PROGRESS REPORT ON CULVERT INVESTIGATION

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GENERAL IMPRESSIONS AND CONCLUSIONS FROM PRELIMINARY SURVEY

This investigation was undertaken by the Highway Research Board at the request of various interested parties, who felt that extensive investigations of existing small drainage structures throughout the country would be of great value in establishing principles of design and construction for such structures It is well known that there is a very great diversity of opinion and practice in this field of work It was expected that the first duty of this committee would be to endeavor to outline acceptable methods of procedure for the making of such investigations so that the data secured by the various agencies in their own localities would be of comparable value and lead to sound conclusions. It was further hoped that this committee would later have an opportunity to study the mass of data thus collected No doubt in order to establish the basic facts upon which the economic value of the different types and classes of small drainage structures depends, for varying local conditions, the correlation of the data from many thousand examinations will be required

For the purpose of clarifying the objectives of this investigation, a conference was held on November 5, 1925, which was attended, on invitation, by representatives of the material interests involved and by several engineers particularly qualified to give helpful counsel

It was agreed at this meeting that this investigation is "for the purpose of conducting a fact-finding survey of small drainage structures to determine *methods* of arriving at the economic values of various types of such structures in highway construction "

Stated in another way, the ultimate objective of this investigation is to provide the engineer with the basic principles by which he may decide upon the economic structure to use under a given set of conditions

The committee recognizes as its first duty the development of procedure for the examination of these structures in the field and the recording of the data thus secured. We are pleased to report satisfactory progress toward this objective A sufficient amount of field work has been done, to afford a basis for tentative recommendations as to such procedure We offer a tentative recommendation at this time for a standard form for recording the data from the examination of small drainage structures, and we shall discuss certain aspects of the matter of a scheme for classification and rating of individual structures

In our field work we have visited 14 States and have examined 516 culverts Detailed notes were recorded during the course of each of these examinations Considerable general information was also obtained from casual observations of a number of installations for which no history of past life was available Conferences and interviews with highway officials and highway engineers were of great assistance in the identification and classification of local conditions The more important impressions gained during this survey of the existing field conditions and of the services rendered by small drainage structures were as follows

1 That insufficient attention has been given to the design of small drainage structures
2 That these structures and their drainage systems quite generally have been and are yet considered relatively unimportant in the design and construction of a highway
3 That the combined effects of local conditions are relatively few for each type of installation
4 That a particular type of failure is common for a given type of installation
5 That the amount of use by hydraulic traffic is an important factor in the life of a culvert
6 That the nature of the hydraulic traffic is a prominent factor in the life of these structures
7 That the height of fill over top of highway culvert ranges from 1 0 to 5 0 feet for the majority of installations
8. That each type of small drainage structure has suffered unwarranted condemnation from injudicious local use under conditions particularly destructive to that type
9 That the cast iron, burned clay, concrete, corrugated metal pipe culverts and the concrete box culverts have economic use in a national highway program
10 That the annual expenditure from highway funds for small drainage structures is an appreciable percentage of the total expenditure, and
11 That an investigation of the nature with which this report is concerned has long been a real need for the correlation and exchange of data or information gained from local experiences

The next phase of this investigation will be to perfect our recommended procedure by more extensive field work After inspection procedure has been established, we should pass on to the collection and study of all available data to establish, if possible, methods for estimating length of serviceable life of various types of small drainage structures under conditions prevailing in the various localities

A number of agencies are at work at the present time on various phases of culvert pipe investigation The Highway Research Board was recently invited to participate in a conference called by T H MacDonald, Chief of the U S. Bureau of Public Roads, to outline in a broad way the future research work along this line. At this conference the following statement of objective was formulated

1 To obtain sufficient data to permit of the formulation of a design theory for culvert pipe structures
2 To obtain data which will permit of the correlation of the results of a simple routine load test with the supporting strength which the pipe will develop under different field conditions
3 To obtain data which will determine the loads which culvert pipe will receive under different field condition, including (a) loads due to filling material, and (b) moving loads
4 To determine the service of culverts under field conditions by means of a condition survey
5 To determine field conditions under which construction of culverts is carried on

