Performance of a Reinforced Concrete Pipe Culvert Under Rock Embankment

Robert C. Deen
Kentucky Department of Highways
Research Report

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PERFORMANCE OF A REINFORCED CONCRETE PIPE CULVERT UNDER ROCK EMBANKMENT

by

Robert C. Deen
Assistant Director

Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky

533 South Limestone
Lexington, Kentucky

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ABSTRACT

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A 48-inch diameter reinforced concrete pipe installation has been observed in order to evaluate the performance of both types of bedding conditions as currently used by the Kentucky Department of Highways. A portion of the pipe was laid using Kentucky's Standard B Bedding. The remainder of the pipe culvert was laid using the B₁ Bedding (imperfect trench); the design height of the fill (36 feet) was sufficient to require the imperfect trench construction. The embankment was primarily of a rock fill material, with the largest particle size limited to a maximum of 3 feet. The portion of the pipe with the Standard B Bedding exhibited stress in relation to each additional height of embankment placed. For every fill increment, there was a corresponding change in the length of the vertical and horizontal diameters of the pipe and in the pipe distress as exhibited by cracking. The absence of signs of distress in the B₁ Bedding portion indicates that the imperfect trench performed its purpose of relieving load on the pipe.
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INTRODUCTION

When taken as a general classification, underground conduits in some form have been used by mankind for at least 3000 years for drainage or water supply purposes. In recent years interstate highways with flatter grades and longer radius curves have resulted in the construction of deeper cuts and higher fills. Concrete pipe culverts under these higher fills require either special methods of installation, such as the imperfect trench, or stronger pipe in order to carry the applied heavier loadings.

An extensive research program on pipe problems was inaugurated at Iowa State College in 1908 and has been carried on practically continuously since that time. Through this research, a comprehensive theory widely known as "Marston's Theory of Loads on Underground Conduits" (1, 2, 3) has been developed.
Conceivably, it would be possible to compute by modern methods of soil mechanics the various factors that affect the load on a conduit, but such a procedure would involve the expenditure of both time and money that would be prohibitive in relation to the total cost of the structure. Therefore, many of these factors may be evaluated by an accumulation of data obtained from measurement and observation of actual installation performances. Many states have specifications or standard plans permitting the use of the imperfect trench as proposed by Marston at Iowa State College, or modifications thereof. Most of these states have adopted the imperfect trench method of construction within the past two decades.

Advancement of the present knowledge of loads on pipe culverts is dependent in part upon an accumulation of field experience and supporting data. One particular pipe has been chosen for this special study because of its installation conditions and because it may add to the knowledge of the performance of the imperfect trench. This pipe has been constructed using both type beddings that were specified in the 1956 edition of the Kentucky Department of Highways Standard Specifications for Road and Bridge Construction and amendments thereto (See Appendix I). Observation of the performance of this installation during and after construction was desirable so as to check the validity of the imperfect trench theory as applied to rockfill material, which was used in this particular installation.

PIPE INSTALLATION AND PERFORMANCE

A 48-inch diameter pipe installation on Interstate 75 near Georgetown, Kentucky, was selected for special study. This study was inaugurated to take advantage of an opportunity to observe at one location the performance of both bedding conditions as used in Kentucky. Distress was first noted in the pipe in the latter part of August 1960, before the full design length of pipe (560
feet, 140 sections) had been laid. At that time, the fill had not reached full design height (36 feet) and the Class III pipe had hardly been in place a month. This first portion of the pipe was laid using Kentucky's Standard B Bedding; after a review and check of plans and specifications revealed that Class III pipe with B Bedding was an inadequate design, the bedding for the remainder of the pipe was changed to B₁ Bedding (imperfect trench) (see Fig. 4, Appendix I). Kentucky's standard pipe classes are the same as ASTM designations with reference to strength requirements. Pipe used in this installation were selected from lots accepted as adequate with respect to 3-edge bearing test results.

A total of 102 4-foot pipe sections manufactured on different dates, from a design length of 140 sections, was placed with Standard B Bedding before the change. Plans specified the Standard B Bedding and it must be assumed that this was obtained. Field data substantiate that the backfill depth requirement above rock (see Fig. 3, Appendix I) was obtained before placing the pipe; therefore, one of the factors, ledge rock in the foundation too close to the bottom of the pipe, considered to be a major contributing cause to pipe failure is nonexistent at this location.

