Piping and related problems at large culvert installations in Montana

by Harvey David Funk

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Civil Engineering
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Abstract:
During the course of an investigation of culverts in Montana (the Large Culvert Research Project, sponsored by the Montana Highway Department and conducted by the Civil Engineering and Engineering Mechanics Department at Montana State University), six cases of piping alongside or under road culverts were found.

In some cases, the piping was evident after a visual inspection.

In other cases, piping was suspected after taking rebound hammer readings with a Schmidt hammer, an instrument designed for estimating concrete strengths. The suspected piping cases were further investigated by punching holes in the culvert plates and observing the fill through the holes. If piping existed, the piping channel could be traced by punching holes.

Soil samples were taken from the piping holes and tested in the soil mechanics laboratory. The tests revealed a range of soil types from a cohesionless sand to plastic clay.

In some cases, the piping had eroded large amounts of backfill material away from the sides of the culverts, excessively reducing the lateral support to the culverts.

In one case of well developed piping, the plates were cracked along a longitudinal seam, located at the side of a pipe-arch culvert.

It was hypothesized that excessive bending moments, due to the loading situation of no lateral support, stressed the plates to failure in the form of cracking the plates.

A computer program was developed to determine the magnitude of the bending moments that might develop under different loading conditions. The results, for the case studied, indicated that the moments developed in a culvert with no lateral support stressed the plates beyond the elastic range. The cracked plates were evidence that the plates had been stressed to incipient fracture.

It was concluded that; piping occurs in a wide variety of soil types; the Schmidt hammer is a useful tool for helping to determine the fill condition behind culvert plates; and, that piping removes backfill from around culverts, sometimes excessively, which may lead to loading conditions that develop bending moments large enough to crack the culvert plates.

It was recommended that the problem of piping be given full consideration in design and construction.

For future study, it is suggested that different plunger face-shapes be tried in the Schmidt hammer in an attempt to reduce or eliminate variations in Schmidt hammer readings.

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CHAPTER I

INTRODUCTION

THE PROBLEM

A major problem which has long concerned the designers of hydraulic structures is the phenomenon of piping. Piping, an internal erosion within soil, caused by seepage, is characterized by a pipe-shaped channel, formed from the tailwater side towards the headwater side of a fill. Piping under or through dams has long been recognized as a major problem. Another area where piping is a problem is alongside and under road culverts and has become increasingly important as the size and cost of culverts has increased. This paper will deal with the problem of piping alongside and under road culverts.

During the past several years, the Civil Engineering and Engineering Mechanics Department at Montana State University has conducted an investigation of culverts in Montana through sponsorship of the Montana State Highway Department. This study, entitled the "Large Culvert Research Project", has revealed at least six cases of culvert piping in Montana. This discovery suggested that an intensive study of these sites should be made, which would involve the verification of piping, the determination of soil types, and the possibility that piping may be the cause of structural failures in the form of cracked plates.

BACKGROUND INFORMATION

The Large Culvert Research Project originated during the spring of 1963. The purpose of the project was to make a detailed survey and analysis of large culvert installations in Montana and obtain information which would lead to recommendations regarding design criteria and construction and maintenance standards.

After a quick inspection of about 400 culverts, six feet in diameter or larger, 55 were selected at various locations throughout the state. The selections were made mainly on the basis of various problems that existed at the sites. These problems included:

- sediment deposits
- fill erosion
- scour holes
- corrosion
- structural deformations
- structural failures
- piping

The selected culverts were given an extensive survey during the summer of 1963 and again during the summer of 1964 The surveys included:

- taking photos
- measurements of the culvert
- level readings of the stream bed and culvert
- soil samples
- rebound hammer reading
- hole punching

The tabulations of data obtained and pictures showing some of the failures can be found in Appendix D.

The remainder of the main body of this thesis will deal with the findings and investigations related to piping.