It is the last two of these objectives with which our present investigation is concerned

FIELD WORK OF PRELIMINARY SURVEY

The field work of this investigation was begun August 1, 1925, a short time after the project was undertaken by the Highway Research Board and was conducted until November 17, 1925 In all 14 States were visited and detailed examinations made upon 516 culvert installations Excepting Minnesota the States visited lie east of the Mississippi River

This work has been essentially a fact finding survey to obtain data relative to the nature and variety of service conditions imposed upon culvert installations on the public highways and to observe and record the actual physical condition at different ages of all types of small drainage structures subjected to each of the various service conditions and to secure all available information concerning the use and behavior of the various types of installations commonly used in each of the States visited

The work thus far accomplished has consisted of conferences with highway engineers, producers of culvert material, and men engaged in various phases of culvert research, of detailed field examinations of existing structures, and of a brief review of data acquired from independent and earlier investigations in two States Three States, Tennessee, California, and Wisconsin are now conducting independently similar investigations and have offered this committee the use of all data which may be secured The first stage of these state investigations will be completed this winter

The primary uses of the data and information collected by this survey to this time have been as a guide in the design of a form for general use in recording the essential data required in the study of the economic life of small drainage structures, in the development of a method of classification or rating scheme which will give a reliable estimate of the length of the remaining useful life of existing structures and in the preparation of a tentative outline for an exhaustive investigation of the use of all types of small drainage structures.

In the field work thus far accomplished, the major activity has been the detailed examinations of existing structures Wherever possible a careful examination was made of the interior of each culvert visited. Such an examination requires that the investigator crawl entirely through the barrel of each culvert and with the aid of flashlight, rule, and such other tools as the case may require, determine the actual condition of the interior of the structure For sizes of opening smaller than 20 or 22 inches such an examination was waived and wherever possible culverts having an opening 24 inches or more in diameter were sought for the purposes of this investigation. Occasionally in a long dark culvert one finds interesting diversion in the form of small snakes, lizards, weasels, ground hogs, or a skunk.

The external portions of each structure were also examined In this classification has been placed headwalls, retaining walls, spillways, drop inlets, footings, and curtain walls

A brief survey of local conditions was also made to determine nature of service conditions to which the installation was subjected

The notes recorded for each of the 516 detailed examinations contain pertinent information under the following general headings

1 Location of installation
2 Type of roadway
3 Type of culvert
4 Type of joints
5 Height of fill over top of culvert
6 Character of fill material.
7 Character of hydraulic traffic.
8 Special notes relative to quality or appearance of culvert material
9 Condition of roadway
10 Condition of embankment
11 Condition of headwalls or other external portions of culvert
12 Condition of stream bed
13 Condition of barrel culvert
14. General remarks.

These notes were recorded on a form similar to that which accompanies this report

SERVICE CONDITIONS OBSERVED

Only the more important field conditions, those which apparently have direct effect upon the life of a culvert have been considered in the preparation of this report Insufficient data will not permit the discussion of the design, of the manufacture, of the material, variation of material, or of the methods of installation These as well as many minor factors must be given consideration in a more comprehensive survey

Installations of all types were examined on both primary and secondary road systems In either case the volume of traffic in local estimation was considered heavy except in a few instances on secondary roads The term "heavy traffic" has however quite different value in each State For future work it is hoped that a definite figure, even though an estimate, may be used instead In order to cover the territory most rapidly and efficiently it was necessray to confine examinations for this preliminary work to installations where data regarding date of installation and location were most readily available For that reason the majority of structures examined were located on primary roads. However, many of the installations had been made before these roads came under the jurisdiction of the State highway departments

An attempt was made to view the oldest culverts to be found in each locality as well as some of the younger ones Quite a satisfactory range in ages was found to be available This range for each type of culvert in common use is as follows

Cast iron pipe	1 to 27 years
Burned clay pipe	1 to 18 years
Concrete pipe	1 to 17 years
Corrugated metal pipe	1 to 18 years
Concrete box culverts	1 to 13 years

