SOIL-CEMENT MIXTURES FOR ROADS

Review of 1937 Symposium

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At the Seventeenth Annual Meeting of the Highway Research Board, November 30–December 3, 1937 Mr. W. H. Mills, Jr., Testing Engineer, South Carolina State Highway Department, presented a digest[1] of a symposium on soil-cement mixtures covering work in Illinois, Iowa, Michigan, Missouri, South Carolina and Wisconsin, and the basic exploratory laboratory work of the Portland Cement Association. The complete reports have been published as part of the Seventeenth Annual Proceedings of the Highway Research Board.[2]

The reports covered a wide range of soil, climatic and construction conditions. They showed that procedures had been developed for testing soil-cement mixtures which placed their analysis on a scientific basis which could be relied upon to give successful field results. The construction experiences reported show that a wide variety of soils can be used in this type of construction under climatic conditions generally prevailing in the United States.

The following review briefly covers the laboratory work which defines soil-cement mixtures and outlines the general construction procedures which the various state reports have shown to be successful.

BASIC CONTROL FACTORS

Basically, laboratory procedures for determining controls for construction are the same for all work requiring a hardened soil-cement road for light traffic. It has been demonstrated repeatedly in the laboratory and field that there are three major factors which control the durability and serviceability of soil-cement roads. These factors are:

1. Incorporation of sufficient cement to produce a hardened product which will have substantial durability.
2. Use of such a quantity of moisture that the soil-cement mixture will pack properly.
3. Compaction of soil-cement mixture, while damp, to proper density.

These control factors were uncovered by the Portland Cement Association.[2,3] They can be determined readily in the laboratory. The moisture and density requirements are shown by the moisture-density test and the cement requirements by the durability tests. These tests have been described in detail previously[2,3] so a brief summary will suffice to emphasize their importance.

A definite relation exists between the moisture content, density and compaction force used to consolidate a disturbed soil. This relation was uncovered by the Materials and Research Department, California Division of Highways in 1929.[4] This is one of the most important and outstanding contributions recently made to soil mechanics and to soil scientists.

[1] W. H. Mills, "Cement-Soil Stabilization," *Proceedings* Highway Research Board, Vol. 17, Part I, p. 513.

[2] "Soil-Cement Mixtures for Roads," *Proceedings*, Highway Research Board, Vol. 17, Part II.

[3] "Basic Principles of Soil-Cement Mixtures," by F. T. Sheets and M. D. Catton, *Engineering News-Record*, June 23, 1938.

[4] "Highway Soil Studies," T. E. Stanton, Jr., Materials and Research Engineer, *California Highways and Public Works*, June, 1938.

It was brought to national attention[5] in 1933 by R. R. Proctor in connection with his work on earth fill dams and the determination of a laboratory and field compaction method which would duplicate results obtained in field construction. The procedure described by Proctor consisted in packing three layers of soil of equal thickness into a cylinder 4 in. in diameter and 4.6 in. high. Each layer is compacted with 25 uniformly distributed blows of a 5.5 lb. rammer, having a 2 in. circular face, dropped a distance of 12 in.

The moisture-density test is made by compacting a soil in this manner with various moisture contents and determining the resulting density or unit dry weight per cubic foot of compacted soil. This test shows that for most soils and this type of compaction there is a moisture content which will give the greatest compacted density and likewise the soil in this condition will have the most stability. It was found that these same relations hold for soil-cement mixtures compacted as soon as the cement and moisture are added. Figure 1 is a typical illustration of results when the moisture contents are plotted as abscissas and the corresponding densities as ordinates. The moisture content required to give the peak of the curve is termed "optimum moisture" and the corresponding density "maximum density."

After laboratory tests define the "optimum moisture" and "maximum density" for the soil-cement mixtures to be studied, specimens are molded using these two control factors. The cement is permitted to hydrate for seven days and the specimens are then subjected to severe durability tests consisting of alternate freezing and thawing or alternate wetting and drying.

[5] "Fundamental Principles of Soil Compaction," by R. R. Proctor, Field Engineer, Bureau of Waterworks and Supply, Los Angeles, Calif., *Engineering News-Record*, August 31, September 7, 21 and 28, 1933.