CHAPTER II

REVIEW OF LITERATURE

PIPING DEFINED

In 1936, A. Casagrande (1)[1] listed piping as a term used to define an internal erosion caused by seepage, with the erosion progressing backward until a pipe-shaped channel is formed from the downstream side to the upstream side. In some cases erosion starts between headwater and tailwater by means of "roofing"; that is, the arching of a harder material over a weaker material which is settling, thus, resulting in a plane of weakness or an open space through which a concentration of seepage develops.

Once a "pipe" has formed, erosion can progress rapidly, making a large channel and possibly causing a failure of the structure.

MECHANICS OF PIPING

In 1929, Charles Terzaghi (3) noted that, for water flowing vertically upward to escape, the fundamental requirement to start piping is that the upward pull exerted by the seepage water overcomes, at some point, the downward pull exerted by the force of gravity. As soon as this occurs, erosion will start, possibly forming a channel.

Terzaghi further explained the mechanics of piping with a system of flow lines and equipotential lines. For the type of flow net used, the quantity of water which flows between each pair of flow lines is equal. The danger spot, where piping would start, is on the downstream end of the flow lines, at a point where the distance between the ends of adjacent flow lines is a minimum. The upward pull exerted by the water at the danger spot

[1]Numbers is parentheses refer to references listed under LITERATURE CITED.

is inversely proportional to the distance between the ends of the flow lines and directly proportional to the quantity of water which flows between two lines.

PIPING ALONG A CORRUGATED METAL PIPE

Most of the concern about piping in the past has been related to dams. A structure similar to a culvert under a road was the subject of research by the Bureau of Land Management at their Earth Laboratory Branch at Denver, Colorado during 1958 (4). The Bureau had constructed numerous small earth dams for water detention and retention purposes and piping difficulties were encountered on several structures. The piping appeared to start between the earth embankment and the corrugated metal outlet pipe and, in some instances, resulted in almost complete failure of the structures. Good design and construction procedures were believed to have been followed. Therefore, the Bureau felt that valuable information could be gained from large scale laboratory model tests on corrugated metal pipe placed in a compacted embankment under various conditions of prototype design and construction.

The following conditions were among those studied during the testing program:

a. One type of soil--sandy clay, reddish brown, about 50 percent sand, slightly plastic. (This soil was shipped from a BLM project and was typical of the soils used in several dams.)

b. Loose foundation versus firm foundation.

c. Poor backfill compaction around pipe versus good backfill compaction.

d. Leaky pipe joints versus nonleaky joints.

e. Flexible metal cutoff collars versus rigid concrete cutoff collars.

f. Headwalls versus no headwalls.

Six tests for studying the above mentioned factors were performed on embankments in a large test flume under closely controlled laboratory conditions.

The equipment consisted of a 4 x 8 x 80-foot test flume in which a 12-inch diameter culvert, 18 feet long, was embedded in an earth fill. The culvert was tested with a concrete cutoff collar and a sheet metal cutoff collar.

The tests lead to the following conclusions and recommendations:

1) The foregoing tests prove conclusively, for the type of soil tested, that to prevent percolation of water around corrugated metal outlet pipes in earth retention dams, the backfill should be placed at optimum moisture and compacted to a minimum of 95 percent of Proctor maximum density.

2) Compaction is important all the way around the pipe.

3) Although well compacted bedding around the pipe will effectively stop or greatly retard piping action from leaky joints, every effort should be made to achieve watertight joints in outlet pipes.

4) Concrete cutoff collars seemed to offer these advantages over corrugated metal cutoff collars: ease of achieving better compaction around the cutoff collar, and no limitations on the size of the cutoff collar.

5) It seems advisable to install a headwall on the upstream end of an outlet pipe but these tests, being rather limited in their scope, offered no proof for or against headwalls.

6) The tests indicated that excellent, uniform compaction under the pipe may be obtained without serious uplifting of the pipe, for the series of pipe tested.