These ranges in age will afford a valuable aid in the study of the economic life

The extreme range in sizes of the culverts examined were as follows

Cast iron pipe	12 to 72 inches
Burned clay pipe	12 to 36 inches
Concrete pipe	12 to 60 inches
Corrugated metal pipe	10 to 108 inches
Concrete box culverts	24 to 96 inches

The usual range in sizes was

Cast iron pipe	18 to 48 inches
Burned clay pipe	12 to 24 inches
Concrete pipe	18 to 48 inches
Corrugated metal pipe	12 to 48 inches
Concrete box culverts	24 to 48 inches

The several States have different specifications as to maximum size of culvert pipe which may be used For openings larger than that afforded by the maximum size of pipe permitted the box culverts are used In some States, however, the dividing line is not definitely established

The character of the different fill materials in addition to the inherent variation of a particular type differed widely in the several States. The types of material may be generally classified as glacial till, shale, sandy clay loam, heavy residual clay, and plastic sedimentary or marl clay These materials differ in weight per cubic foot in behavior under different moisture and load conditions, in chemical activity and in manner of settlement and compaction in embankments. No statistical data were taken in this survey, the nature of the material only being recorded

The range in height of fill over top of culvert for each type of installation was as follows

Cast iron pipe	0 0 to 27 0 feet
Burned clay pipe	0 5 to 15 0 feet
Concrete pipe	0 5 to 27 5 feet
Corrugated metal pipe	0 0 to 25 0 feet
Concrete box culverts	1 0 to 12 0 feet

The most striking observation regarding the height of fill was that the range for the majority of installations on the highways was from about 1 to 5 feet above top of culvert

The term "hydraulic traffic" has been used throughout this survey as the general heading under which has been classified the various liquids flowing through the culvert The term came into use because the word "water" seemed inadequate, especially when at times large amounts of solid material are carried in it

The hydraulic traffic may be classified according to source from which it enters the culvert, as surface water, and underground water The surface water is further classified as water carrying little or no abrasive material and as water carrying sand, gravel, coal screenings, boulders, or other solid material The underground water is not such in the strict interpretation of the word. In this classification, however, we have placed spring water, drainage from farm tile, and seepage from swamp lands A third tentative classification is that of stagnant water which may be originally any of the above waters and its presence in the culvert was generally due to improper installation or lack of maintenance

The movement of the hydraulic traffic is by occasional, prolonged, or constant flow Each constitutes a separate and particular condition The occasional flow consists in the majority of cases of surface water of either classification, the prolonged flow may be surface water, swamp drainage, or farm underdrainage, and the constant flow either spring water or swamp drainage

Since there seemed to be a considerable difference in these waters, especially in the corrosive effect on metal culverts, an attempt was made to determine roughly their chemical characteristics by use of different indicators The active corrosive agents were not detected by any of the four indicators used, litmus paper, phenolthalein, methylorange and sodium hydroxide The difference in the activity of the waters is believed to be due to electrolytes for which no field test is at present available

The classifications of the hydraulic traffic may seem somewhat lengthy and rather detailed, but from observations thus far made in the field, it is apparent that each type has a decidedly different effect on the rate of corrosion of sheet-metal culverts and the variation in the kind of hydraulic traffic is largely responsive for the variation in the rates of failure of this type of culvert

EFFECTS OF SERVICE CONDITIONS

It has been impossible so far in the work to observe the behavior of each type of culvert under each of the service conditions peculiar to a given section of the country. In any one locality the types of installation were limited to two or three Not enough data is available to determine the degree of similarity between conditions which are apparently not greatly different From the data on physical condition of structure no attempt has been made to compare effects of conditions on different types of culvert. The main object of this part of the survey has been merely to record the effects of conditions as seen in the physical condition of each installation Only the types of culvert in common use have been included in this report Freak and obsolete types have been omitted

Cast Iron Pipe —The varieties of cast iron pipe used were standard water pipe, railroad culvert pipe, highway culvert pipe, plain and spiral corrugated and highway culvert pipe of sectional construction The older installations were for the most part of standard water pipe which had been rejected for the original purpose on account of small defects perhaps harmful in pressure pipe but in no way affecting their efficiency as culvert pipe.