Two specimens are molded for the "Freeze-Thaw" test and two for the "Wet-Dry" test. One specimen in each test is used to determine volume and moisture changes and one to determine soil loss. The soil loss specimens are vigorously wire brushed on each cycle to remove any material loosened during the durability test.

A cycle of the "Freeze-Thaw" test consists of freezing for 20 hours at −15°F. and thawing for 24 hours with water fed to the specimen to permit capillary absorption of water. The test is continued for 12 cycles. A cycle of the "Wet-Dry"

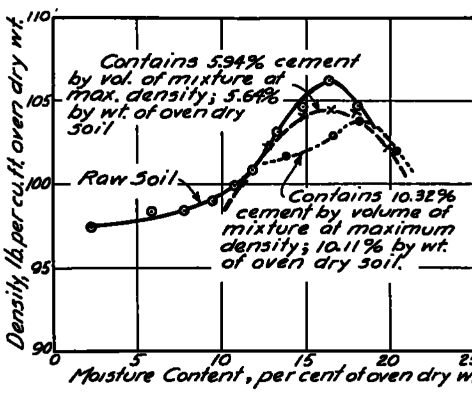

Figure 1. Moisture-Density Relations of Raw Soil and Soil-Cement Mixtures Compacted by Proctor Method. Clay Loam. U. S. B. P. R. Soil Group A-4.

test consists of immersion of the specimen in water for 5 hours and oven drying for 42 hours at 160°F. The test is continued for 12 cycles. The cement content required to give low soil losses, volume and moisture changes in twelve cycles will produce satisfactory hardness and durability in the field.

CONSTRUCTION

Thus, the field control factors required for success are determined in the laboratory before construction starts. The engineer is armed with these three major requirements, cement content, moisture content and density. He knows the soil must be pulverized for the required depth of treatment and cement incorporated uniformly. This information is given by station limits for each soil type occurring on the project. With these control factors as objectives, he is at liberty, within economic limits, to use any equipment and procedures which will accomplish the desired results.

Initial Grade and Line Work

The first concern of the project engineer is the profile and grade of the existing roadway. Before construction starts, correct profile and grade should be established as it has a predominate influence on these items after the road is finished. Grade stakes are then set on the shoulders about six inches above crown at each station. These stakes are used all during construction to control depth of treatment by stretching a string across the road at each station or by using the stakes as hubs for "T" boards. At the same time, lath line stakes are set about 18 in. from the edge of treatment as guides for operators of scarifying and pulverizing equipment.

Equipment

Soil-cement roads can be built efficiently and economically by mixed-in-place procedures. The operation can be said to be a very efficient field cultivation process requiring many tools common to farming. This is due primarily to the need of pulverizing, mulching, the soil. The tools generally used for pulverizing and mixing are subgrade rooters or scarifiers, disc harrows, field cultivators and gang plows. A pressure bituminous distributor can be used to apply water although it is a simple matter to make a pressure water distributor at low cost. Other major equipment items are trucks for hauling cement, sheepsfoot rollers for packing, a motor patrol for shaping and a tandem smooth roller for final finishing operations. The experienced resident engineer and the experienced construction superintendent will critically check each piece of equipment as it arrives on the job.

Scarifying and Pulverizing

The roadway is scarified, as shown by Figure 2, to a depth of not over 5.5 in. and about 6 in. beyond each outside edge. Offset disc harrows then pulverize the soil. (Figure 3.) Usually, the moisture-content of a packed roadway will be about right for easy pulverizing. Occasionally the scarified material will need to be moistened to hasten pulverizing and occasionally a day of air drying will be beneficial. Most soils pulverize readily, and while the soils with the higher clay contents may require special attention, farmers in the neighborhood can tell how to mulch the soil if the contractor lacks experience. About 1500 ft. is pulverized

Figure 2. Scarifying Existing Roadway

Figure 3. Pulverizing Roadway

before processing begins. The pulverized soil is bladed smooth to crown and grade and, during the rainy season covered with paper or canvas to shed rains. Windrowing is also effective provided the water is drained rapidly from the subgrade so it does not soften. Sandy and silty subgrades soften easily and should generally be protected. A soft subgrade prevents proper packing of the surface later.

