with local material, high-priced surfaces on main thoroughfares, or on roads which could not be classed as farm-to-market roads within our interpretation of the term. We have, however, built stabilized gravel roads as a foundation to future construction work where we knew a concrete pavement was to be built within the next two or three years. We were able to save enough in our final construction more than to pay for the initial investment in gravel through the reduction of thickness of concrete.

Perhaps, in closing, it would not be amiss to quote the words of caution expressed in an editorial appearing in the Engineering News Record on December 8, last, directed to those who expect too much of this type of construction or to those who specify the use of elaborate construction methods:

Equally evident in the Research Board meeting was the prominence of earth-road problems. Soil stabilization appears to be a word to conjure with, for the time being, and the many unanswered questions that lie in this type of construction give assurance that future technical meetings will also find much of their time occupied by earth-road discussions. Some developments suggest, however, that the original term “low-cost roads” no longer can be applied, generally, to modern earth roads, for some of the construction procedures used in building stabilized soil roads are fully as complex and costly as those required to lay a concrete slab pavement. This development compels thought, because it departs so far from the important low-cost objective which brought about the current interest in earth roads. Ingenuity and study should be invoked to show a way back to the low-cost concept, or else we will be in the absurd position of combining high construction cost with high maintenance cost. The situation forecasts extensive further growth of investigation and practice in the application of local materials, from the shale rock roadbeds of Pennsylvania to the soil concretes of the North, and topsoil surfaces of the South.

ROAD STABILIZATION WITH PORTLAND CEMENT

Bert Myers,
Engineer of Materials and Tests,
Iowa State Highway Commission,
Ames, Iowa

Among the more interesting of the recent developments in highway engineering are the methods that have been devised for the use of large proportions of soil in the construction of road surfaces and base courses. These methods for the use of soil have been designated by the term “stabilization.” One of the most interesting methods of soil stabilization is the one in which portland cement is used as the stabilizing agent.

The methods that have been used for determining the proper proportions of soil, cement, and water to be used, and
the construction methods that have been followed have been very well described in several published discussions. Among these are the following:


Since the design of the mixture and the methods of construction are so well covered in publications available to anyone interested in this type of construction it would seem desirable to discuss these points only briefly.

**DESIGN OF MIXTURE**

The design of the mixture, or the determination of the proper proportions of soil, cement, and water, has been accomplished by experimental methods.

Samples of each kind of soil to be stabilized are mixed with a series of different percentages of cement. The optimum moisture content for each of these mixtures is determined by the Proctor method.

From each of these mixtures cylindrical specimens 4" in diameter and 4 1/2" high, to be used in durability tests, are molded at optimum moisture content. These specimens for durability tests are cured for 7 days in a moist closet or in damp sand.

One set of specimens for each mixture is then subjected to alternate wetting and drying. The wetting treatment consists of immersion for 5 hours in tap water. The drying treatment consists of exposure in an oven to a temperature of 160°F for a period of 42 hours. The specimens are measured and weighed at the end of each drying period. The specimens are immersed in water as quickly as the weights and measurements have been made. This wetting and drying cycle is usually repeated 12 times.

Another set of specimens from each mixture is subjected to alternate freezing and thawing. After the curing period, they are placed on moist felt pads for from 5 to 7 days to permit complete capillary moisture absorption. They are then placed in a freezing chamber for 20 hours. After removal from the freezing chamber, the specimens are weighed and measured. They are then placed on wet felt pads in a moist room to thaw for 24 hours. The cylinders are then weighed and measured again. This constitutes one freezing and one thawing
cycle; the process is usually repeated 12 times. The behavior of the specimens in these durability tests is taken as an indication of the percentage of cement necessary for the stabilization of the soil represented.

CONSTRUCTION METHODS

Cement-stabilized roads have ordinarily been constructed by road-mix methods. This consists of the following procedure:

The road is brought to the desired profile and cross-section. For the width and depth to be treated, it is scarified. The scarified soil is pulverized with disc harrows, spike tooth harrows, or other suitable equipment.

