"Future of Roads in Indiana?—The Editor believes it would be good policy for the State Highway Commission to double or treble its present road mileage within the next ten years, arriving at a maximum of about 25,000 miles. This could be done at the rate of, say, 1,500 miles per year with a proportionate additional allocation of gasoline tax and license fees to the State Highway Commission for the necessary improvement and maintenance of this mileage. This gradual absorption of the more heavily travelled county roads, on which much of the county maintenance money is expended, would not interfere with the efficient functioning of the State Highway Commission. We believe that all roads in the State of Indiana, on which traffic justifies a surface better than an ordinary untreated gravel or stone surface, belong in the state highway system. The remaining 52,000 miles of county roads would be largely local farm roads and should be maintained by county road authorities."

These last two suggestions that I have placed before you—namely, the inclusion of the city streets in the state highway system, and Professor Petty's viewpoints on enlarging the state highway system—are purely matters for the electorate of Indiana to decide, and I leave them with you for discussion.

DESIGN AND CONSTRUCTION OF CEMENT-BOUND MACADAM PAVEMENTS

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My knowledge of cement-bound macadam pavements is limited to one job of actual construction and to considerable study of theory and methods. When it was decided to build a cement-bound macadam road at Fort Sheridan, it was necessary for the officers charged with this work to study the methods of construction. I can not pose as an expert on the theory of this type of construction. However, from the practical viewpoint, I believe I can now build this type of road so that it will pass any state highway inspector. I say this because, through the school of bitter experience, I learned about all the errors of constructing cement-bound macadam roads. So, through the errors committed on the Fort Sheridan road, I feel that I can come before you gentlemen and tell you how to construct this revived type of cement-bound macadam.

You will note that I have used the expression "revived type." In order to explain that expression, I must go back a few years and delve into the history of cement-bound macadam to see just when and where the first-known section of this type of road was constructed.
HISTORICAL DEVELOPMENT

The first recorded section of cement-bound macadam was built in Edinburgh, Scotland, in 1872. This section, called Gillespie Crescent, is a mile and a quarter long and, while still in use, had had only $200 spent on it in maintenance up to 1920. Two additional sections called Glengyle Terrace and Blackwood Crescent were laid in 1873, and are still in service. Regardless of condition, any road that is still in use after fifty years must have been pretty good.

Since that time, several stretches were so satisfactorily built in England, France, and Australia that the use of this type of road has been greatly extended throughout these countries.

In the United States, the first section was built in 1905 in Massachusetts. A year later a second section was built at Lynn, Massachusetts, and is still in use. Since that time, about 100 miles have been constructed in New York state, 200 miles in Massachusetts, 100 miles in Connecticut, 200 miles in Oregon and Washington, and about 44 miles in Detroit, Michigan. Four sections on the Boston Post road were built in 1914, and although the traffic since that time has increased to 25,000 vehicles per day, the road is still in serviceable condition. During the past few years, sections have been completed in several states: namely, New Jersey, Pennsylvania, New York, and Illinois. From this brief résumé you can readily see that the expression “revived type” is most apt.

It is not my purpose to extol the use of any particular type of road or material or construction, but I believe that a few necessary details such as the above history and the following brief description of the relative merits of this particular type must be presented.

First of all, this type of construction has been advocated principally for secondary roads. In the past, mixed concrete has been little used on secondary roads, being limited almost exclusively to primary roads on account of its cost. If all of the facts are available to me, the strengths obtained with cement-bound macadam compare favorably with regular concrete construction. As far as quality is concerned, there should be no hesitancy in using it. If coarse aggregate is available at reasonable cost, there can be no question of the economy of cement-bound macadam. In order to present fully the problems of construction, it is necessary to dwell briefly on the general plan of construction.