PROCESSING

All operations of adding and mixing cement and water, compacting and surface finishing must be continuous and these operations collectively are called "processing." It should be borne in mind that cement hydration and hardening takes place in soil-cement roads the same as in concrete. Generally, the moisture present in the soil is so low that it has very little influence on cement hydration but after the water application is started cement hydration can proceed. Therefore, the water application should not occupy much over $2\frac{1}{2}$ hours and should be followed immediately with compaction. Experience and tests have shown that the moist mixing and compaction may extend for as long as 6 hours but longer periods definitely influence the hardness and durability of the resulting product.

Spotting and Spreading Cement

Experience has shown that hand spotting of cement is economical and easy. The resident engineer knows the quantities of cement required per square yard and computes the transverse and longitudinal spacing of cement bags which will give this spread. Usually a rope or wire is marked with red cloth tags at the proper longitudinal intervals and a strawboss spots the bags for proper transverse spacing. The bags are then dumped by hand on the roadway. (Figure 4.) After the bags are dumped they can be spread by hand with rakes or by a spike tooth harrow pulled slowly by a tractor or truck.

While the cement spotting is taking place, a protective cover of about 6 in. of earth is placed on about 30 ft. of the adjoining day's work. The equipment can then move over this work without marring the surface. A plank cover is most effective for about ten feet back from the junction of sections since they can be made as platforms which can be readily removed during final finishing operations and later moved ahead for the next day's work.

Mixing Cement and Soil

As soon as cement spreading is completed, mixing of soil and cement gets under way with the use of field cultivators. These are essentially spring tooth harrows on wheels, the teeth being equipped with 4 in. or 5 in. shovels. (Figure 5). These field cultivators mix the top one-half to two-thirds of loose material very quickly and easily. The remainder of mixing operations are speeded up by turning the roadway over once or twice with a two or three bottom gang plow. (Figure 6). An occasional trip of the disc harrow also is beneficial. The field cultivators complete the mixing of the soil and cement.

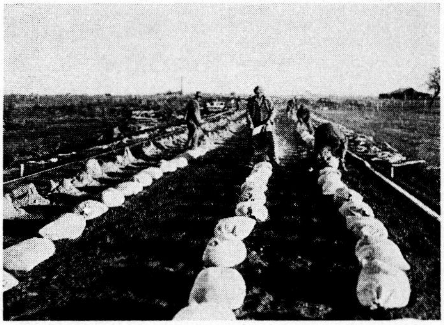

Figure 4. Applying Required Cement

While the dry mix is progressing, the blade grader is used to push the mixture away from the previously placed header.

The soil and cement are moved out on the section where they are mixed. The blade grader operations are timed so the material can be moved back against the header as the mixing operations are completed on the remainder of the section.

Toward the conclusion of the dry mix, the soil engineer takes typical roadway samples to determine the moisture content. He uses this information to com-

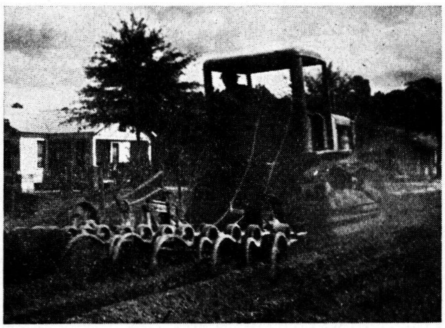

Figure 5. Field Cultivators Mix Soil and Cement

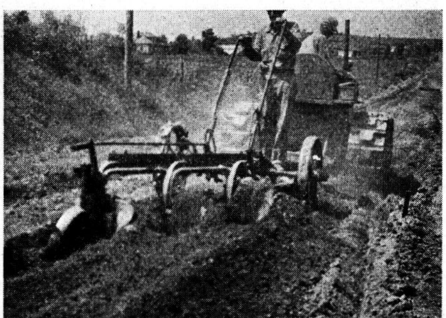

Figure 6. Three Bottom Gang Plow Turns Up Bottom Material

pute the approximate amount of water required to bring the mixture up to the optimum moistures specified. The resident engineer is advised of these quantities so that water spreading can start immediately after the dry mix is completed. When the dry mix is completed, the soil engineer takes final samples of the mixture from which final quantities of required water are determined. Since some time is required for these final tests, they do not become available until after some water has been added but the results will be available before the approximate quantities of water have been reached.

