penetration</th>
<th>ASTM D 217, Unworked, 150 gm.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25° C., 5 sec.</td>
<td>1/10 mm</td>
<td>175</td>
<td>250</td>
</tr>
<tr>
<td>Weight per gal., lbs</td>
<td></td>
<td>9.75</td>
<td>.....</td>
</tr>
<tr>
<td>Non-Volatile (10 gm.)</td>
<td></td>
<td></td>
<td>.....</td>
</tr>
<tr>
<td>105° C.-110° C., 24 hrs.</td>
<td></td>
<td>75</td>
<td>.....</td>
</tr>
<tr>
<td>Ash (by ignition), pct.</td>
<td></td>
<td>25</td>
<td>45</td>
</tr>
</tbody>
</table>
The bituminous mastic jointing compound shall be applied to the ends of the pipe sections on the site immediately prior to placement and in the same manner as in the use of mortar except that jointing surfaces shall be precoated or primed with a paint-coat of emulsified asphalt, SS-1, Article 7.7.6, diluted with one part water to one part of the emulsion. The primer coat shall be allowed to cure for at least one hour before the mastic compound is applied. A slight excess of the sealer shall be applied so that when the joints are completely meshed, a bead of the sealer compound will be extruded from the joint on the inside and outside of the pipe. The excess material shall then be removed so as to form a smooth, flush joint.

G. Bituminous Coated and Paved Corrugated Metal Pipe. Bituminous coated and paved corrugated metal pipe shall be laid true to the established line and grade, and in such a manner that the outside laps of circumferential joints point upstream with no longitudinal joints in the lower quadrant. Field joints shall be made by abutting the ends of the sections, and by securing with a metal band of the same material firmly bolted in place. Corrugated metal pipe and pipe-arches having a paving material shall always be placed with the paving along the bottom or flow line. Wire strutting or vertical elongation of corrugated metal pipe shall be in accordance with standard plans.

H. Extensions to Existing Pipe Culverts. All pertinent requirements in the foregoing paragraphs shall apply to the extensions of existing pipe culverts. The extensions shall conform to the lines and grades as established and to the dimensions shown on the plans. The portions of the existing structure designated to be removed, shall be removed in such a manner as to provide a neat junction with the extension and leave undamaged that portion of the existing structure remaining in service. Any damage to the portion remaining in service shall be repaired by the Contractor at his expense. All silt or other debris that may have collected within the barrel of the existing structure shall be removed and disposed or by the Contractor, the payment for which shall be incidental to the work.

5.11.4 METHOD OF MEASUREMENT
The footage to be paid for shall be the actual number of linear feet of pipe of the several sizes, types and classes, installed in place, complete and accepted.

5.11.5 BASIS OF PAYMENT
The footages thus determined shall be paid for at the contract unit prices per linear foot of the several sizes, shapes, types and classes, which payment shall constitute full compensation for furnishing, hauling, installing and back-filling pipe; and for all materials, labor, equipment, tools and incidentals necessary to complete the work; but shall not constitute payment for structure excavation. Structure excavation shall be paid for as specified in Article 2.4.0 for structure excavation for pipe culverts.
APPENDIX C

Kentucky Department of Highways
Standard Drawings Showing Pipe Bedding
Details and Allowable Fill Heights
### TABLE FOR SAFE FILL COVER HEIGHTS AND CLASSES FOR CORRUGATED METAL CIRCULAR PIPE

<table>
<thead>
<tr>
<th>SIZE OF PIPE</th>
<th>Class of Risk</th>
<th>Height of Fill Cover Over Top of Pipe (Inches)</th>
<th>Standard Bearing</th>
<th>Gage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>H over TOP (Inches)</td>
<td>Standard Bearing</td>
<td>Gage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>12&quot;</td>
<td>A</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>18&quot;</td>
<td>A</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
</tbody>
</table>

### GENERAL NOTES

- For Division 3 Sections of K of the KDOT Standard Specifications for Reinforced Concrete Elliptical Piping, specify covering of Fill Cover over Top of Pipe, including all corrugated metal pipe, as shown in the chart for Tables for safe FILL COVER Heights and Classes for Reinforced Concrete Elliptical Pipe.

- The minimum safe fill cover height for non-circular pipe, including corrugated metal pipe, as shown in the chart for Tables for safe FILL COVER Heights and Classes for Reinforced Concrete Elliptical Pipe, shall be the minimum safe fill cover height for circular pipe, as shown in the chart for Tables for safe FILL COVER Heights and Classes for Reinforced Concrete Elliptical Pipe.

- The minimum safe fill cover height for non-circular pipe, including corrugated metal pipe, as shown in the chart for Tables for safe FILL COVER Heights and Classes for Reinforced Concrete Elliptical Pipe, shall be the minimum safe fill cover height for circular pipe, as shown in the chart for Tables for safe FILL COVER Heights and Classes for Reinforced Concrete Elliptical Pipe.