PRINCIPLES OF DESIGN AND CONSTRUCTION

Cement-bound macadam consists of a coarse aggregate held together by cement grout. The coarse aggregate is placed on the subgrade, rolled to reduce voids and to true up the surface, and a cement-sand grout, mixed to a consistency of thick
cream, is poured over the coarse aggregate. After standing for a time sufficient to permit the escape of excess water, it is then rolled to consolidate the mass and to bring sufficient grout to the surface for finishing purposes. After rolling, a longitudinal tamp is used to take out any surface irregularities. After tamping, the surface is smoothed with long-handled floats, then dragged with burlap and, if desired, can be given a broomed finish. In appearance the resulting slab resembles a standard concrete pavement. This certainly sounds like a simple method of construction, and it really is, but there are certain features about the construction which must be considered both before and during the actual operations.

First and foremost is the question of design. The width will depend upon the volume of traffic, while the cross-section will depend upon the weight and number of expected wheel loads. The same formulae and principles used in the design of mixed concrete pavements are applicable to cement-bound macadam.

Edge and dowel bars have not been used in this type of construction as far as I know. Longitudinal joints dividing the pavement into 8- to 12-foot lanes are obtained either by constructing the pavement in strips or by using a longitudinal dummy joint. This dummy joint is provided by setting a 1 x 2 1/2-inch wooden strip on the subgrade with the 2 1/2-inch edge vertical. This will form a plane of weakness and will cause the pavement to crack over this wooden strip.

Expansion joints are provided at intervals of 100 to 200 feet transversely across the pavement. They can be of any one of the following types:

1. Pre-moulded bituminous joints.
2. Open or poured type.
3. Wooden boards left in place.

In the Fort Sheridan job, a width of 27 feet was selected, as this road was to be the main entrance to the Post. The road was divided into two strips by the use of a dummy longitudinal center joint. The thickness originally contemplated was to be 6 inches. However, because of lack of experience in placing the aggregate, a much greater thickness was actually obtained. This will be discussed later. Wooden board joints at 100-foot intervals were installed transversely across the pavement for expansion.

**THE AGGREGATE**

The next important feature is the selection of the aggregates. Coarse aggregates of crushed stone, gravel, or slag may be used. The same quality of aggregates as required in concrete construction should be specified. The grading and size of coarse aggregates are, however, materially different from those ordinarily used for mixed concrete. In regular
concrete, well-graded aggregates are required, while in cement-bound macadam well-graded aggregates (coarse to fine) are not desirable. Any size from a maximum of 3 1/2 inches to a minimum of 3/4 inch may be used. However, in the particular size selected for any one job, the range between the maximum and the minimum should not exceed 1 1/2 inches. That is, if a maximum size of 3 1/2 inches is selected, the minimum size should be limited to 2 inches, and if a 2 1/2-inch maximum size is selected, the minimum should be 1 inch. Limiting the sizes in this manner results in a uniformity of size and shape of voids which is necessary for successful grout penetration. The optimum size of coarse aggregate is that ranging between 1 1/2 to 2 1/2 inches, since coarse aggregate of large size is more difficult to finish and usually results in a larger subgrade loss, while a small size is more difficult to penetrate. So far as resulting strengths are concerned, there is little difference, provided the proper size of sand is used for the size of coarse aggregate selected.

The selection of the proper size of sand is rather an important subject for successful penetration. In general, ordinary concrete sand (100-4) can be used with the larger-sized coarse aggregate, while a medium-sized sand (100-8) should be used with the medium-sized coarse aggregate and a fine sand (100-14) should be used with the smaller-sized coarse aggregate. However, successful penetration can be obtained with the fine and medium sand with either the large- or medium-sized coarse aggregate, the only limitations being that the coarse sand should be used only with the large-sized coarse aggregate and the fine sand only with the small coarse aggregate.

Regardless of the size of sand used, the sand should meet the standard specifications for concrete construction as far as quality is concerned. Any standard brand of portland cement may be used successfully.

On the Fort Sheridan job, the coarse aggregate selected was a 1- to 2-inch crushed limestone. The sand purchased, graded from 100 to 14 and is known commercially as a plaster sand. We could have used a coarser sand (100-8) with the size of coarse aggregate which we had.

