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
Iowa State College, Ames, Iowa

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

Station, of which the writer is director, has been conducting research into the loads on conduits used for drains, sewers, and culverts, and into the supporting strengths of conduit pipe as one of its major lines of work Already four bulletins and two progress reports have been published, and five more bulletins are now in process of publication These five bulletins will give a complete theory of loads on conduits in ditches or projecting into embankments, both from embankment (or trench fill) materials and from concentrated superloads, whether static or moving, together with an experimental and theoretical discussion of the different supporting strengths developed in actual use by rigid conduit pipes of 18 to 84 inches in diameter

In the "Second Progress Report of Culvert Pipe Investigations," published in 1922, the writer said

"The only way we can determine good engineering practice is to obtain definite and reliable data of a large number of actual culverts, some cracked and some sound, and then apply theory in each case It is proposed to do this systematically and as extensively as possible, proceeding actively in the immediate future "

The field inspections reported by Mr Crum are in exact line with the above quoted plan

The Highway Research Board has been extremely fortunate in securing Mr. Crum's services for this important work Some 10 years ago, in 1915, he first began systematic field inspection of pipe culverts under the joint auspices of the Iowa State Highway Commission and the Iowa Engineering Experiment Station, a work which has continued from time to time ever since, mostly in Iowa One of the five bulletins on highway culvert research now being published by the Station will be by Mr Crum, and will give the results of his 10 years' work in this line. Many of the culverts under observation have been visited several times

The reason that the only feasible way to determine good engineering practice in highway culvert design and construction is to obtain definite and reliable data of a large number of actual culverts by such field examinations as have been and are being made by Mr Crum, or under his direction, is that the range of loads imposed on culverts by an embankment of any given great height is several hundred per cent, depending on the different loading conditions encountered in construction practice In addition, the supporting strength of a given culvert pipe may vary 150 per cent or more, depending on the pipe laying conditions during the construction of the culvert.

The writer classifies the loading conditions usually encountered in practice under five heads, as follows

1 The "ditch condition "[1]
2 The "imperfect ditch condition "[1]
3 The "combined ditch-projection condition "[1]
4 The "imperfect projection condition "[1]
5 The "projection condition "[1]

The writer pointed out in 1922, in the "Second Progress Report" above referred to, that the range of loads on a 42 inch culvert projecting 90 per cent of its diameter up into an embankment 20 feet high will be 400 per cent as between conditions 1 and 5 above In other words, the load on the culvert in the above case would be only one fifth as much for the "ditch condition" as for the "projection condition "

Conditions 2, 3, and 4 above, would give loads intermediate between conditions 1 and 5

The writer classifies the pipe laying conditions actually used in building pipe culverts, as follows

1 The "impermissible" pipe laying condition [1]
2 The "ordinary" pipe laying condition [1]
3 The "first class" pipe laying condition [1]
4 The "concrete cradle" pipe laying condition [1]

The supporting strength developed by a given culvert pipe with pipe-laying condition 4, above, may be twice the supporting strength developed with pipe laying condition 2, or 2⅔ times that developed with condition 1

The net result of making all possible combinations of loading conditions and pipe laying conditions may be stated as follows

Under the most unfavorable construction conditions the laboratory test strength of a 42 inch culvert pipe would have to be 1,333 per cent of the laboratory strength required under the most favorable construction conditions in order to prevent cracking under the load imposed by any given embankment 20 feet high

For different embankments there is an even greater variation, due to differences in embankment materials and their internal conditions

Under embankments higher than 20 feet the extreme conditions would be still further apart In fact, the loads under the unfavorable conditions become so great under quite high embankments as frequently to force the whole culvert structure down several inches, sometimes even 1 or 2 feet, into the earth foundations, thereby relieving the loads in large degree, and probably making the true "projection condition" practically impossible under high fills.

On the other hand, the low embankments of 1 to 5 feet height, which Mr Crum reports to be the typical fills over culverts, give little varia-

[1] For definitions of these terms see Appendix to this discussion

tion in the loads imposed under different loading conditions Under all loading conditions the loads imposed on culverts by such low fills closely approximate the actual weight of the materials directly over the culvert.

In the case of low fills, however, the effects of super-loads, such as those from truck wheels, locomotive and car wheels become important, and doubtless in many cases they are the cause of the loading cracks which Mr Crum reports to be so prevalent in culvert pipe of the rigid types.