The common effects of local conditions were slight sag in grade line, seldom more than a few inches, removal of asphaltic or tar dip coat either by erosion or by corrosion, and corrosion of the metal. The nature of the corrosion is pustular at the start, forming little pimples under the paint, later becomes granular if undisturbed and finally forms a thin tight rust skin covering entire surface of metal The rate of corrosion is apparently slow No appreciable effects of erosion were observed None of this type of pipe found in localities where effects of erosion were most prominent on other types of culvert

Burned Clay Pipe —The variety in this type of installation was introduced in the wall thickness Three classifications were secured in this way, single, double, and triple strength pipe All were bell and spigot pipe

The common effects of local conditions were sag in grade line (a few inches), load cracks, open joints and check cracks The load cracks varied from very fine cracks to those of such dimensions that pieces of tile had fallen or were badly displaced and the pipe much deformed In another State a better clay pipe under similar loading showed no sign of distress Open joints were partly due to careless installation Some were probably due to side slippage of embankment. The check cracks were not explained satisfactorily The hydraulic traffic had no appreciable effect on any clay pipe examined

Concrete Pipe —The concrete pipe were either plain or reinforced and the joints were bell and spigot, dovetail, or plain The variation in manufacture also extended to the manner of forming pipe. In some cases pipe were made of concrete of consistency such that it could be poured into molds provided for the purpose In other cases a very dry mixture was used and rammed or tamped by machinery into rigid steel molds The culvert pipe specifications of at least one State require a half-inch greater wall thickness for molded than for the tamped pipe No comparison can be made at this time between plain and reinforced pipe or between various types of joints.

The common effects of local conditions were sag in grade line (a few inches at the most), load cracks, open joints, spawling of concrete over pulling reinforcing (occasionally), deformation (occasional), and erosion of grade line (occasional).

The load cracks apparently appear early in the life of the culvert and may or may not become larger than about 0 01 to 0.05 inch in width as they grow older Such cracks in the pipe were common for all heights of fill They were likewise frequently absent under all heights of fill, excepting the few deep fills 18 to 22 feet in height. Under the fills 15 feet or more in height load cracks were generally quite wide and reinforcing was pulling thus spawling concrete Also similar conditions were observed under a few fills less than 5 feet in height. However cracked, the status of the condition of pipe apparently remains unchanged for long periods of time. Opening joints were due to careless installation and uneven settlement of embankment. Abrasion of invert was slight excepting in a few cases where concrete had been loosened by pulling reinforcing

Corrugated Metal Pipe—Corrugated metal pipe were of several different alloys and were fabricated with three different types of side joints, riveted lap joints, riveted butt joints, and bolted flanged joints All excepting a very few of the corrugated metal pipe were spelter coated

The common effects of local conditions were sag in grade line, deformation, erosion of spelter coat from invert, and corrosion of base metal on invert The sag in grade line in a few cases was about equal to the diameter of the pipe. These installations were in a swampy locality Deformation was usually less than one-tenth of the diameter A few pipe with flanged side joints had collapsed and a few with riveted butt joints at side had pulled the countersunk rivets through. No defects were observed for the usual type of riveted lap joint except the slight rusting of the rivets.

The erosion of spelter coat was noticeable only in territories where the soil erodes easily and the storm water carries large amounts of sand, clay, and gravel In these cases erosion is more rapid than corrosion and the base metal is frequently seen brightly polished or but little rusted The corrosion of base metal in all other cases begins as soon as the spelter coating is penetrated and goes on at a varying rate for the different hydraulic traffic conditions, until the base metal is completely gone on the invert The remainder of the pipe will usually show practically no effects of the condition which has destroyed the invert The corrosion exhibits a considerable variety of forms, at least eight or nine of which are readily recognized after a few examinations The rate of action of each is unknown.

The metal pipe frequently suffer mashed or broken ends where installed in low fills and without headwalls. This damage comes from careless use of maintenance machinery. Also in fills 1 0 foot or less in depth dents caused by heavy vehicles may be observed in top of pipe if roadway is unsurfaced

Concrete Box Culverts—Concrete box culverts are usually either simple reinforced boxes or double boxes with a load-bearing wall in center

The common effects of local conditions are vertical load cracks in sidewalls near center line of roadway, erosion of floor, disintegration of concrete in and near construction joint at junction of side wall and floor, and an occasional load crack in center of top.