### CORRUGATED METAL PIPE ARCH

<table>
<thead>
<tr>
<th>Size of Pipe</th>
<th>Span (Inches)</th>
<th>Rise</th>
<th>Class of Risk</th>
<th>Minimum Height of Fill Cover (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12&quot;</td>
<td>12</td>
<td>24</td>
<td>C</td>
<td>18</td>
</tr>
<tr>
<td>18&quot;</td>
<td>18</td>
<td>24</td>
<td>C</td>
<td>21</td>
</tr>
<tr>
<td>24&quot;</td>
<td>24</td>
<td>24</td>
<td>C</td>
<td>24</td>
</tr>
</tbody>
</table>

### REINFORCED CONCRETE Elliptical Pipe

<table>
<thead>
<tr>
<th>Size of Pipe</th>
<th>Span (Inches)</th>
<th>Rise</th>
<th>Class of Risk</th>
<th>Minimum Height of Fill Cover (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12&quot;</td>
<td>12</td>
<td>24</td>
<td>C</td>
<td>18</td>
</tr>
<tr>
<td>18&quot;</td>
<td>18</td>
<td>24</td>
<td>C</td>
<td>21</td>
</tr>
<tr>
<td>24&quot;</td>
<td>24</td>
<td>24</td>
<td>C</td>
<td>24</td>
</tr>
</tbody>
</table>

### COMMONWEALTH OF KENTUCKY DEPARTMENT OF HIGHWAYS

- FILL COVER Heights for Circular Pipe and Non-Circular Pipe.
D - 1

ASTM Specification C 76-60T

Appendix D
Tentative Specifications for
REINFORCED CONCRETE CULVERT, STORM DRAIN, AND SEWER PIPE

ASTM Designation: C70-67T

These Tentative Specifications have been approved by the sponsoring com-
mittee and accepted by the Society in accord ance with established proce-
dures, for use pending adoption as standard. Suggestions for revisions
should be add ressed to the Society at 1916 Race St., Philadelphia 3, Pa.

Scope
These specifications cover rein-
forced concrete pipe from 12 to 108 in.
intended to be used for the conveyance
of sewage, industrial waste, and storm
water, and for the construction of cul-
verts.

Note 1—These specifications are manufac-
turing and purchasing guidelines only, and do
not include requirements for bonding, backfill,
or the relationship between earth cover and the
strength classification of pipe. However, speci-
cation has shown that the successful performance
of this product depends on equal amounts upon
the proper selection of the class of pipe, type of
building and backfill, controlled manufacture
on the plant, and due care in construction work.
The purchaser of the reinforced concrete pipe
studied herein is cautioned that he must prop-
ertly correlate the field requirements with the
class of pipe specified and provide adequate in-
spection in the manufacturing plant and at the
construction site.

Class
Pipe manufactured according to
these specifications shall be of five cl asses
ident i ed as class I, class II, class III,
class IV, and class V. The corresponding
strength requirements are prescribed in
Tables I to V.

Basis of Acceptance

(a) Unless otherwise designated by the
 purchaser at the time of, or before,
 placing an order, three separate and
 alternate bases of acceptance are per-
mitted as follows:
(1) Acceptance on Basis of Plant
Load Bearing Tests, Material Tests,
and Inspection of the Complete Prod-
uct.—Acceptability of the pipe in all
diameters and classes shall be deter-
dined by the results of the three-
edged edge-bearing or sand-bearing
or by the spot load to produce a 0.01-in.
and ultimate load, by such mate-
terial tests as are required in Sections
5, 6, and 7, by absorption tests on
selected samples from the wall of the
pipe; and by inspection of the finished
pipe to determine its conformance
with the design prescribed in these
specifications and its freedom from
defects.

(b) Acceptance on Basis of Material
Tests and Inspection of the Complete
Product.—Acceptability of the pipe in
diameters and classes shall be deter-
dined by the results of such
material tests as are required in Sec-
tions 5, 6, and 7; by crushing tests on
concrete cores or cured concrete cylin-
ders; by absorption tests on selected
samples from the wall of the pipe; and
by inspection of the finished pipe, in-
cluding amount and placement of rein-
forcement, to determine its confor-
ma nee with the design prescribed in
these specifications and its freedom
from defects.

(c) When agreed upon by the
manufacturer, the pipe may be
examined by the purchaser in the
manufacturing plant and at the
construction site.

Materials
Reinforced Concrete

1. Reinforcement shall conform to the
requirements of the Specifications
for Portland Cement (ASTM Designa-
tion: C 150), or shall be air-entraining
portland cement con forming to the re-
quirements of the Specifications for Air-
Entrain ing Portland Cement (ASTM
Designation: C 175); or shall be port-
dland blast-furnace slag cement con-
foming to the requirements of the Speci-
fications for Portland Blast-Furnace Slag
Cement (ASTM Designation: C 205).

Steel Reinforcement

2. Reinforcement may consist of wire
conforming to the Specifications for
Cold-Drawn Steel Wire for Concrete
Reinforcement (ASTM Designation: A 92),
or of wire fabric conforming to the
Specifications for Welded Steel Wire
Fabric for Concrete Reinforcement
(ASTM Designation: A 183), or of
bars of structural or intermediate grade
conforming to the Specifications for
Billet-Steel Bars for Concrete Reinforce-
ment (ASTM Designation: A 15).

Aggregates

3. Aggregates shall conform to the
Specifications for Concrete Aggregates
(ASTM Designation: C 33), except that
the requirement for gradation shall not
apply.

