increase is not unreasonable, and Figure B, according to this theory, shows that the data are not always too exact.

Apparently in these finely divided soils the lubricating action of moisture is more important than its weakening effect in shear, and hence for any desired density the optimum water content is roughly that which fills the voids less the amount of entrained air necessarily left. This minimum entrained air corresponding to the optimum moisture is somewhat dependent upon the particular soil, and probably varies with the individual sample, but it tends to lie between 1 per cent and 5 per cent, with some indication that it decreases as the compaction effort increases, all of which seems reasonable enough. An exactly similar situation may not exist in bituminous aggregate mixes.

While the proposal that densification be carried on to an arbitrarily predetermined figure has theoretical merit, it seems a questionable method of design; the economic factors must also be considered, with the cost of densification balanced against thicker bearing courses.

In general, it seems obvious that in addition to the properties of the actual soil or aggregate encountered we must consider not merely the amount of liquid (either moisture or bitumen) present, but likewise the degree of compaction to which the mixture will have been subjected and the consequent density existing at the time of the occurrence of the stress conditions designed for. This paper is a very commendable effort to bring out some of these effects, discloses the importance of the problem, and is therefore an excellent contribution to this field.

DESIGN AND CAPACITY OF GUTTER INLETS

By N. W. Conner, *Professor of Fluid Mechanics, North Carolina State College*

IN ABSTRACT[1]

The design and installation of gutter inlets to carry water from city streets to the sewer systems has long been a troublesome problem. The capacities of existing designs are known only in a general way, and new types of construction give no assurance of improvement in capacity.

Several years ago, in Raleigh, North Carolina, the replacement of several types of old street surfaces with smooth concrete base pavement and gutters so increased the rate of run-off that the existing drainage facilities had to be revamped to take care of the additional water. In many instances the sizes of culverts were adequate, but the number, size and design of many of the inlets and catch basins had to be changed to meet the new conditions. A standard design of inlet was adopted for use in the newly-paved streets, which consisted of an opening in the side of the curb 6 in. by 24 in. and a 24 in by 24 in castiron grate in the gutter. Before the paving program had been completed, trouble began to develop because of flooding conditions

In order to secure information on the performance of inlets, the City of Raleigh and the North Carolina State College Engineering Experiment station undertook a joint research project The purpose of the investigation was twofold: first, to determine the capacities of the several types of inlets in use when installed on various grades, and second, to study the hydraulic principles involved whereby improvement in inlet design could be effected, especially on steep grades.

[1]For a complete report of the tests see "Design and Capacity of Gutter Inlets" by N. W. Conner, Bulletin No. 30, Engineering Experiment Station, North Carolina State College, Raleigh, North Carolina.

In general there are three types of inlets now in use. The first is an open cast-iron grating directly over a catch basin. This type is used only at the foot of the intersection of two or more streets. It is easily closed by the accumulation of waste paper and leaves and may be of little value in a short time after the first run-off. The second type is an inlet placed in the side of the concrete curb with an adjacent grating in the bottom of the gutter. This grating is subject to the same difficulty as the one placed in the street. The third inlet type is located in the side of the curb but without the grating.

As the City of Raleigh had experienced considerable trouble with the failure of the grate type because of leaves and paper, the first part of the investigation was aimed primarily at the development of a plain side inlet without any grate

The apparatus used in the study of inlets was located on a hill sloping down to a small creek. It consisted essentially of a half section of street with a concrete gutter and curb on one side. The section was of standard design and full scale The length of the test section was 110 ft and was so designed that the street level could be adjusted to any grade between 0 and 10 per cent. Water was supplied to the test section by means of a 6-in. pipe connected to a 14-in city main With this arrangement, the maximum flow of water available was about 1.5 cu ft per sec. For this reason, the capacity of some of the inlets tested could not be determined for all grades.