For the remaining 37 sections actually placed, a B₁ Bedding was used. At least three feet of unsuitable material were removed from the foundation area below the bottom of the pipe before the backfill was placed (See Fig. 5, Appendix II); the Resident Engineer estimated a 7-foot soil foundation for camber calculations (4). Pans placed the backfill in approximately one-foot lifts and a rubber-tire dozer (Michigan) was used to compact it. A sand cushion bedding was prepared in a satisfactory manner.

The pipe was laid in the sand cushion bedding (see Fig. 8, Appendix II) and the backfill brought up uniformly in layers not exceeding 6 inches to a minimum height of 18 inches (0.30 times the outside pipe diameter). Each
layer was compacted thoroughly by single-action pneumatic tampers under the haunches of the pipe to insure that the backfill was in intimate contact with the sides of the pipe. The embankment was then extended upward in a normal manner to such an elevation that there was a soil cover equal to the overall height of the pipe plus 12 inches in preparation for construction of the imperfect trench (see Fig. 9, Appendix II).

A trench equal in width and height to the outside width and height of the pipe was dug in the compacted embankment with a backhoe (see Fig. 10, Appendix II). At this time the alignment of the pipe and the trench were noted to be off approximately one foot in some places; this was corrected by refilling and compacting the trench in 6-inch layers and redigging the trench over the centerline of the pipe. The trench was then filled with loose straw to a depth of approximately 24 inches. Loose backfill in the remainder of the trench compressed the straw to a thickness of about 16 inches. The trench was then covered and bridged by a 2-foot layer of compacted soil to a width of 20 feet on each side of the pipe (see Fig. 11, Appendix II).

By this time, it was late in the season and construction equipment had been moved from the general construction area. Consequently, the rockfill over the pipe was not completed until the spring of 1961. However, a small volume of earth fill (see Fig. 1) was placed the last part of the year as an approach for construction of a nearby overpass pier.

The embankment material placed in 1960, other than that used in the immediate backfill near the pipe and imperfect trench, consisted for the most part of rock. With the placement of the rock material (see Figs. 1 and 2) during the latter part of August 1960 over the 102 sections laid with Standard B Bedding, there developed a series of hairline cracks. A survey of pipe conditions revealed nearly every section, beginning at Section 13 through Section 71, had at least one hairline crack in the top and bottom by the last of August.
Hairline cracks were visible in Section 13 through Section 86 by the last of September with a progressive increase in the size and number of cracks in Sections 33 to 76 since the survey made the last part of August.

In January 1961, the sections constructed with Standard B Bedding still exhibited progressive development of hairline cracks under the partial fill load but seemed to be approaching an equilibrium condition with respect to the load. By May of 1961, the approximate maximum load appeared to have been reached, since progressive distress was no longer noted in the form of increased size or number of cracks.

Construction of the rock embankment over the pipe was completed the last of May 1961. The additional load on the pipe sections with Standard B Bedding resulted in a renewed increase of signs of distress. The amount of additional fill may be seen in Fig. 1. Increased distress in the B Bedding sections due to the additional embankment was most noticeable in Sections 75 through 100. The sections with B₁ Bedding, now with nearly full embankment design height, remained in good condition and exhibited no distress.

Changes in the inside vertical and horizontal pipe diameters were measured at established check points located in selected sections as the embankment load developed. The ends of the initial vertical and horizontal diameters were marked by punch-marks in the inner surface of the pipe structure. All subsequent measurements were made at these same points. Changes of the vertical and horizontal dimensions measured were less than one percent, a change sometimes considered sufficient to cause materially injurious cracks in rigid pipes (5). The maximum change measured over the observational period occurred in Section 63 and was only 1/4 inch vertical and 3/8 inch horizontal. The pipe diameter changes in Section 38 were 1/8 inch vertical decrease and 1/4 inch horizontal increase.
RESULTS AND CONCLUSIONS

The development of distress in the sections laid with Standard B Bedding can be attributed to the 36-foot high fill constructed over the pipe. Formation of a hairline crack, which has been defined as a crack 0.01 inch or less, does not constitute a pipe failure; nevertheless, the existence of hairline cracks was an indication of pipe overload. The 102 sections with Standard B Bedding have been overloaded and distress may progress to a point that will constitute a failure, but observations to date indicate that equilibrium is being approached. Cracks as wide as 1/4 inch were often observed. No indications of autogenous healing of cracks have been noted. Field data does indicate a significant difference in performance of pipe placed with Standard B Bedding and B_1 Bedding (imperfect trench).