Mixture

4. The aggregates shall be so sized
and so graded and proportioned and
thoroughly mixed in a batch mixer with
such proportions of cement and water as
will produce a homogeneous concrete
mixture of such quality that the pipe will
conform to the test and design require-
ments of these specifications. Admixtures
or blends may be used with the approval
of the consumer. In no case, however,
shall the proportion of Portland cement

1 Supplement to Book of ASTM Standards, Part 4.
Specifications for Reinforced Concrete Pipe (C 75)

in the mixture be less than six U. S. standard bags (94 lb) per cubic yard of concrete.

of circumferential reinforcement shall be not less than that prescribed for classes I to V in Tables I to V, except as provided in Section 10.

Design

Minimum Design

9. The shell thickness and the amount

Alternate and Special Design

10. Manufacturers may submit to

TABLE I—DESIGN REQUIREMENTS FOR CLASS I REINFORCED CONCRETE PIPE

<table>
<thead>
<tr>
<th>Wall A</th>
<th>Wall B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Strength, psi</td>
<td>Concrete Strength, psi</td>
</tr>
<tr>
<td>Internal Diameter, in.</td>
<td>Internal Diameter, in.</td>
</tr>
<tr>
<td>50 &amp; 60 &amp; 72 &amp; 75 &amp; 90 &amp; 102 &amp; 8 0.95 0.40 0.20 0.08 0.38</td>
<td>8 0.31 0.16 0.08 0.38</td>
</tr>
<tr>
<td>84 &amp; 90 &amp; 102 &amp; 108 &amp; 0.96 0.11</td>
<td>10 0.61 0.49</td>
</tr>
</tbody>
</table>

*For more and less than the sizes shown in the table, pipes may be supplied using special designs involving more or less than the following wall thicknesses, high strength concrete, shear reinforcement, in accordance with the provisions of Section 10.

Steel may be used to strengthen these shown for variations in diameter, loading, or wall thickness. Over 96 in. in diameter shall have two circular cages or inner circular plus one elliptical cage of the minimum steel area shown.

The elliptical steel in circular pipe and elliptical steel in elliptical pipes must be held in place by means of holding rods or chains or other positive means throughout the entire length of the pipe and throughout the entire casing and remain in place until the concrete has taken its final set.

See Section 10 for provisions for alternate designs.

TABLE II—DESIGN REQUIREMENTS FOR CLASS II REINFORCED CONCRETE PIPE

<table>
<thead>
<tr>
<th>Wall A</th>
<th>Wall B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Wall Thickness, in.</td>
<td>Minimum Wall Thickness, in.</td>
</tr>
<tr>
<td>Circular Reinforcement in Circular Pipe</td>
<td>Circular Reinforcement in Circular Pipe</td>
</tr>
<tr>
<td>Inner Placing</td>
<td>Outer Placing</td>
</tr>
<tr>
<td>8 0.31 0.16 0.08 0.38</td>
<td>8 0.31 0.16 0.08 0.38</td>
</tr>
<tr>
<td>8 0.31 0.16 0.08 0.38</td>
<td>8 0.31 0.16 0.08 0.38</td>
</tr>
</tbody>
</table>

*For more and less than those shown in the table, pipes may be supplied using special designs involving one or more of the following: wall thicknesses, high strength concrete, shear reinforcement, in accordance with the provisions of Section 10.

Steel may be interposed between those shown for variations in diameter, loading, or wall thickness. Pipes over 96 in. in diameter shall have two circular cages or inner circular plus one elliptical cage of the minimum steel area shown.

Elliptical steel in circular pipe over 60 in. in diameter or circular steel in elliptical pipe over 60 in. in diameter must be held in place by means of holding rods or chains or other positive means throughout the entire length of the pipe and throughout the entire casing and remain in place until the concrete has taken its final set.

See Section 10 for provisions for alternate designs.
### SPECIFICATIONS FOR REINFORCED CONCRETE PIPE (C 76)

#### TABLE III.—DESIGN REQUIREMENTS FOR CLASS III REINFORCED CONCRETE PIPE

**Note:** See Section 3 for the basis of acceptance specified by the purchaser.

The strength test requirements in pounds per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce the ultimate load

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.08</td>
<td>2.07</td>
<td>2.07</td>
</tr>
<tr>
<td>15</td>
<td>0.09</td>
<td>2.39</td>
<td>2.39</td>
</tr>
<tr>
<td>20</td>
<td>0.10</td>
<td>2.10</td>
<td>2.10</td>
</tr>
<tr>
<td>20</td>
<td>0.12</td>
<td>3.14</td>
<td>3.14</td>
</tr>
<tr>
<td>25</td>
<td>0.15</td>
<td>3.10</td>
<td>3.10</td>
</tr>
<tr>
<td>30</td>
<td>0.19</td>
<td>3.16</td>
<td>3.16</td>
</tr>
<tr>
<td>33</td>
<td>0.21</td>
<td>3.17</td>
<td>3.17</td>
</tr>
<tr>
<td>35</td>
<td>0.25</td>
<td>3.19</td>
<td>3.19</td>
</tr>
<tr>
<td>40</td>
<td>0.33</td>
<td>3.26</td>
<td>3.26</td>
</tr>
<tr>
<td>44</td>
<td>0.40</td>
<td>3.32</td>
<td>3.32</td>
</tr>
<tr>
<td>50</td>
<td>0.50</td>
<td>3.40</td>
<td>3.40</td>
</tr>
</tbody>
</table>