The vertical load cracks in side walls of the barrel are no doubt caused by unequal settlement which causes culvert to act as a beam.

These cracks are of quite general appearance wherever this type of culvert is under about 10 feet or more of fill Apparently they do not become a very serious menace to the life of culvert Erosion in the floor of culverts is partly due to the faulty concrete resulting from careless construction of this portion of the culvert. No serious effects were observed thus far in the work The disintegration at the construction joint in the side wall near the floor appears to affect only the faulty concrete in the joint in most cases. An occasional head wall was observed to be breaking away from barrel

ULTIMATE FAILURE

The ultimate failure of the cast iron, burned clay and plain concrete pipe seems most likely to occur in one way, breaking down under load, that of the reinforced concrete pipe in the same manner but with actual failure prolonged or retarded by presence of reinforcing, that of corrugated metal in the corrosion of the invert, and that of concrete boxes in breaking down under load

For the cast iron pipe and the concrete boxes no examples of near failure or actual failure could be found. For each of the other types many installations near failure were observed although but few actual failures were found

SUGGESTED FORM FOR RECORDING DATA

The principal requisite for a form for this purpose is that it shall be complete in rather minute detail, so that a perusal of the form will give anyone familiar with culvert inspection a clear mental picture of the structure, so that he will probably assign the structure approximately the same rating as the man who made the original inspection It should be complete enough that a reasonable rating can be made under any probable rating system that may be used The form herein proposed is tentative only and we hope that anyone using it will give the committee the benefit of their criticism It is not to be expected, under such conditions, that it will be possible to tabulate all of the needed information The form will not be fully useful unless full descriptions are made in the spaces provided

(FRONT OF DATA SHEET)

INSPECTION REPORT ON CULVERTS IN SERVICE

Kind..........................
Type..........................
Nominal Size..................Inspection No...........

State........................County.................Township...........
Name of Road..............Project...............Station..................
Map Location, Section.............Township.............Range...........
Location by speedometer, Starting Point.............Mile Post.............
Culvert used for.....................Drainage Area........................
Manufactured by..
Installed by.....................Date.................Cost..............
Inspected by.....................Date..................Age...............
Width of Roadway.............Type of Surface.............Vol. of Traffic....
Height of Fill, above top of culvert, center of roadway........................
At shoulders of road, Right.....................Left.....................
Above natural surface of ground, Right................Left.................
Character of Fill Material...............Wt. per cubic foot.................
Fill compacted, by traffic.............by rolling.............by water.......
Probable maximum live load...
Hydraulic traffic, Surface water..........Underground water.................
Swamp water...............
Source of Hydraulic Traffic..
Stream Scouring or Filling...
Nature of Flow, Occasional............Prolonged...........Constant.......
Nature of watersheds..................Solids in water...................
Kind of Headwalls............Length of Culvert.........Length Sections.....
Probable Installation Condition, Trench...........Projection........%.......
Foundation material..................Bedding of Culvert....................
Diameter inside, at ends, Vertical.............Horizontal....................
Under center of roadway, Vertical...........Horizontal....................
At point of max. Deflection, Vertical............Horizontal................
Location of Max. deflection..
Shell or wall thickness: Top........Bot........Rt. Side.......Left Side.......
Type of joints......................Joints filled or unfilled...................
Type of joint connections..
Burned clay pipe...
Hard or soft burned..................Uniform stock.....................
Color uniform throughout thickness........Fine or coarse grain...............
Concrete pipe, reinforcement...
Rich in cement..................Properly cured.........................
Machine tamped.............Molded...........Hand tamped............
Character of aggregate...
Corrugated metal pipe..
Weight of spelter coating...........Width of corrugations..................
Rivet spacing, side seams...............Connecting Joints...................
Type of rivets..................Rivets spelter coated.........................
Identification of, Photos..
Water sample...
Soil samples...
Metal Culvert Sample...