The pulverized soil is brought to the proper cross-section. Cement in the predetermined quantity is spread on the soil by means of mechanical spreaders, or by hand.

The soil and cement are mixed together by means of disc harrows, quack-grass diggers, farm plows, or other suitable equipment until the color of the mixture is uniform.

Water is added by means of bituminous distributors. The water is mixed with the soil and cement in much the same way as the cement was mixed with the soil. When the required amount of water has been added and properly mixed, the sur-

Fig. 1. Compacting 8% cement-soil road mix with a sheepsfoot roller.

face is smoothed. The treated soil is then compacted by means of sheepsfoot rollers until the feet of the roller penetrate the surface only about 1½ inches. The surface is scarified with a spike tooth harrow or similar tool to remove compaction planes. The surface is then shaped, and final rolling is done with smooth-faced rollers or a combination of pneumatic-tired
rollers and smooth-faced rollers. The finished pavement is cured in the same way as a concrete pavement would be cured.

Under this method of construction it is very important that the length of roadway to which the cement is added shall not be more than can be compacted within the working time remaining available for that day. This is necessary because the mixture must be compacted before the cement has hardened.

Special care is necessary at the junction between successive day’s operations. Turning equipment on the previously finished work will damage the surface unless it is properly protected. In some cases the area at the end of the previous day’s run has been protected by a covering of earth and in some cases with planks. Particular attention is also required to insure proper proportions and mixing in this area.

Some difficulty has been experienced in securing a uniform depth of scarification. Variation affects both the depth of pavement and the proportions. In Iowa, the loosened and pulverized soil is bladed into a windrow which is equalized with a windrow equalizer and then spread. This is an effective method for overcoming the difficulty.

On some roads in South Carolina the mixing has been done by a mixing plant traveling on the subgrade.

While the construction of this type of road is not complicated, the writer would recommend that anyone who is to supervise such construction become thoroughly familiar with the literature on the subject.

STRUCTURAL PROPERTIES

There is evidence that some engineers are confused as to just what kind of material this cement stabilized soil is. There is some tendency to think of any mixture containing cement and water as concrete and to predict its behavior from the behavior of concrete. It is not strange that an engineer who has been working with concrete having a compressive strength of 3,000 to 5,000 lbs. per square inch should have some doubt as to the load carrying capacity of a slab of equal thickness built of a material having a strength about one tenth as great. He must take cognizance of other differences in the physical characteristics of the two materials. It may require some mental readjustment for the man who has been rejecting aggregates for concrete because they contained 2% of soil to develop much confidence in a material composed entirely of soil, cement, and water, if he is thinking of the soil mixture as concrete.

However, in 20 states more than 150 miles of road built of cement-stabilized soil are carrying traffic. Of this total, 1.5 miles were built in 1935, 7.72 miles in 1936, 35.13 miles in 1937, and the remainder in 1938. These mileages do not include short sections built in South Carolina in 1933 and in
1934. The Portland Cement Association, which has kept in close contact with all this work, reports that there have been no structural failures and that all these roads are giving good or excellent service. The only defects that have been noted are surface defects due to improper finishing procedure, which has been attributed to inexperience with this particular type of construction.

Since there is considerable proof that this type of pavement does have the capacity to carry traffic, it may be worthwhile to speculate on why or how it does it. We have mentioned that cement-stabilized soil has a compressive strength only about one tenth as great as that of concrete. There is a greater and more significant difference in the physical characteristics of the two materials. Concrete will have a modulus of elasticity of from 3,000,000 to 5,000,000 lbs. per square inch. Specimens of cement-stabilized soil tested by the Iowa Highway Commission laboratories had moduli of elasticity of from 10,000 to 13,000 lbs. per square inch. This means that, for a given unit stress, the stabilized soil will be distorted or deflected about 300 times as much as concrete under the same unit stress. This shows that the stabilized soil is quite flexible as compared with concrete and that a soil-cement pavement is definitely a flexible pavement and not a rigid pavement as is concrete. It is obvious that the two types of pavement cannot be expected to behave in the same way under loads. The modulus of elasticity of the cement-stabilized soil is about the same as that of stabilized gravel at the moisture content we have found to be common for such material in the road.