Compaction under the haunches of the pipe to insure development of lateral support and prevent settlement of the embankment material in the exterior prisms is most important. Care in compacting the backfill area is most important since the stiffer the side supporting material, the greater will be the tendency of the mass directly above the conduit to arch over the adjacent bodies, thus relieving the top of the structure from part of the overburden pressure.

Specifications now used by the Kentucky Department of Highways give requirements pertaining to the nature of the side supporting material, method of placing the side supporting material, and size of the surrounding mass. The requirements now used appear to be satisfactory, but control presents a problem. Inspection should be continuous during construction to verify that the desired results are being obtained. Pipe bedding must be obtained which is the same as that assumed in design; otherwise, there is no criteria on which to base design methods.

The compressibility of the imperfect trench material must be greater than that of the adjacent compacted mass and should be in the loosest possible state
when placed in the trench. The lower one-third of the excavated trench should be filled with loose hay or straw, even when the soil is very compressible, to insure settlement of the interior prism. Settlement of the interior prism was not noticeable at the surface of the embankment at the test site at any time during the observational period.

When placing the last of the rockfill material in May of 1961, hairline cracks formed in the portion with Standard B Bedding right up to sections with B₁ Bedding. The Standard B Bedding portion exhibited distress in relation to the additional embankment added. For every fill increment there was a corresponding change in the length of the vertical and horizontal diameters of the pipe and in pipe distress as the load developed. The sections that had complete design fill heights over them before May, and required no additional embankment material, remained in an equilibrium condition of distress. This was expected to be true but could not be verified until this time. The performance of this pipe installation was successful in proving the value of B₁ Bedding over the Standard B Bedding for construction of high fills under rock embankments. Previous work had assumed this to be true but actual verification was desired. The formation of cracks right up to the B₁ Bedding portion suggests that the imperfect trench performed its purpose of relieving load on the pipe. Therefore, the rock embankment material appears to act much as soil material does in arching over the pipe.
BIBLIOGRAPHY


APPENDIX I

Kentucky Department of Highways Standard
Drawings Showing Pipe Bedding Details and Allowable
Fill Heights
Figure 1. Fill Profiles.
Fig. 3 Kentucky Pipe Bedding Details.
### Table for Safe Fill Cover Heights and Classes for Reinforced Concrete Circular Pipe

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<th>Class 3</th>
<th>Class 4</th>
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**General Notes**

- All dimensions are in inches.
- Class 1 is for light traffic areas, Class 2 for medium traffic areas, Class 3 for heavy traffic areas, and Class 4 for extremely heavy traffic areas.

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**Corrugated Metal Pipe**

- For general guidance, consult the manufacturer's specifications.
- Always ensure sufficient cover to protect the pipe from external forces.

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**Fig. 4**

Kentucky Allowable Fill Heights.
APPENDIX II

Photographic Sequence of Construction of Pipe Installed with B₁ Bedding (Imperfect Trench)
Fig. 5  Pipe Bedding Prepared. Undesirable material removed and replaced with selected compacted backfill.

Fig. 6  Patrol Grader with Special Blade Preparing Soil for Laying Pipe.
Fig. 7 Close-up of Special Blade on Patrol Grader.

Fig 8 Placing Pipe in Sand Cushion Bedding.
Fig. 9  Placing Backfill before Construction of the Imperfect Trench. (when specified)

Fig. 10  Construction of the Imperfect Trench. (when specified)
Fig. 11: Loose Backfilling of Imperfect Trench. Straw placed to a depth of 1/3 Trench depth.

Fig. 12: Completion of the Imperfect Trench. Embankment Placed 2 ft. Above Top of Trench.
Fig. 13 Embankment Material placed over Culvert. Line between soil and rock material shown.