DETAILED PROCEDURE

Subgrade. The subgrade is a subject which I regret had not been carefully considered when we put in our road. We had had marvelous weather up to and including our subgrading operations. A portion of this road was in a cut and we did not excavate wide enough to permit the construction of side ditches. We therefore had made no provision in case of rain to drain the subgrade properly. I will show later that this caused considerable trouble.
Forms. Forms may be of wood or steel. They should be firmly and adequately staked and of such rigidity as to withstand subsequent rolling operations. The weight of the roller on the coarse aggregate, when operating near the edge, transmits a lateral pressure on the forms which only the most rigid and well-braced forms can withstand. If wood forms are used, they should be of at least 3-inch timber. If curbing is contemplated, it should be constructed first and forms eliminated entirely. At Fort Sheridan, we planned to construct curbing but, on account of lack of funds, we were unable to provide for this feature at the time of constructing the road.

Placing Aggregate. After the forms or curbing have been constructed, the coarse aggregate is then placed on the subgrade to a depth so that after compaction the final pavement will be of the desired thickness. This is not so difficult as it would appear. From various methods of compaction used during the Elmhurst Road Test, definite compaction factors were determined. The percentage of compaction is based on the designed grouted depth, and the compaction factor is then expressed as this percentage plus one. The depth of the loose stone is computed by multiplying the compaction factor with the desired grouted depth and adding the estimated subgrade loss, which is dependent upon the nature of the soil. If it is virgin soil, the subgrade loss will vary from $\frac{1}{2}$ to 1 inch when a 6-ton roller is used for compaction. On an old traveled, well compacted, earth road, the subgrade loss will be materially reduced. On an old stone base, there will be no subgrade loss.

The coarse aggregate can be spread either by hand or by the use of spreader boxes. If it is spread by hand, either a template, cut to the crown of the road, should be used as a guide, or grade stakes should be used. On the Fort Sheridan job, we attempted to level and spread the stone by eye. A second lieutenant was in direct supervision of this work and his eye was no better than mine. As a result, instead of placing the stone to a depth of 7 1/2 to 8 inches, we had nearer 10 inches. This caused our costs to increase beyond our calculated figures, but did give us a slab suitable to run freight trains over. I would strongly recommend, both from the standpoint of economy and from resultant smoothness of the finished surface, that the stone be placed with great care and, by all means, that the eye be not trusted either for the depth or the surface smoothness. If spreader boxes are available, they should be used. The even spreading of the loose stone is the first requirement for a smooth-riding pavement.

Rolling. The next step is the rolling of the loose stone. In this operation, the weight of the roller is an important feature. If the roller is too heavy, it will tend to break down or crush the aggregate particles. While this is not objectionable in water-bound macadam roads, it is vitally important in cement-bound macadam, since such broken particles tend to reduce the
void spaces and hinder full penetration of the grout. It was found by experiment on the Elmhurst test road that a 3- to 6-ton tandem roller is the most satisfactory. At Fort Sheridan, the only available roller was a 7½-ton steam roller which actually had a weight of 8.6 tons when carrying coal and water.

Proper construction requires the rolling of loose stone immediately following or as soon as possible after it has been placed. The reason for this is apparent, as any rainfall before rolling will soften the subgrade and not only result in a large subgrade loss but also add to the difficulty of maintaining a smooth surface when rolling. Such was the case on our job at Fort Sheridan. We had heavy rains before the aggregate could be rolled. This, together with the excessive weight of the roller, would not allow us to key the stone properly or maintain a true surface. It would have been possible to drain the subgrade if trenches and side ditches had been provided during subgrading operations.

In any event, rolling of coarse aggregate should not be carried to a point where there will be crushing of aggregate particles. The primary purpose of rolling is to key the stone and smooth the surface. Usually one to two trips over the entire surface are all that are required. After the coarse aggregate has been rolled, it should be checked with a straight-edge and longitudinal and transverse inequalities corrected.