Unfortunately, no commonly accepted theory has been developed for computing the stresses in flexible pavements. Benkelman\(^1\) has discussed various theories proposed and the difficulties to be overcome in securing the data necessary to the derivation of an accurate theory for the design of flexible pavements.

Westergaard\(^2\) has developed a theory for the design of rigid pavements which was never intended to and obviously does not apply to flexible pavements. However, he employs one concept which may help to explain some features of the behavior of flexible pavements. The index of the reaction of the subgrade against the bottom of the slab when the slab is deflected under a load, called the “modulus of subgrade reaction,” is expressed in pounds per cubic inch. This means that the resistance of the subgrade is due to its resistance to change in volume or shape, and the total resistance exerted is proportional to the volume by which the subgrade is distorted.

In the case of a rigid slab like concrete, the area of subgrade affected by a given load will be relatively large but the

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\(^1\) “What We Know About the Design of Pavements of the Flexible Type,” by A. C. Benkelman, *Public Roads*, January, 1938.

distance the rigid slab may be deflected without rupture is relatively small. In the case of the flexible slab, the area of slab which will be deflected by the same load is relatively small but the distance through which it may be deflected without failure is relatively great.

It is interesting to note the type of failure which occurs under compressive stress. In concrete the specimen is shattered. In flexible materials such as stabilized gravel and cement-stabilized soil, the specimen fails gradually without shattering. One specimen of cement-stabilized soil was tested to failure at a stress of 376 pounds per square inch, after which the load was removed. It was then loaded again and failed at a stress of 328 pounds per square inch.

Another difference between concrete and stabilized soil which would tend to reduce the stress in the more flexible material is the matter of temperature stress. The flexibility or low modulus of elasticity of the stabilized material will reduce (by a very great amount) the possible temperature stresses both from subgrade friction and from curling.

Bradbury has computed stresses in an 8"-6"-8" concrete pavement under an 8,000-pound wheel load as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>Max. Stress, lb. per Square Inch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stress Due to Wheel Load</td>
</tr>
<tr>
<td>Slab interior</td>
<td>235</td>
</tr>
<tr>
<td>Exterior longitudinal edge</td>
<td>204</td>
</tr>
<tr>
<td>Center longitudinal joint edge</td>
<td>170</td>
</tr>
<tr>
<td>Transverse-joint edge</td>
<td>270</td>
</tr>
<tr>
<td>Exterior corner</td>
<td>274</td>
</tr>
<tr>
<td>Interior corner</td>
<td>172</td>
</tr>
</tbody>
</table>

Where the total stress is highest, the temperature stress is higher than the stress due to wheel load. It is difficult to imagine any considerable warping stress in a material having a modulus of elasticity as low as 10,000 pounds per square inch.

While a mixture of cement, soil, and water is not concrete and has entirely different structural properties when used as a pavement slab, it is also entirely different from the untreated soil. Specimens of the compacted and cured soil-cement mixture withstand 12 alternations of a severe wetting and drying cycle and 12 alternations of freezing and thawing with a loss in weight of only a few percent, even when brushed vigorously.

\(^3\) Reinforced Concrete Pavements, by Royall D. Bradbury.
with a stiff wire brush after each cycle. The raw soil, similarly compacted, will slake down to its natural angle of repose in one of these cycles.

How the cement changes the properties of the soil so radically is not well understood. The effect of the cement is apparently both chemical and mechanical. It changes the texture of the soil very materially. A sample of cement-treated soil, when tested for particle size in the usual way, will show practically no particles smaller than .005 mm., while the original soil showed as high as 20% of the .005 mm. size and 10% of the .001 mm. size. The lower plastic limit of the treated soil is much higher than the lower plastic limit of the raw soil. The difference in lower liquid limits between the treated and untreated material is not great. Thus, the plasticity index is much reduced by the treatment. The hardening of the cement in the mass has a considerable effect upon the strength and durability of the material. For this reason it is important that soil-cement mixtures be cured properly.