The inlets to be tested were placed in the gutter section at a point 100 ft. from the upper end of the street. This was done to allow the water to flow in the gutter for a sufficient distance to simulate actual conditions as nearly as possible. The bottom of the inlets were all depressed 3 in. below the grade line of the bottom of the gutter. This depression began at a point 10 ft above the inlet and reached the maximum of 3 in. at the edge of the inlet. On the other side of the inlet the bottom of the gutter gradually sloped up to the normal grade in a distance of 10 ft

Three types of inlets were tested. Those of the first type were plain rectangular openings in the side of the gutter All of them were 6 in high and had lengths of 1, 2, 4, 5, 6, and 7 ft. The second type of inlet consisted of side inlets with grates. There were two of this type tested, each 2 ft long and 6 in. high with a grate 24 in by 24 in. One grate was made with 7 bars, each 1¼ in. wide and 2½ in thick, perpendicular to the length of the inlet. In the other grate the bars were 2 in. high and ¾ in. wide These bars were placed at 45 deg with the inlet and inclined at 45 deg. The grates were of course flush with the bottom of the gutter Inlets of the third type were of the deflected flow class. Side inlets 2 ft long and 6 in high were used with various deflecting vanes placed in the gutter to cause the water to flow into the inlet.

The procedure followed in testing the inlets was to measure the capacity of each inlet in cubic feet per second on grades of 0 5, 1.0, 1 5, 2 0, 2 5, 3 0, 4 0, 6 0, 8 0, and 10 per cent When the capacity of an inlet was determined, water was barely lapping past the downstream edge of the inlet Of course greater capacities could have been obtained by allowing a greater amount of water to flow by the inlet Five separate determinations were made for each inlet on each grade The rate of discharge of the gutter in cu ft per sec and the corresponding depth of water, and width of free surface of water, were also measured at each grade.

The results of the tests on the plain side inlets show that at some grade greater than 10 per cent the capacity of all inlets of this type will be zero This grade for zero capacity will vary with the length of the inlet, being higher for the longer inlets. Since the City of Raleigh was interested in inlets of this type, an equation relating the capacity and length was developed. This equation is

$$q = CL^{N}$$

where q is the rate of discharge in cu ft. per sec. and L is the inlet length in feet The coefficient C and the exponent N are constant for only one grade, and curves were worked out giving values of C and N for all grades up to 10 per cent (See Figure 1). For a grade of 1.0 per cent the equation is

$$q = 0.108\ L^{1.4}$$

A study of the data shows that plain side inlets can be satisfactory even at steep grades. The effect of increasing the length is greater in the larger lengths and at the higher grades. Thus on a two per cent grade, increasing the length of the inlet from 6 to 7 ft. will result in almost double the capacity of the inlet change from 1 to 2 ft

The capacity of an inlet of the grate-in-gutter type is determined not only by how much water will go through the side inlet but also by the amount passing through the grate. At low grades and moderate velocity of water in the gutter, a very considerable amount of water can flow through the grate However, as the grade increases, the flow through the grate decreases very rapidly. The conclusion that the grate type of inlet is most efficient at low grades and becomes less effective at higher grades was borne out by the tests on this type On a 10 per cent grade it was found that the grate only discharged about 27 per cent of the water, the other 73 per cent going through the side In this case

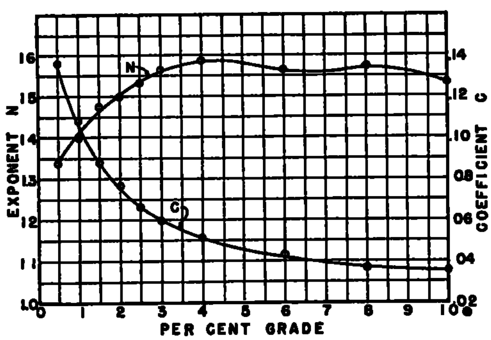

Figure 1. Curves giving the values of Exponent N, and Coefficient C, for the Equation: $q = CL^N$.

the total discharge was 0 139 cu ft. per sec By using grate bars at 45 deg and sloped 45 deg., instead of the conventional bars, the effectiveness of the grate was considerably increased On a 10 per cent grade the grate discharged 73 per cent of the water and the side opening only 29 per cent The total discharge was 0 358 cu ft per sec

The use of deflecting vanes to make the water flow into the side inlets proved highly satisfactory The type where the vanes were above the level of the gutter gave, by far, better results than did the type where the vanes were level with the bottom of the gutter. Although straight and curved deflecting vanes were both used, the rate of discharge was affected very little by the shape of the vane. The width of the vane also seemed to be relatively unimportant At steep grades all deflecting vanes tested seemed to be about equally effective When used on a 10 per cent grade, the deflecting vanes increased the capacity of the 2 ft side inlet by about 460 per cent The discharge without vanes was 0.099 cu. ft. per sec., while with vanes it was 0 460 cu. ft. per sec Setting the vanes flush with the bottom of the gutter was not nearly as effective as when the vanes projected above the bottom of the gutter. For the 2 ft. side inlet, the increase in capacity obtained on the 10 per cent grade was only 52 per cent.