Damp Mix

The moisture needed to bring the soil-cement mixture to the optimum moisture required by the specifications is added with pressure distributors. Bituminous or homemade pressure distributors can be used. (Figure 7.) Homemade distributors should be equipped with a pump having a capacity of 200 to 300 gal. per min. Auxiliary water supply tanks will be needed to bring water to the section

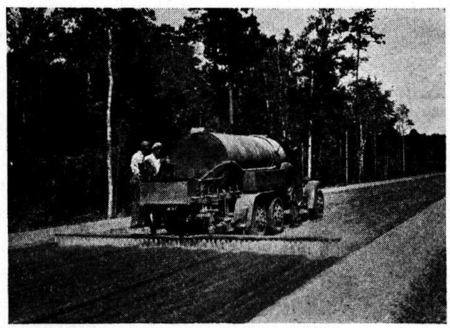

Figure 7. Pressure Distributor Spreads Required Water

under construction. A pressure distributor of this capacity can spread about 6,000 gal. per hour after the water supply is properly adjusted. All required water should be applied in about three hours. This means that one pressure distributor, and necessary auxiliary equipment, will be required for each 15,000 gal. of water required.

Water spread is controlled the easiest by spreading full width of treatment with a uniform quantity of water so the tank is emptied on each trip of the distributor. Each increment of water is mixed in partially by the field cultivators following directly behind the distributor. When about half the required water has been added, the entire section is turned with gang plows, as in the dry mix, and mixing then continued with the diggers. Toward the conclusion of the damp mix, the plow is again placed on the section and assists the field cultivators in attaining final mix.

Toward the conclusion of the damp mix, the blade grader moves the dampened soil and cement out on the section from the header board. The subgrade is exposed for about 10 ft., the header removed and as the final damp mixing is completed, the properly dampened and mixed soil and cement are returned against the previous day's work. This is then loosened for full depth to permit proper packing.

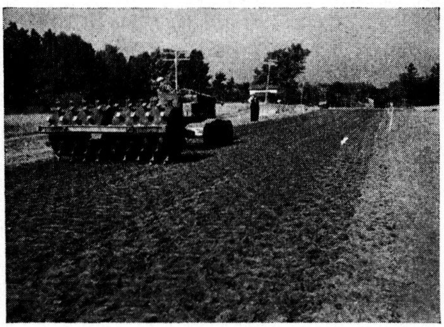

Figure 8. Sheeps Foot Roller Packs from Bottom Up

The soil engineer comes in on the section again as the final increments of water are added, checks moisture content of the mixture and determines when it is at the final required optimum moisture. The final operation in the damp mix is the loosening of the mixture from the bottom with the cultivators to leave the dampened material in a loose condition at the start of compaction with the sheepsfoot roller.

Initial Compaction and Shaping

The material adjacent to the previous day's work is first cross rolled with the sheepsfoot roller to attain proper density where sections join. Rolling then proceeds up and down the section working in from the outside edges. (Figure 8.) When about three inches of mulch remain for packing, the blade grader shapes the section to preliminary line and grade and works with the sheepsfoot roller until only about one inch of mulch remains. The grader then gives the section final grade and crown. (Figure 9.)

A spike tooth harrow or similar tool (Fig. 10) is then brought on the section to remove all compaction planes remaining

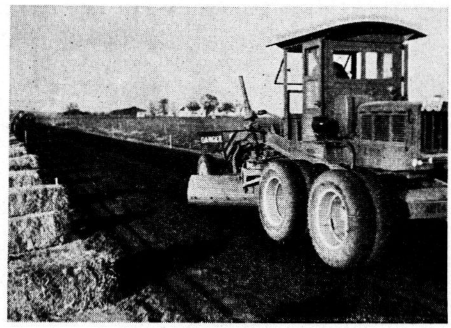

Figure 9. Blade Grader Gives Section Final Crown and Grade

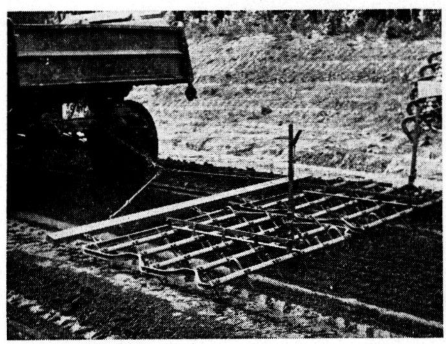

Figure 10. Spike Tooth Harrow Cuts Out Compaction Planes

in the surface from the operation of the sheepsfoot rollers and blade grader. In some cases a few additional trips of the sheepsfoot roller may then be required and this followed again with light surface scratching with the spike tooth harrow. During this shaping operation, the cover on the adjacent section is removed for a distance of about 20 ft. This permits proper joining of the grade lines on the old and new work.