**TABLE IV.—DESIGN REQUIREMENTS FOR CLASS IV REINFORCED CONCRETE PIPE**

**Note:** See Section 3 for the basis of acceptance specified by the purchaser.

The strength test requirements in pounds per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce the ultimate load

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.08</td>
<td>2.07</td>
<td>2.07</td>
</tr>
<tr>
<td>15</td>
<td>0.09</td>
<td>2.39</td>
<td>2.39</td>
</tr>
<tr>
<td>20</td>
<td>0.10</td>
<td>2.10</td>
<td>2.10</td>
</tr>
<tr>
<td>20</td>
<td>0.12</td>
<td>3.14</td>
<td>3.14</td>
</tr>
<tr>
<td>25</td>
<td>0.15</td>
<td>3.10</td>
<td>3.10</td>
</tr>
<tr>
<td>30</td>
<td>0.19</td>
<td>3.16</td>
<td>3.16</td>
</tr>
<tr>
<td>33</td>
<td>0.21</td>
<td>3.17</td>
<td>3.17</td>
</tr>
<tr>
<td>35</td>
<td>0.25</td>
<td>3.19</td>
<td>3.19</td>
</tr>
<tr>
<td>40</td>
<td>0.33</td>
<td>3.26</td>
<td>3.26</td>
</tr>
<tr>
<td>44</td>
<td>0.40</td>
<td>3.32</td>
<td>3.32</td>
</tr>
<tr>
<td>50</td>
<td>0.50</td>
<td>3.40</td>
<td>3.40</td>
</tr>
</tbody>
</table>

---

*See Footnote a under Table II*
TABLE V.—DESIGN REQUIREMENTS FOR CLASS V REINFORCED CONCRETE PIPE

<table>
<thead>
<tr>
<th>Internal Diameter, in.</th>
<th>Concrete Strength, 6000 psi</th>
<th>Concrete Strength, 6000 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wall S</td>
<td>Wall C</td>
</tr>
<tr>
<td></td>
<td>Minimum Wall Thickness, in.</td>
<td>Minimum Wall Thickness, in.</td>
</tr>
<tr>
<td></td>
<td>Circular Reinforcement in Elliptical Pipe</td>
<td>Elliptical Reinforcement in Circular Pipe</td>
</tr>
<tr>
<td></td>
<td>Wall C</td>
<td>Wall C</td>
</tr>
<tr>
<td></td>
<td>Circular Reinforcement in Elliptical Pipe</td>
<td>Elliptical Reinforcement in Circular Pipe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I.D.</th>
<th>Wall Thickness</th>
<th>Circular Reinforcement</th>
<th>Elliptical Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inner Cage</td>
<td>Outer Cage</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2/4</td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>0.23</td>
<td>0.34</td>
</tr>
<tr>
<td>24</td>
<td>3</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>27</td>
<td>3/4</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td>33</td>
<td>3/5</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>36</td>
<td>3</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>42</td>
<td>4</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>48</td>
<td>4</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td>54</td>
<td>4</td>
<td>0.56</td>
<td>0.56</td>
</tr>
<tr>
<td>60</td>
<td>4</td>
<td>0.59</td>
<td>0.59</td>
</tr>
<tr>
<td>72</td>
<td>4</td>
<td>0.63</td>
<td>0.63</td>
</tr>
</tbody>
</table>

- For sizes and loads beyond those shown in the above table, pipe may be supplied using special designs involving one or more of the following: wall thickness, high strength concrete, and a reinforcement in accordance with the provisions of Section 10.

**Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness.**

Elliptical steel in circular pipe or circular steel in elliptical pipe must be held in place by means of holding rods or chairing or other positive means throughout the entire length of the pipe and throughout the entire casting operation and remain in place until the concrete has taken its initial set.

**See Section 10 for provisions for alternate designs.**

Specifications for Reinforced Concrete Pipe (C 76)

### Laps, Welds, and Spacing

13. If the splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars, and 40 diameters for plain bars and cold-drawn wire. The spacing center to center of adjacent rings of circumferential reinforcement in a cage shall not exceed 4 in. for pipe up to and including pipe having a 4-in. wall thickness nor exceed the wall thickness for larger pipe, and shall in no case exceed 6 in. The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe.

### Joints

14. The ends of reinforced concrete pipe sections shall be so formed that when the pipe are laid together they will make a continuous and uniform line of pipe, compatible with the tolerances given in Section 25 (a). The joints shall be of such design as will permit effective jointing to reduce leakage and infiltration to a satisfactory minimum and to permit movement without appreciable irregularities in the flow line.

### Elliptical Pipe

15. Elliptical pipe, within the meaning of these specifications, shall be pipe having a vertical diameter longer than the horizontal diameter by an amount approximately equal to the wall thickness of the pipe. Elliptical pipe shall meet the same type of tests as are required of circular pipe. The wall thickness, horizontal diameter, vertical diameter, and placement of reinforcement shall meet the tolerances as given in Section 25.

### Diameter Relationship Between Elliptical and Circular Pipe

The diameter relationship between elliptical and circular pipe shall be as prescribed in Section 24.