Grouting. Now comes the most interesting phase of the entire job—that of grouting. Before actual grouting is undertaken, it is necessary to determine the fluidity characteristics of the grout mix to be used. The fluidity of the grout and the size of spaces between the coarse aggregate influence the penetration. It is essential that some manner of measuring the fluidity of grouts be determined and specified. During the Elmhurst Road Test, such an apparatus was developed. It is a receptacle in the shape of a funnel, having a capacity of about 220 cubic inches, to which is fitted a 1½-inch tube, 1½ inches in length. The receptacle is filled with cement grout of a known water content. After the filling, the grout is allowed to discharge through the 1½-inch tube and the time, in seconds, for it to empty is measured by a stop watch. With such an apparatus, a flow curve of a particular sand and mix can be made, using different amounts of water and plotting the time in seconds taken to empty against the amount of mixing water per sack of cement. Different sand gradings require different amounts of mixing water to produce the same time of flow, with the proportioning of sand to cement remaining constant. Coarser sands require less water, while finer sands require more water.

Again referring to the Elmhurst Road Tests, it was found that 1½ to 3-inch coarse aggregate required grouts of 23 to 25 seconds flow for successful penetration, while 1 to 2-inch
coarse aggregates required grouts having 20 to 22 seconds flow and $\frac{1}{2}$ to $1\frac{1}{2}$-inch aggregates required grout with 17 to 19 seconds flow. On our job, the coarse aggregate was 1 inch to 2 inches in size and required a grout having a fluidity of 20 to 22 seconds.

A flow curve for the particular sand and mix to be used was then made. Such a flow curve is essential in that not only the amount of mixing water required to give a 20- to 22-second flow is obtained, but also the degree of safety of the sand can be seen at a glance.

During actual grouting operations, the fluidity of the grout can be checked in the field by using the same apparatus. Any change in moisture in the sand can be readily detected and corrections made at the mixer during grouting.

The grout can be either mixed on the job, or mixed in transit by using truck mixers. If it is mixed on the job, either a spout or boom-and-bucket type of mixer can be used. Regardless of the method used, the grout must be deposited on the coarse aggregate without segregation and in such a manner as not to disturb or displace the coarse aggregate. If a spout is used, baffle plates may be necessary to reduce the velocity of the grout, and a grout box should also be attached to the end of the spout. The bottom of this box is placed in such a position that it is parallel to and about 6 to 8 inches above the surface of the pavement. The box is provided with sides of about 10 inches in height to prevent spilling of the grout, and the bottom is perforated with 1-inch holes on 3-inch centers.

At Fort Sheridan, the only mixer that could be rented was a 27-E caterpillar-tread mixer of the boom-and-bucket type. (Fig. 1.) So far as I know, this was the first time a boom-and-

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**Fig. 1.** Pioneering with a 27-E crawler-tread concrete mixer for mixing and placing the grout.
bucket type had ever been used in placing grout on cement-bound macadam work. It was necessary to devise some means of distributing the grout, as it was evident that it would be undesirable to deposit an entire batch at one time on the surface without checking the velocity in some manner. Therefore, the gates of the bucket were wired so that the maximum opening would not exceed \( \frac{3}{4} \) inch, and a grout box constructed of wood of the same horizontal dimensions as the bucket was placed underneath the bucket and supported with four iron rods hung from the top of the bucket. (Fig. 2.) This box was provided with 1-inch holes on 3-inch centers. The method proved to be very successful, as the distribution of the grout could be controlled by running the bucket out to the end of the boom and returning the bucket to the mixer during discharge. (Fig. 3.)

Since the mixer was of the crawler-tread type, it was operated on the ungrouted coarse aggregate without any serious trouble. An eight-sack batch was used. All proportioning was done by volume, and the mix used was equivalent to a 1:2 by weight. The mixer was charged by wheelbarrows from storage piles of sand and cement alongside the road. The grout was deposited continuously from side to side of the pavement and swept ahead with push brooms (we call them stable brooms in the army) to prevent formation of air and water pockets back of the grouting. Sufficient grout was left on the surface to leave a thin film over the coarse aggregate.

In order to check the thoroughness of the penetration, holes were dug through the coarse aggregate to the subgrade at
Fig. 3. Showing grout box attached to bucket discharging grout uniformly.

some distance ahead of the grouting. These holes were observed as the grouting operations proceeded towards them. In all cases, unsegregated grout entered at the bottom of the test holes when the grout in the surface was one foot or more away, which indicated satisfactory penetration. Should the grout not have entered at the bottom of the test hole when surface grout was within a foot of the hole, penetration would have been doubtful.