OVER

(For rating of structure and for effects of Local Conditions)

(REVERSE OF DATA SHEET)

DESCRIBE IN DETAIL

Condition of Roadway over Culvert..

Condition of Embankment

Condition of Headwalls, and External Portion of Culvert

Condition of Stream Bed

Condition of Barrel of Culvert

Rating of Culvert

Reason for Rating Given

CLASSIFICATION OR RATING OF SMALL DRAINAGE STRUCTURES

Before an attempt can be made to outline a theory for estimating the economic value or cost per year of various types of small drainage structures, it will be necessary to examine a very large number of existing structures in order to establish the various forces which tend to destroy the culverts, the influence of the varying natural and installation conditions, and the behavior of the various materials and types in common use in resisting the destructive forces. When making such inspections on a large scale, it is desirable in addition to recording the detailed data to assign to each structure a rating or classification number, in order to facilitate the analysis and classificatoin of the data

The requisites of such a rating scheme are as follows

(a) The rating must indicate the present condition of the structure
(b) The rating must indicate the length of time it has taken for the structure to reach its present condition
(c) The rating must give some indication of the strength of the destructive forces
(d) The rating should afford a comparison between individuals of the same type and between types
(e) The rating system should be such that approximately the same rating would be given by different operators working independently

One of the most significant impressions secured during our field work is that the great majority of small culverts come to their final end through a single destructive process. Various conditions may retard or accelerate the progress of destruction

Depreciation and deterioration of small drainage structures is usually due to the action of a single destructive agency In the preparation of a rating schedule or a means of evaluating the condition of these small drainage structures, the effects of the principal destructive force since it may produce failure or destruction of the culvert with or without the assistance of other agencies, must be assigned such a value that the rating given a structure will be but little influenced by the rating of the effects of other relatively unimportant destructive forces acting upon the structure.

A destructive agency which may be in some localities or under some conditions the principal factor affecting the life of a structure may be so modified in other localities that it has lost the former significance and has passed from primary consideration even though it still be active. The corrosion on the invert of corrugated metal culvert may at times be progressing at a much slower rate than the erosion, the deformation under load may be progressing at such a rapid rate that the failure of the culvert by collapse will occur before the effects of corrosion or erosion are more than apparent Also the progressive failure of reinforced concrete pipe under load may be outdistanced by disintegration of the concrete and under some conditions, burned clay, plain concrete, or cast iron pipe may tend to fail more rapidly by disintegration or corrosion than by crushing Whether it is from the effect of loading, corrosive or erosive hydraulic traffic, or other destructive forces, the measure of the present condition of the culvert should be on the basis of the effects of that force which is contributing most rapidly to the ultimate failure of the structure

One of the difficulties encountered in the preparation of a method of rating or evaluating the present condition of small drainage structures is the establishment of definite land marks or guide posts which indicate the stage which physical depreciation has reached The rate of progress for each destructive agency acting under different conditions must be at least approximately determined before this difficulty can be overcome A large number of detailed field examinations of existing structures supplemented by field and laboratory tests and by technical researches will be required to furnish data for the determination of this factor

The field examinations either for the purpose of acquiring data for the development of the method of rating or for that of applying the method must determine by what agency the technical failure of the structure will be eventually accomplished Since the rate of depreciation for any culvert material or type of structure is at present unknown, the attribution of a future failure to a given known cause of the several present may be at times difficult or impossible However, the impression gained from observations of a considerable number of small drainage structures is that in the large majority of cases failure due to effects of a single known destructive agency can be with certainty predicted to occur before effects of the other agencies are particularly harmful

With the aid of data obtained from the brief survey of culvert installations on primary and secondary roads in 14 States, a tentative rating schedule has been devised, but in view of the limited number of culvert examinations upon which it is based, it was decided not to publish it until more data have been accumulated and more correct values can be assigned to the factors involved

DISCUSSION OF PROGRESS REPORT ON CULVERT INVESTIGATION

Led by ANSON MARSTON
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The writer is greatly interested in the field investigations of pipe culverts upon which such a clear preliminary report has just been made by Mr Crum For some 16 years the Iowa Engineering Experiment