### Manufacture

**Placement of Concrete**

16. The transporting and placement of concrete shall be by methods that will...
pHosphorus maintained by the injection outside prevents the segregation placed in a curing chamber, free from drafts, and cured in a moist atmosphere. The pipe shall be cured for a sufficient length of time so that the concrete will develop the specified compressive strength at 28 days or more. The purchaser, that will give satisfactory results. The pipe shall be water-cured by covering with water or by any other approved method or combination of methods approved by the purchaser, that will give satisfactory results. The pipe shall be watered-cured by covering with water saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

(a) Steam Curing.—Pipe may be placed in a curing chamber, free from outside drafts, and cured in a moist atmosphere, maintained by the injection of steam for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

(b) Water Curing—Concrete pipe may be water-cured by covering with water saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the curing period.

(c) The manufacturer may, at his option, combine the methods described in Paragraphs (a) and (b) as long as the required concrete compressive strength is attained.

(d) A sealing membrane conforming to the requirements of the Specifications for Liquid Membrane-Forming Compounds for Curing Concrete (ASTM Designation: C 309) may be applied and should be left intact until the required strength requirements are met. The concrete at the time of application shall be within 10°F of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

**Lift Holes**

18. When agreed upon by the purchaser and the manufacturer, not more than two holes shall be cast or drilled in the shell of each piece of pipe for the purpose of handling and laying.

**Physical Test Requirements**

**Test Specimens**

19. The specified number of pipe required for the tests prescribed in Sections 20 to 23 shall be furnished without charge by the manufacturer and shall be selected at random by the purchaser, and shall be pipe that would not otherwise be rejected under these specifications. The selection shall be made at the point or points designated by the purchaser when placing the order. The test specimens shall be surface-dry when tested and shall not have been exposed to a temperature below 40°F for the 24 hr immediately preceding the test.

**External Load Crushing Strength Test Requirements**

20. (a) The load to produce an 0.01-in. crack or the ultimate load, as determined by either the three-edge-bearing method or the sand-bearing method as described in Sections 31 through 33, shall not be less than that prescribed in Tables 1 to V for each respective class of pipe. The ultimate load is reached when the pipe will sustain no greater load. The 0.01-in. crack load is the maximum load applied to the pipe before a crack having a width of 0.01 in., measured at close intervals, occurs throughout a length of 1 ft or more. The crack shall be considered 0.01 in. in width when the point of the measuring gage will, without forcing, penetrate it 1/8 in. at close intervals throughout the specified distance of 1 ft.

The width of crack shall be measured by means of a gage made from a leaf 0.01 in. in thickness (as in a set of standard machinist’s gages), ground to a point 1/8 in. in width, with corners rounded, and a taper of 1/2 in. per inch, as illustrated in Fig. 1. Pipe that have been tested only to the formation of a 0.01-in. crack and that meet the 0.01-in. test load requirements shall be accepted for use.

(b) Retests of Pipe Not Meeting the Strength Test Requirements—Pipe shall be considered as meeting the strength test requirements when all test specimens conform to the test requirements. Should any of the test specimens fail to meet the test requirements, the manufacturer shall be allowed a retest on two additional specimens for each specimen that failed, and all of the retest specimens meet the test requirements. The pipe shall be acceptable only when the core-holes have been drilled from the barrel of the pipe, as determined by the manufacturer in a manner such that the concrete will develop the required design strength of the concrete. If a core does not meet the required strength, another core from the same pipe may be tested. If this core does not meet the required strength, that pipe shall be rejected. Additional tests shall be made on other pipe to determine the acceptability of the lot. When the cores cut from a section of pipe successfully meet the strength test requirement, the core-holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the test requirements of these specifications. Pipe sections, so sealed shall be considered as satisfactory for use.

(b) Absorption Test Requirements of Concrete—The absorption of a sample from the wall of the pipe, as determined in Section 34, shall not exceed 8 per cent of the dry weight. Pipe shall be considered as conforming to these specifications for absorption when not less than 80 per cent of the number of specimens tested, including any retested, conform to the test requirements. When the initial absorption specimen from a pipe fails to conform to these specifications, the ab-

---

*1936 Book of ASTM Standards, Part 4.*
Specifications for Reinforced Concrete Pipe (C 76)

Porosity test shall be made on another specimen from the same pipe and the results of the test shall be substituted for the original test results.

(c) Repairs of Pipe Not Meeting the Concrete Test Requirements.—When not more than 20 per cent of the concrete test specimens fail to pass the requirements of the specification, the manufacturer may call his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipes that they will not be shipped. The required tests shall be made on the balance of the order and the pipe shall be accepted if they conform to the test requirements.

Number and Type of Test Required for Various Delivery Schedules
22. (a) Preliminary Tests for Extended Delivery Schedules.—A purchaser of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to such tests, preliminary to delivery of pipe, as are required by the type of basis of acceptance specified by the purchaser in Section 3, of not more than three sections of pipe covering each size in which he is interested.

(b) Additional Tests for Extended Delivery Schedules.—After the preliminary tests described in Paragraph (a), a purchaser shall be entitled to additional tests in such numbers and at such times as he may deem necessary, provided that the total number of pipe tested shall not exceed 1 per cent of the pipe delivered.