The five forthcoming bulletins [1] of the Iowa Engineering Experiment Station will give a complete theory of the loads on conduits under all loading conditions, both from embankment (or trench fill) materials and from super-loads, together with a complete discussion of the supporting strengths which will be developed by culvert pipes under all the pipe laying conditions All the theory will be amply supported by experimental field data

APPENDIX

(Discussion by ANSON MARSTON)

DEFINITIONS OF CONDUIT LOADING CONDITIONS AND PIPE LAYING CONDITIONS

W = load on conduit, per unit of length.
W = weight of embankment or trench fill materials, per unit of volume
B = breadth of conduit, greatest horizontal dimension, over all
b = clearance each side between conduit and side of ditch
H_e = height of equal settlement
H = height from top of conduit to top of embankment or trench fill.
C_d = coefficient for "ditch condition"
C_p = coefficient for "projection condition"

NOTE —C_d and C_p are dependent on the internal friction coefficient of the materials and on the value of the ratio H/B

LOADING CONDITIONS

1 *The "Ditch Condition"*—The "ditch condition" is the loading condition in which all of the material directly above the top of the conduit, extending upward to the surface of the ground or to the top of the embankment, settles downward relative to the materials alongside during the entire process of building the embankment or refilling the trench

The "ditch condition" load is given by the formula $W = C_d w(B+2b)^2$.

2. *The "Imperfect Ditch Condition"*—The "imperfect ditch condi-

[1] Three of these are cooperative with the U S Bureau of Public Roads and one is cooperative with the Iowa State Highway Commission

tion" is the loading condition in which all the material directly above the top of the conduit settles downward relative to the materials alongside until the top of the embankment reaches a level called the "height of equal settlement" The materials above the "height of equal settlement" settle equally, whether directly above the top of the conduit or alongside

The "imperfect ditch condition" load is given by the formula $W = C_d wB^2$, or by the formula $W = wBH$, up to the "height of equal settlement." Above the "height of equal settlement" the load increases at a rate equal to a constant times the weight of the materials added directly above the top of the conduit.

3 *The "Combined Ditch-Projection Condition"*—The "combined ditch-projection condition" is the loading condition in which the conduit projects above the bottom of a ditch with vertical or sloping sides whose width at the level of the top of the conduit is relatively considerably greater than the breadth of the conduit.

There is a "height of equal settlement" in this case

The "combined ditch-projection" loads is given by a combination of the "ditch condition" formula $W = C_d w(B+2b)^2$ and the "projection condition" formula $W = C_p wB^2$.

4. *The "Imperfect Projection Condition"*—The "imperfect projection condition" is the loading condition in which the conduit projects upwards a distance pB above the natural surface of the ground into an embankment, and in which the lowering of the top of the conduit due to yielding of the foundation plus shortening of the vertical diameter during the process of building the embankment is considerable but is smaller than the settlement of the materials alongside which originally were at the level of the top of the conduit

There is a "height of equal settlement" in this case

The "imperfect projection condition" load is given by the "projection condition" formula $W = C_p wB^2$, but using a value of C for $p_i = p \frac{s_m - s_e}{s_m}$ instead of p s_t = settlement of top of conduit and s_m = settlement of materials alongside which were originally at the level of the top of the conduit

5 *The "Projection Condition"*—The "projection condition" is the loading condition in which the conduit is rectangular or of *rigid* culvert pipe and is supported on rock or other practically unyielding foundation, and projects upward a distance pB above the natural surface of the ground into an embankment.

The materials alongside settle more during the process of building the embankment than the materials directly over the top of the conduit until the top of the embankment reaches a certain level called the "height of equal settlement" All materials above the "height of equal settlement" settle equally whether alongside or directly over the top of the conduit

The "projection condition" load is given by the formula $W = C_p B^2$.

PIPE LAYING CONDITIONS

1 *The "Impermissible" Pipe Laying Condition*—The "impermissible" pipe laying condition is the condition in which the pipe is laid on a flat or irregular surface not rounded to fit the pipe, and with no provision of hub holes for pipe with hubs, or in which the refilling material is not properly placed to fill all around the pipe, or in which other impermissible defects of similar general character occur

The supporting strength with "impermissible" pipe laying conditions can not be estimated safely at more than 75 per cent of the supporting strength which would be developed with "ordinary" pipe laying conditions

2 *The "Ordinary" Pipe Laying Condition*—The "ordinary" pipe laying condition is the condition in which the underside of the pipe is carefully bedded on soil for 60° to 90° of the circumference, suitably rounding the surface on which the pipe is laid for this purpose and providing hub holes for all pipe with hubs, and in which the pipe is surrounded by soil placed with ordinary care