Ordinarily, during the summer months, the coarse aggregate would have been sprinkled slightly before depositing the grout. This sprinkling should be just enough to wet the stones but not enough to cause any dampening of the subgrade.

Final Rolling. As stated previously, several showers of rain fell after the coarse aggregate was spread and before it could be rolled. Our subgrade was in a very soft condition, which, as before mentioned, did not permit proper rolling of the loose aggregate. During the first day of the grouting operation, there was no sunshine and the humidity of the air was high. Then a light rain began to fall. All of this, together with the excessive weight of the roller, worked against us in obtaining a final smooth finish. Usually the time between the final rolling and the grouting operations will range from 30 minutes to about one hour. Final rolling of the grouted aggregates should not be undertaken until there is a stiffening of the grout sufficient to support the roller without causing a quakiness of the mass. This is usually indicated by no further release of free water from the grout to the pavement surface.

Since our subgrade was in a very soft condition because
of rains, it could not absorb any of this free water from the grout; consequently, all of this water had to come to the surface, where because of high humidity and cloudy weather evaporation was extremely slow. As a result, our grouted surface was not ready to roll for several hours after grouting—in fact, grout which was deposited at 11 o'clock in the morning was not ready for final rolling until 4 P.M. that day. Grouting operations were stopped shortly after 3 o'clock, but it was necessary to carry on the work late into the night before we could complete our rolling and finishing operations. Good workmanship under these conditions could not be expected. Ordinarily from three to six trips over with the roller lapped about one-half its width are sufficient. During rolling operations, hand squeegees or light push brooms were used to distribute the grout evenly over the surface, and remove excess grout.

Rolling, as we found through experience, should be done only by a man familiar with macadam construction. We took a soldier who had done ordinary rolling around the Post such as athletic fields, etc. He did remarkably well for his inexperience, but part of our trouble in our surface finish was due to poor operation of the roller.

**Finishing.** After rolling, the surface was gone over from two to three times with a longitudinal tamping template in order to remove any surface irregularities which may have been caused by the rolling operation. This was immediately followed by floating the entire surface with a long-handled wooden float. The surface was then smoothed by dragging a strip of wetted burlap over it longitudinally. The final surface finish was obtained by brooming.

During our second day's grouting, which was also the last, we decided to accelerate the hardening of the grout by the admixture of about 2 pounds of calcium chloride per sack of cement. This, in solution, was added to the last 50 feet of grout poured, as a part of the mixing water. We finished grouting at about 5 o'clock. We should have added this admixture sooner, as the last 50 feet set up faster than the section preceding it and by the time we reached it with the roller the surface had become so hard that little could be done with it and, to add to the difficulty, finishing operations had to be continued after dark. The resulting finish was not as satisfactory as we desired. Hereafter, under similar circumstances, I would use calcium chloride throughout the full day's operation.

**CONCLUSION**

To sum up, I believe we learned a great deal about practical construction work on this type of road. Bear in mind that we had an inexperienced crew, short duration of work (two days' grouting), adverse weather conditions, and a roller
too heavy for this kind of work. In spite of these handicaps, we did obtain a substantially good pavement as far as quality and serviceability are concerned, but the surface finish on some sections left much to be desired. (Fig. 4.) I am confident that on any future work of this type I could eliminate the mistakes we made and produce a pavement with a satisfactory surface finish with much less effort than we put into the work I have described.

WHAT SHALL WE DO WITH THE LOWER-THAN-COST BID?

By R. E. O'Connor, Director, Indiana Highway Constructors, Inc., Fort Wayne

There is only one path by which we can make a proper approach to the subject assigned for discussion in this paper. It leads through the past history of our industry and our associations up to the present time, and ends in the basic ideas back of the National Recovery Act.

We realize that there is no need here for a general review of our experiences as contractors in the competitive market as it has existed and does yet exist in the construction industry. We can dispose of this part of our discussion by stating that any one of us not now convinced of the need for a change in this market cannot be convinced or converted, and that any attempt we might make to do so would simply be a wasted effort.