(c) Tests for Occasional Orders.—A purchaser who places occasional orders shall be entitled to test a number of pipe not to exceed 2 per cent of an order, and not to exceed five pieces of any one size; otherwise the number of pipe desired for testing shall be included in the order.

Test Equipment
23. Every manufacturer furnishing pipe under these specifications shall furnish all facilities and personnel necessary to carry out the tests described in Sections 31 to 34.

Sizes and Permissible Variations
24. Pipe of the internal diameters listed in Tables I to V shall be the standard sizes for culvert, storm drain, and sewer pipe construction. In elliptical pipe, the inside diameter at the minor axis of the pipe shall be equal to the diameter of the corresponding size of circular pipe.

Permissible Variations in Dimensions
25. (a) The internal diameter of 12- to 24-in. pipe shall not vary more than ±1.5 per cent from the nominal diameter. The internal diameter of 27- to 108-in. pipe shall not vary more than ±1 per cent or ±1 in., whichever is greater, from the nominal diameter. The wall thickness shall not be less than that shown in the design by more than 5 per cent or ±8 in., whichever is greater. A wall thickness more than that required in the design shall not be a cause for rejection.

(b) Permissible Variations in the Position of the Reinforcement.—For pipe with a 4-in. wall or less, the maximum variation in the position of the reinforcement shall be ±10 per cent of the wall or ±4 in., whichever is the greater. For pipe with a wall thickness greater than 4 in., the maximum variation shall be ±10 per cent of the wall or ±4 in., whichever is the lesser. In no case, however, shall the cover over the circumferential reinforcement be less than 1 in. for wall thicknesses less than 2 in., or less than 1 in. for wall thicknesses 2 in. or greater.

(c) Where single cage circular reinforcement is used in either circular pipe or elliptical pipe and for all elliptical cage reinforcement, a steel area that is not less than 97 per cent of that area shown in Tables I to V, will be considered as meeting the required steel area. Where two circular cage reinforcements (one inner and one outer cage) are used, again referring to Tables I to V, the inner cage steel area may vary to the lower limit of being not less than 85 per cent of the same design elliptical steel area, and the outer cage steel area may vary to the lower limit of being not less than 64 per cent of the same design elliptical steel area, provided that in no case shall the total steel area of the inner cage plus the outer cage be less than 133 per cent of the same design elliptical steel area.

(d) Variations in laying lengths of two opposite sides of pipe shall not be more than ±1 in. per foot of diameter, with a maximum of ±1 in. in any length of pipe, except where beveled end pipe for laying on curves is specified by the purchaser.

(a) Fractures or cracks passing through the shell, except for a single end crack that does not exceed the depth of the joint.

(b) Defects that indicate imperfect proportioning, mixing, and molding.

(c) Surface defects indicating honeycombed or open texture.

(d) Damaged ends, where such damage would prevent making a satisfactory joint.

Marking
27. The following information shall be clearly marked on each section of pipe:
(a) The pipe class,
(b) The date of manufacture, and
(c) The name or trade-mark of the manufacturer.

(d) One end of each section of pipes with elliptical reinforcement shall be clearly marked, during the process of manufacturing or immediately thereafter, on the inside and outside of opposite walls along the minor axes of the elliptical reinforcing. Markings shall be indented on the pipe section or painted thereon with waterproof paint.

Inspection and Rejection
28. The quality of materials, the process of manufacture, and the finished pipe shall be subject to inspection and approval by an inspector employed by the purchaser.

Rejection
29. Pipe shall be subject to rejection on account of failure to conform to any of the specification requirements. Individual sections of pipe may be rejected because of any of the following:
(a) Fractures or cracks passing through the shell, except for a single end crack that does not exceed the depth of the joint.
(b) Defects that indicate imperfect proportioning, mixing, and molding.
(c) Surface defects indicating honeycombed or open texture.
(d) Damaged ends, where such damage would prevent making a satisfactory joint.

Repairs
30. Pipe may be repaired, if necessary, because of occasional imperfections in manufacture or accidental injury during handling and will be acceptable if, in the opinion of the purchaser, the repairs are sound and properly finished and cured and the repaired pipe conforms to the requirements of these specifications.
**Specifications for Reinforced Concrete Pipe (C 76)**

**Test Methods**

*External Load Crushing Strength Tests*  

**Apparatus**  

31. (a) In making the test, any mechanical or hand-power device may be used in which the head that applies the load moves at such a speed as to increase the load at a uniform rate of approximately 2000 lb per linear foot of pipe per minute.

(b) It is necessary that the testing machine used for the strength tests shall produce a uniform deflection throughout the full length of the pipe. The testing machine shall be substantial and rigid throughout, so that the distribution of the load will not be affected appreciably by the deformation or yielding of any part.