The material appears dry when examined in the field, but tests made on samples taken from two sections of road in December, 1938, showed the following percentages of moisture:

Road in Cass County, Loess Soil, Built July, 1938

<table>
<thead>
<tr>
<th>Station</th>
<th>Percentage of Moisture</th>
<th>Lower Plastic Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>73+00</td>
<td>13.7</td>
<td>29.4</td>
</tr>
<tr>
<td>61+00</td>
<td>12.5</td>
<td>27.7</td>
</tr>
<tr>
<td>108+00</td>
<td>12.5</td>
<td>28.0</td>
</tr>
<tr>
<td>94+00</td>
<td>15.4</td>
<td>27.7</td>
</tr>
<tr>
<td>22+00</td>
<td>14.0</td>
<td>27.5</td>
</tr>
<tr>
<td>35+00</td>
<td>15.7</td>
<td>27.5</td>
</tr>
<tr>
<td>44+00</td>
<td>13.4</td>
<td>26.5</td>
</tr>
<tr>
<td>57+00</td>
<td>15.5</td>
<td>28.0</td>
</tr>
<tr>
<td>147+00</td>
<td>7.1</td>
<td>24.5</td>
</tr>
<tr>
<td>167+00</td>
<td>13.3</td>
<td>33.0</td>
</tr>
<tr>
<td>192+00</td>
<td>10.8</td>
<td>28.2</td>
</tr>
<tr>
<td>217+00</td>
<td>11.6</td>
<td>27.0</td>
</tr>
</tbody>
</table>

While the moisture content of these roads would be alarmingly high for some kinds of material, it does not seem at all alarming when it is considered that in no case is the moisture content much more than one half the lower plastic limit for this material.

In comparing cement-stabilized soil with stabilized gravel, it is interesting to note that the soil-cement mixture has considerably less density than the stabilized gravel. A common value for the percentage of solids in a stabilized gravel road is 84, while the percentage of solids in a cement stabilized road is likely to be 60 to 70; yet the two materials may have about the same strength. This must indicate that in the case of the
soil-cement mixture the particles are cemented together at their contact faces.

Since the oldest cement-stabilized road is only 6 years old and it has not been subjected to the most severe climatic conditions, it would be dangerous to make a prediction as to the probable life of this type of construction. It is the writer's belief that little or no consideration should be given to an attempt to stabilize soils with cement in Iowa in 1924. The work done at that time was very similar to the present practice with two very important exceptions. In the 1924 work, the mixture of soil and cement was not wetted artificially and it was not rolled. The dry mixture of cement and soil was smoothed off and left to be moistened by rains and compacted with traffic. The road was never considered a success, and now, 15 years after it was constructed, there is no evidence that the soil is different from what it was originally. It is unfortunate that this old road was not properly wetted and compacted so that we would now have some reliable evidence as to the durability of this type of construction built according to modern practice.

Constant improvements are being made in methods for constructing soil-cement roads. There is one point where further improvement would seem possible. It has been observed that the density obtainable by the Proctor method, immediately after the water has been incorporated into the mixture, is considerably greater than it is on the material that has been allowed to stand two or three hours. With the road-mix method of construction now followed, a considerable period of time elapsed between the addition of the water and the compaction of the mixture. It would seem worthwhile to consider some method that would reduce this delay.

The present method used for designing the mixture consumes more than a month. This length of time is much too great to meet situations frequently encountered in highway work. Haunsel has mentioned this and has suggested the possibility that the void-cement ratio might be a criterion which could be used. Serious consideration should be given this or some other substitute for the present method for routine work.

STABILIZING GRAVEL AND STONE ROADS WITH TAR

Ralph Witt,
St. Joseph County Road Supervisor,
South Bend, Indiana

I believe that all of us are interested in developing a secondary road type that will stand a reasonable amount of heavy traffic and yet not cost so much as to keep it out of the reach of any of our counties. It was with this idea in mind that in our county we interested ourselves in the use of tar as a road-