The supporting strength with "ordinary pipe laying conditions is just about equal to the laboratory test strength obtained with "sand bearings" or to 1½ times the laboratory test strength with "3-edge bearings"

3 *The "First-Class" Pipe Laying Condition*—The "first-class" pipe laying condition is the condition in which the underside of the pipe is very thoroughly bedded on soil for at least 90° of its circumference, suitably rounding for this purpose the surface on which the pipe is laid and providing hub holes for pipe with hubs, and in which the entire pipe is surrounded with thoroughly compacted soil, all under the direction of a competent inspector constantly on the work

The supporting strength with "first-class" pipe laying conditions may be estimated safely as at least 125 per cent of the supporting strength which would be developed with "ordinary" pipe laying conditions

4 *The "Concrete Cradle" Pipe Laying Condition*—The "concrete cradle" pipe laying condition is the condition in which the pipe is supported on a fairly thick bed of concrete, which extends upward on each side of the pipe to a height at least equal to one-fourth the diameter

The supporting strength with well-designed "concrete cradles" will be at least 200 per cent of the supporting strength which would be developed with "ordinary" pipe laying conditions

Chairman Mehren Will you permit me a word in closing this meeting? As one who has been closely associated with you for many years—I don't mean merely with the Highway Research Board, but with highway matters in general—and having been withdrawn during the last few years more or less by other duties, possibly I have a perspective of what you are doing here that may be a bit better than that which you gentlemen have yourselves I want to say that I have been greatly inspired by attending these sessions, and seeing the progress that has been made in scientific inquiry into highway work Of course, scientific inquiry has been going on—a high class of scientific inquiry—for many years in the colleges, in the State highway departmnets, and particularly in the U S Bureau of Public Roads But in its organized form it seems to me that you are displaying a strength which promises very well for the future

I have been impressed in the course of the discussions of these two days with what I should say would be the triune division of your work. The first is that of preparation I presume that some of the committee chairmen themselves admit that they are only in the preliminary stages But before you can have any research worthy of the name you must know the best current practice' You must know the best the literature of the art furnishes And, having determined the best practice, and then only, are you ready to begin on what, presumably is the true object of this organization—the research program Presumably the committees of the American Association of State Highway Officials and the American Society of Engineers could do that preliminary work They could gather the data upon the best practice, they could search the literature They could catalog the results that had been secured Obviously, however, that is a necessary function of this organization as well, to be sure that before you try to outline the research problems proper that you have in hand the best of the available data I should say that some of the committee chairmen themselves would admit that they have merely completed this preliminary step They are now ready for the survey and mapping out of the high degree of research indicated by Dean Marston's work, the plans that Mr Crum and his committee have indicated and the results that were given yesterday in conneciton with materials for road construction and in design In other words, some of the committees like the committee on design, and the committee on materials of construction are very well advanced on the research program

You gentlemen should bear in mind that there is a difference between the work to be done by this research organization and that which may be done by other organizations You have set up for yourself a specific mission—to attack and break down the unknown problems—those that baffle everybody else, and those that defy the best practice of the moment Then comes the third step, and that is the need of disseminating the results of your research after they have been obtained. The results of highway research are of no value unless the application is made. Possibly it is not the function of the Highway Research Board to say how that educational work shall be done, and how the dissemination of the results of your work shall be effected But there is such a function and it is a necessary one In some way this task must be done, and this Board should see that it is done, not by actually doing it yourselves, perhaps, but at least by assuring yourselves that there is some agency by which the good things you discover are disseminated

May I say finally, as I started to say, that I have been greatly inspired by what has been accomplished here. There is a definiteness of direction in what you are doing, a versatility of attack, and a clarity and sanity in the conclusions that have already been reached which seem to me to constitute an admirable record for an organization that has only five years of life behind it. Someone certainly should express before the meeting adjourns the appreciation of those who are attending here, and who may not be directly concerned as are Mr Upham and others of the directing committee of the Highway Research Board, for what you are doing I heard a number of such expressions at the banquet last night, and I should like to take it upon myself to express publicly the appreciation of those engaged in highway work of the accomplishments of this Board, and to congratulate Mr Upham, Mr MacDonald and their co-workers in the direction of the Highway Research Board Truly they have laid the whole nation under debt to them by their vision and by the strong executive direction they have given this work It is truly a matter for great congratulation in highway circles