**Three-Edge-Bearing Method**  

32. (a) When the three-edge-bearing method is used (see Figs. 2 and 3), the ends of each specimen of pipe shall be accurately marked in halves of the circumference prior to the test. The lower bearings shall consist of two wooden strips with vertical sides having their interior top corners rounded to a radius of approximately \(\frac{1}{2}\) in. The strips shall be straight and shall be securely fastened to a rigid base. The interior vertical sides of the strips shall be parallel and spaced a distance apart of not more than \(\frac{1}{8}\) in. per foot of pipe diameter, but in no case less than 1 in. If requested by the manufacturer or purchaser, a fillet of plaster of Paris and sand thick enough to compensate for the inequalities of the pipe barrel, but not exceeding 1 in. in thickness, shall be cast on the surface of the lower bearings. The upper bearing shall be a rigid wooden block, free of knots, and straight and true from end to end. The load shall be applied to this block through a metal beam of such dimensions that it will transmit the full load without appreciable deflection. A fillet of plaster of Paris, not exceeding 1 in. in thickness, may also be cast along the length of the crown of the pipe to equalize the bearings. The upper and lower bearings shall extend the full length of the pipe exclusive of the bell. The pipe shall be placed symmetrically between the two bearings as illustrated in Figs. 2 and 3. In testing pipe that is "out of line," the lines of the bearings chosen shall be from those that appear to give the most favorable conditions for fair test.

(b) If mutually agreed upon by the manufacturer or other seller and the purchaser, hard rubber blocks or sand-filled high-pressure hose may be used in lieu of wooden bearings as prescribed in Paragraph (a).

When hard rubber blocks are used for bearings, they shall be cut from material having a durometer hardness of not less than 45 nor more than 60. They shall be rectangular in cross-section, and have a width of 2 in. and a thickness of not less than 1 in. nor more than \(\frac{3}{4}\) in. Two hard rubber blocks shall be secured to a rigid wooden block at least 6 by 6 in. in cross-section, in such a manner that their interior vertical sides shall be parallel and spaced a distance apart of not more than 1 in. per foot of pipe diameter, but in no case less than 1 in. When sand-filled hose are used for bearings, they shall be made from heavy canvas duck or woven cloth hose such as is commonly used for fire hose. They shall be such that, when filled with tightly packed dry sand (all of which
Specifications for Reinforced Concrete Pipe (C 76)

will pass a No. 6 (3360-micron) sieve conforming to the Specifications for Sieves for Testing Purposes (ASTM Designation: E 11) they will have an a rigid block at least 6 by 6 in. in cross-section in such a manner that their interior sides shall be parallel and spaced a distance apart of not more than 1 in.

outside diameter of not less than 2 in. nor more than 2 1/8 in. The ends of each hose shall be tightly stitched with belt lacing to prevent any sand from escaping. Two sand-filled hose shall be secured to

NOTE 2—A satisfactory method for securing either the hard rubber blocks or sand-filled hose to the upper and lower rigid block is by cutting grooves in one face. The depth of the grooves shall be not greater than half the thickness of the hard rubber block or the outside diameter of the hose. The width shall be such that each block or hose will fit snugly.

(c) The load shall be applied continuously until the required strength of the pipe specified in Tables I to V is reached. The load per linear foot of pipe shall be calculated by dividing the total recorded load by the laying length. The pipe shall not be allowed to stand under load longer than is required to apply the load and to observe and record it. The pipe shall be surface-dry when tested.

Sand-Bearing Method

33. (a) When the sand-bearing method is used (see Figs. 4 and 5), the ends of each specimen of pipe shall be accurately marked in quarters of the circumference prior to the test. Specimens shall be carefully bedded in sand, above and below, for one fourth the circumference of the pipe measured on the middle line of the barrel. The depth of bedding above and below the pipe at the thinnest points shall be one half the radius of the middle line of the barrel.

(b) The sand used shall be clean and shall contain not less than 5 per cent of moisture, and shall be such as will pass a No. 4 (4760-micron) sieve. The sand in the lower bearing shall be loose when the pipe is placed.

(c) The top bearing frame shall not be allowed to come in contact with the pipe nor with the top bearing plate. The upper surface of the sand in the top bearing shall be struck off level with a straightedge, and shall be covered with a rigid top bearing plate, the lower surface of which is a true plane, made of heavy timbers or other rigid material capable of distributing the test load uniformly without appreciable bending.

The test load shall be applied at the exact center of this top bearing plate, or in such manner as to produce uniform deflection throughout the full length of the pipe. For this purpose a spherical bearing is preferred, but two rollers at right angles may be used.

(d) The test may be made without the use of a testing machine, by piling weights directly on a platform resting on the top bearing plate; provided, however, that the weights shall be piled symmetrically about a vertical line through the center of the pipe, and that the platform shall not be allowed to touch the top bearing frame.

(e) The frames of the top and bottom bearings shall be made of timbers so heavy as to avoid appreciable bending by the side pressure of the sand. The interior surfaces of the frames shall be dressed. No frame shall come in contact with the pipe during the test. A strip of cloth may be attached, if desired, to the inside of the upper frame on each side, along the lower edge, to prevent the escape of sand between the frame and the pipe.

(f) The load shall be applied continuously until the required strength of the pipe specified in Tables I to V is reached. The load per linear foot of pipe shall be calculated by dividing the total...
recorded load by the laying length. The pipe shall not be allowed to stand under load longer than is required to apply the load and to observe and record it. The pipe shall be surface-dry when tested.

Absorption Test

Absorption Test

34. (a) Test Specimen.—The number of absorption test specimens shall be equal to the number of pipe provided for testing. The specimens shall be obtained from pipe that are acceptable as to strength, and shall be taken from pipe used in making the strength test after that test is made. The specimens shall be marked with the number or identification mark of the pipe from which they were taken. Each specimen shall have an area of 16 to 24 sq in., as measured on one surface of the pipe, and a thickness equal to the full depth of the pipe shell, and shall be free from visible cracks.