7) After a well compacted bedding is provided, it is re-

> commended that soil at optimum moisture content be compacted in two-inch layers to at least 95 percent Proctor maximum density under the pipe to the 120-degree line. Tampers equipped with rectangular tamping feet of about two-by five-inch size are recommended. Short tampers are required if trenches are narrow. Adequate air pressure for tampers must be maintained.
>
> After completion of backfill under pipe to 120-degree line, the remaining compacted backfill around the pipe is placed in the pipe trench or as the adjacent compacted embankment is constructed. Optimum moisture conditions and compaction of at least 95 percent Proctor maximum are required.

Although these tests were all performed on a small culvert, they probably have some relevance to large culverts.

MONTANA HIGHWAY DEPARTMENT SPECIFICATIONS ON CULVERT INSTALLATIONS

In the current standard specifications of the Montana State Highway Department (5), the following specifications for bedding and backfill requirements are noted for culverts: bedding and backfill for culverts is specified to be compacted to between 90 and 100 percent of maximum density, depending on the material in question. For circular and elliptical pipes, the bedding is to be shaped to fit the lower part of the pipe for at least ten percent of its overall diameter. For arch type culverts, the bedding shall conform to the full width of the slightly curved bottom, not to include the smaller radius corners.

The backfill shall be placed uniformly over the entire culvert and foundation area around the pipe in layers of not more than four inches loose thickness. The material shall be compacted to the required density with particular care exercised in uniformly and firmly tamping the backfill material under the haunches of the pipe.

Placing of embankment over the pipe, in conjunction with overall grading operations, shall not proceed until the pipe has been covered, to a depth equal to one-half the diameter of the pipe, with properly compacted material.

The similarity can be seen between the requirements of the Montana Highway specifications for culvert bedding and backfill and the recommendations for the prevention of piping by the Bureau of Land Management in the previous section.

STRENGTH TESTS ON CULVERT PLATES

When piping removes the backfill material from portions of the culvert, a different loading condition develops because of the loss of the supporting backfill. Excessive bending moments may develop in the culvert walls and cause structural failure along longitudinal seams. Several cases of cracked plates along longitudinal seams were observed in the course of the culvert surveys. It is hypothesized that these failures were caused by bending moments in excess of the "safe moment capacity" of the seams.

An estimate of the loads necessary to crack the plates, at seams which are susceptible to this type of failure, was obtained from Bulletin 109 of the Michigan Engineering Experiment Station, entitled "Load Deflection Tests on Corrugated Metal Sections." (2) During the summer of 1951, the Michigan Engineering Experiment Station ran laboratory investigations on different types of corrugated metal sections used in the construction of culverts. Of particular interest were tests three, four, five and six which involved bending of conventional bolted structural plate sections, standard type R.

In tests three and four, the curved specimens were supported on edge with the chord vertical and tested as columns. Tests five and six were simple beam tests in which the specimens were supported at both ends and subjected to a downward force at the center.

The maximum moments resisted by the specimens during the tests were calculated by the author of this thesis with information provided in Bulletin 109. The information used pertained to single bolted sections of one, seven, and twelve-gage corrugated metal. Figure 14 on page 34 shows a plot of plate thickness versus maximum moments.

The failure moments on this graph will be used for making comparisons with moments calculated from estimated loading situations in a case study in Chapter V.

Also of interest to this study were the pictures of cracked plates from tests five and six, shown on page 30 of the Bulletin. These cracks were caused by excessive stresses due to the bending moments developed during the simple beam tests. These cracks were similar to those found in the Emigrant culvert.

The search of literature involved the investigation of many sources not cited herein; a list of these sources will be found in the Bibliography under Other Sources Investigated.

No evidence was found that the work described in this thesis had been performed previously.