Final Compaction and Shaping

When the final one-inch mulch remains, with the section properly shaped, final compaction is attained with a tandem smooth roller. (Figure 11.) It irons out the entire section, working in from each outside edge. This ironing operation requires some training and experience but a very hard, dense surface can be obtained. Smooth rolling may often be preceded, advantageously, by a partial compaction with pneumatic equipment.

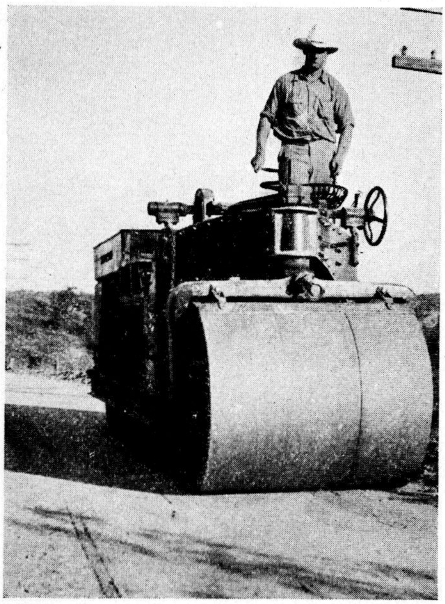

Figure 11. Tandem Smooth Roller Irons and Knits Surface

In friable soils, free from gravel, stones, sticks and trash, it is possible to blade the section very close to crown and grade after the ironing operations. After the section is bladed (skinned) in this manner, it should be again rolled, starting from the outside edges.

Protective Cover

One of the fundamentals involved in the production of a dense, hard, durable soil-cement roadway is the incorporation of a specified quantity of moisture. Considerable sums are spent to accomplish this. Further, this moisture must be retained until the cement has hardened enough to hold the soil-cement mixture in place. Therefore, as soon as the section has been finished, evaporation of moisture from the surface will want to be avoided for about 7 days. This is accomplished by covering the section with about two inches of shoulder material or four inches of hay or straw. (Figure 12.) This cover is kept moist for seven days when it may be removed. When it is necessary to moisten the cover, only enough water to wet it should be used and free water on top of the finished roadway should be avoided.

Figure 12. Protective Cover Permits Soil-Cement to Harden at Compacted Volume

Opening to Traffic

Since high compaction forces are used to build soil-cement roads, the contractor can haul over his completed work at once provided the protective cover is not disturbed. At the end of seven days, the protective cover can be removed and the surface opened to traffic. Since final finishing is not foolproof, traffic should use the road for a few weeks to develop any surface weaknesses produced by faulty surface compaction. Preferably, a few rains should occur before thought is given to smoothing up the surface.

After the roadway has been used by traffic for a month or six weeks, most surface weaknesses, which may produce a rough riding surface, will have been developed The roadway should then be critically surveyed from a riding surface standpoint Perhaps slight changes in grade are evident at junctions of the various sections or some laminations have developed In case a smooth, easy riding surface was not obtained, such a surface can be obtained by placing a 25-lb bituminous seal coat on the road First, all loose material and dust should be swept and blown from the surface This is followed with a bituminous prime coat varying from 0 1 to 0 2 gal per sq yd, depending on the texture of the hardened soil-cement The 25-lb bituminous seal or riding cover is then built Care should be taken to see that the seal is bonded to the hard soil-cement and not to a loose layer of material on top of the soil-cement If the seal is placed on loose material it will soon peel off

COSTS

Soil-cement roads are a low cost, light traffic road They will carry traffic volumes up to 400 or 500 vehicles per day, including the usual proportion of trucks Costs under average conditions range from 35 cents to 45 cents per square yard Most favorable conditions bring costs down to about 25 cents per square yard They should have a compacted depth of six inches