(b) Drying Specimens.—Specimens shall be dried in a ventilated oven at a temperature of 221 to 239°F (105 to 115°C) until two successive weighings at intervals of not less than 2 hr show an increment of loss not greater than 0.1 per cent of the original weight of the specimen.

(c) Immersion and Reweighing.—The dried specimens shall be placed in a suitable receptacle and covered with clean water. This shall be distilled water or rain water, except that tap water may be used if it is known that such use will not affect the test results. The water shall be heated to boiling, boiled continuously for 5 hr, and then allowed to cool by natural loss of heat for not less than 16 hr. When cool, the specimens shall be removed from the water and allowed to drain for not more than 1 min. The superficial water shall then be removed by absorbent cloth or paper and the specimens weighed immediately.

(d) Weighing Apparatus.—The balance used shall be sensitive to 0.5 g when loaded with 1 kg, and weighings shall be read at least to the nearest gram. When other than metric weights are used, the same degree of accuracy shall be obtained.

(e) Calculations and Report.—The increase in weight of the boiled specimen over its dry weight shall be taken as the absorption of the specimen, and shall be expressed as a percentage of the dry weight. The results shall be reported separately for each specimen.
E - 1

Miscellaneous Data

Appendix E
Table 8. Summary of Flexural Strengths of Concrete Beams

<table>
<thead>
<tr>
<th>Cylinder No.</th>
<th>Date Made</th>
<th>Date Broken</th>
<th>Age (Days)</th>
<th>Flexural Strength (Third-Point Loading) (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2</td>
<td>11-10-60</td>
<td>12-9-60</td>
<td>29</td>
<td>1020</td>
</tr>
<tr>
<td>A-3</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1000</td>
</tr>
<tr>
<td>A-4</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1520</td>
</tr>
<tr>
<td>B-2</td>
<td>11-10-60</td>
<td>12-9-60</td>
<td>29</td>
<td>920</td>
</tr>
<tr>
<td>B-3</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1260</td>
</tr>
<tr>
<td>B-4</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1500</td>
</tr>
<tr>
<td>C-2</td>
<td>11-10-60</td>
<td>12-9-60</td>
<td>29</td>
<td>1020</td>
</tr>
<tr>
<td>C-3</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1360</td>
</tr>
<tr>
<td>C-4</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1520</td>
</tr>
<tr>
<td>D-2</td>
<td>11-10-60</td>
<td>12-9-60</td>
<td>29</td>
<td>1200</td>
</tr>
<tr>
<td>D-3</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1480</td>
</tr>
<tr>
<td>D-4</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1540</td>
</tr>
<tr>
<td>E-2</td>
<td>11-10-60</td>
<td>12-21-60</td>
<td>42</td>
<td>1160</td>
</tr>
<tr>
<td>E-3</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1380</td>
</tr>
<tr>
<td>E-4</td>
<td>11-10-60</td>
<td>5-26-61</td>
<td>197</td>
<td>1400</td>
</tr>
<tr>
<td>F-2</td>
<td>11-9-60</td>
<td>12-9-60</td>
<td>30</td>
<td>1000</td>
</tr>
<tr>
<td>F-3</td>
<td>11-9-60</td>
<td>7-21-61</td>
<td>254</td>
<td>1460</td>
</tr>
<tr>
<td>F-4</td>
<td>11-9-60</td>
<td>7-21-61</td>
<td>254</td>
<td>1300</td>
</tr>
<tr>
<td>G-1</td>
<td>11-14-60</td>
<td>12-9-60</td>
<td>25</td>
<td>1000</td>
</tr>
<tr>
<td>G-2</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1480</td>
</tr>
<tr>
<td>G-3</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1320</td>
</tr>
<tr>
<td>H-1</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1320</td>
</tr>
<tr>
<td>H-2</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1380</td>
</tr>
<tr>
<td>H-3</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1400</td>
</tr>
<tr>
<td>J-1</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1320</td>
</tr>
<tr>
<td>J-2</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1440</td>
</tr>
<tr>
<td>J-3</td>
<td>11-14-60</td>
<td>5-26-61</td>
<td>193</td>
<td>1440</td>
</tr>
<tr>
<td>C-3-1</td>
<td>6-13-61</td>
<td>7-21-61</td>
<td>38</td>
<td>675</td>
</tr>
<tr>
<td>C-3-2</td>
<td>6-13-61</td>
<td>7-21-61</td>
<td>38</td>
<td>638</td>
</tr>
<tr>
<td>E-2-1</td>
<td>6-13-61</td>
<td>7-21-61</td>
<td>38</td>
<td>638</td>
</tr>
<tr>
<td>E-2-2</td>
<td>6-13-61</td>
<td>7-21-61</td>
<td>38</td>
<td>638</td>
</tr>
<tr>
<td>J-2-1</td>
<td>6-13-61</td>
<td>7-21-61</td>
<td>38</td>
<td>375</td>
</tr>
<tr>
<td>J-2-2</td>
<td>6-13-61</td>
<td>7-21-61</td>
<td>38</td>
<td>113</td>
</tr>
</tbody>
</table>