CHAPTER III

CHRONOLOGY OF THE STUDY

During the initial inspection tour in 1963 for the Large Culvert Research Project, several methods for determining the condition of the backfill around the culvert were used. One method consisted of visual inspection, where often, weeds and riprap around inlets and outlets would hamper the inspection. Another method was using a geologist's hammer, striking the culvert plates from the inside and listening to and feeling the results. A distinction could sometimes be made between "hollow" sounding spots and "solid" sounding spots. Finally, in an attempt to put the inspections on a more quantitative basis, the Schmidt rebound hammer was used to take readings on the culvert walls. Several culverts were selected for detailed future study because the preliminary inspection indicated that piping existed or was suspected.

During the summer of 1963 when the first extensive survey of the project culverts was made, a systematic set of Schmidt hammer readings were taken in each culvert. During the summer of 1964, holes were punched through the culvert plates, usually where the Schmidt hammer readings indicated poor backfill conditions. Through these holes, the condition of the backfill was determined by visual inspection and by probing with a wire. With this information, a decision could sometimes be made whether or not piping existed.

Soil samples were taken from the piping holes at culverts when piping definitely existed, and from holes suspected to be piping holes.

Chapter IV will cover the details of the investigations and describe where piping was found. The Schmidt hammer readings and supporting data from the hole punch surveys will be analysed and presented in tabular form and discussed. The results of the soil analysis will be given also.

Chapter V will be a case study of a culvert where piping and cracked plates were both found. There is a possibility that the lack of lateral support due to piping may have caused the cracked plates. To help show this possibility, a moment analysis for different loading conditions will be given.

Chapter VI will be devoted to discussion, conclusions and recommendations.

CHAPTER IV

FIELD SURVEYS AND FINDINGS

PIPING FOUND

During the initial inspection tour for the Large Culvert Research Project, several culverts with piping holes were found and others were suspected of having piping. After investigations of the sites with suspected piping were completed, several were recorded as having some degree of piping. Shown in Table I is a list of the culverts with piping, and their location. Of the six culverts with piping, four are of the 55 Large Culvert Research Project culverts and the other two, at Okeefe and Chester, were studied in addition because of the piping. For the four Large Culvert Research Project culverts, additional information can be found in Appendix D, a summary of the findings for the Large Culvert Research Project.

Emigrant Culvert

The Emigrant culvert, a pipe-arch, had no visible evidence of piping at the inlet (See Figure 1). The stream bed, both upstream and downstream, was a gravelly sand with boulders. The culvert was undermined at the outlet, and water flowing from under the culvert was visible. The undermining at the outlet can be seen in Figure 2. The hole punch survey revealed a large void along much of the left side (when facing downstream), indicating piping. This culvert will be used as a case study in Chapter V and more details will be given there.

Cardwell Culvert

The Cardwell culvert has a circular shape, 108 inches in diameter. A well developed piping hole was observed during the first inspection, as

Table I. DESCRIPTION AND LOCATION OF CULVERTS WITH PIPING

CULVERT	LARGE CULVERT RESEARCH PROJECT CULVERT NO.	TYPE & SIZE	GAGE	HIGHWAY NO.	COUNTY	CREEK NAME	PROJECT NO. & DESCRIPTION OF LOCATION
Emigrant	1	SPPA 16'-7" x 10'-1"	3	89 Alt.	Park	Eight-mile	F 217 (10) 3.5 mi. N. of Emigrant
Cardwell	6	SPPE 108"	10	359	Madison	---	S 167 1.1 mi. S. of Jefferson Island
Okeefe	---	RCP 48" double	--	10	Missoula	Okeefe	7 mi. N.W. of Missoula
Chester	---	SPPA 8' x 6'	10	County Road	Liberty	---	6 mi. S. of Chester just E. of Jct. with highway 223
Wolf Point No. 1	46	SPPE 120"	10	2	Roosevelt	---	F 84 7.1 mi. W. of Wolf Point
Wolf Point No. 2	47	SPPE 120"	10	2	Roosevelt	---	F 84 5.4 mi. W. of Wolf Point

Remarks: SPPA refers to structural plate pipe-arch
SPPE refers to structural plate pipe-ellipse
RCP refers to reinforced concrete pipe