While the data presented are believed to be reasonably accurate for the particular test section and inlets used, caution must be observed in using the results This is particularly true of the data pertaining to the gutter itself As a channel, the gutter section is hydraulically rough, even though the surface appears smooth. It was built in length of 10 ft. and with separating strips between each section The water in the gutter was also spread out over considerable width of gutter and street, with a rather small depth in comparison . Coefficients of roughness for Manning's Formula of from 0 016 to 0 019 were the rule for the gutter section The agreement of data for the flow in the gutter seems rather surprising in view of the difficulty of measuring the depth of water and the width of the water surface.

To be of practical value to city engineers, or others who may design and install gutter inlets, the results of this investigation must be modified by practical considerations. This means that the actual design of a system of gutters and side inlets must be based not only on the hydraulic performance of the gutters and inlets, but also upon the consideration of appearance and any limitations imposed by traffic and pedestrians. While the use of deflecting vanes does greatly increase the effectiveness of side inlets, it is questionable that such devices could be used at some locations on city streets This applies especially to the vanes above the bottom of the gutter Vanes flush with the bottom of the gutter could probably be used without objection.

One other objection to the deflecting vane should be noted The effect of the vane is to produce a standing wave at the inlet and thus enable the water to be deflected into the opening in the side of the curb. At moderate grades the wave is low and the water flows smoothly into the inlet As the grade is increased, the height of the wave also increases and eventually the water actually leaves the gutter and forms an arc When the height of the wave is great enough to cause it to fall upon the top of the curb, the usefulness of this device is reduced This condition existed for all grades over 4 per cent with deflecting vanes above the gutter bottom.

One of the side inlets with grate gave the best over-all performance The inlet was 2 ft. long and had a 24 in x 24 in. grate. The bars of the grate were set at 45 deg with the curb and also inclined at 45 deg. This inlet, when used on an 8 per cent grade, discharged 290 per cent more water than did the same size inlet with conventional bars. The discharge was 0 462 cu. ft. per sec

Since the purpose of the investigation was to secure information on the capacity of several types of side inlets when used on various grades, no attempt was made to test a large number of inlets merely for quantitative results. The scope of the investigation was purposely limited. All of the tests were run on a 3-in. depression. The length of the inlets was limited by the quantity of water available.

It is planned to continue work on inlets Several possible lines of attack suggest themselves For one thing, other ways of causing water to flow into side inlets should be studied. This might be done by controlling the water as it approached the inlet by the shape of the gutter. Also there are many good inlet designs whose capacities are not known It would probably be worthwhile to conduct tests on some of these

In conclusion, the writer feels that so far the results obtained may be termed only a beginning. There is much to be learned about inlet design Suggestions as to further investigation will be welcomed.

REPORT OF COMMITTEE ON ROADSIDE DEVELOPMENT

THE DESIGN OF STABILIZED EARTH SHOULDERS FOR TURF COVER

H. J. Neale, *Chairman*

SYNOPSIS

A road shoulder is an essential part of the traveled way. No primary road is safe unless an adequate shoulder is provided where vehicles can stop in an emergency out of the way of moving traffic. A good shoulder provides free cross drainage of surface water from the pavement to the gutter and ready passage of subsurface water from beneath the subgrade Such a shoulder supports the edge of the surfaced traffic lanes and should be designed, stabilized and surfaced with as much care as the traffic lanes themselves

Many types of shoulder surfaces have been evolved and each has a place in the development of a highway system. All types to be satisfactory must be designed with proper pitch, with adequate subdrainage and with a mixture of soils selected for whatever surface treatment is to be given the finished shoulder.

Because untreated or unpaved earth shoulders in humid regions are sooner or later covered by growing grass or weeds, the Committee on Roadside Development, during 1945, made a study of all available information relating to the design and development of earth shoulders with turf surfaces This report analyses some of the main points of what has been learned and what still remains to be found out on this subject. It is hoped to bring to the attention of highway engineers the need for systematic field research, and recording of field experience relating to the design of better road shoulders constructed of selected stabilized soils and protected in humid regions by a cover of turf grasses