be absolutely sure of satisfactory results, it is recommended that all tests outlined in this report be performed on each soil as it is encountered for study

All of the laboratory results obtained have been most encouraging It has been possible to evolve basic principles governing soil-cement mixtures Their application permits the production of consistent, predictable results which have been applied on many field projects with success Specimens prepared and tested in the laboratory have shown substantial durability when subjected to severe tests

As a result of this work a large field for research on a new building material is opening up It will require the resources of all interests to define its characteristics and bring our knowledge of it up to a par with our knowledge of other building materials

## SOUTH CAROLINA INVESTIGATION OF SOIL-CEMENT MIXTURES

By W H Mills, Jr

*Testing Engineer, South Carolina State Highway Department*

The early experiments of the South Carolina Highway Department were described at the meeting of the Highway Research Board in November 1936 [1] These original installations are still in excellent condition and although one has been removed on account of new construction, the others are all carrying the traffic satisfactorily without indication of breakdown or disintegration.

Construction of this type of road has been continued and in 1937 approximately 18 4 miles of cement stabilized base were completed

A one half mile project at Clemson, S C, was planned to give information on the minimum quantity of cement which would stabilize soil The soil in this experiment was a red clay typical of that found in large areas of the state It contained 40 per cent clay, no coarse material and had a plasticity index of 25 As a result of laboratory tests, which included alternate wetting-drying and freezing-thawing of specimens of soil molded at optimum moisture content with various percentages of cement, it was concluded that 7 per cent of cement by weight should be used This quantity was used on one section 6 per cent on one and 5 per cent on the third section Usual methods of mixed-in-place procedure were followed. The 5 per cent cement section did not harden so rapidly as the others, but there have been no failures in this project during the six months it has been subjected to very light traffic In planning the project the idea was to reduce the quantity of cement for one section below the minimum required for stabilization in order to have field information which could be correlated with laboratory durability tests to use as a criterion in setting the cement content for future work in similar soils Failures are expected to develop in the section containing 5 per cent cement

During the winter of 1936 and 1937 10 5 miles of Route 63, Hampton County were constructed by contract The specifications required a compacted base 22 ft wide and 6 in thick This base was covered with a mixed-in-place bituminous wearing surface $\frac{1}{2}$ in thick, 20 ft wide The bid price for the base was $0 495 per square yard and for the surfacing $0 18 per square yard. Work was begun on December 5, 1936 but the

[1] *Proceedings*, Highway Research Board, Vol 16, p 322

last of the base was not placed until May 6, 1937 due to many delays on account of bad weather

The soil in this project varied from almost pure fine sand to soil containing as much as 25 per cent clay Six per cent cement by weight was used with sandy soil and 8 per cent with soil containing considerable clay No curing was provided but in most instances weather conditions were favorable to retarding evaporation of moisture

The contractor used a travelling mixing plant The soil was scarified, pulverized, and windrowed to the center of the road, picked up from the windrow by the travelling mixing plant and emptied into a bin from which it flowed by gravity through a measuring gate into the pug mill Cement was applied from a bin on the platform of the mixer A continuous feed belt from the cement bin was interlocked with the feed belt from the soil bin so that cement and soil flowed into the mixer at a constant rate The moisture content of the soil in the windrow was within the requirements for compaction on many sections but when necessary to increase the moisture to the optimum for compaction, water was applied to the mixture after the cement had entered the pug mill The completed mixture was discharged from the end of the pug mill, shoveled into place by hand, and packed with a sheepsfoot roller operated back and forth parallel to the centerline of the road When the feet of the roller had compacted the mix to within about $1\frac{1}{2}$ in of the top, the surface was bladed to the correct grade and cross section, compaction planes were removed by light scarifying, and the mulch thus obtained was compacted with loaded trucks or a pneumatic roller The final surface was obtained with a multiple blade drag, but the riding qualities of the road were not entirely satisfactory due to the short sections finished as a unit

During the construction of this project the necessity for a stable subgrade was definitely shown when an attempt was made to construct a short section over subgrade in which the moisture content was considerably above the optimum Cracking appeared during compaction and the mix did not harden satisfactorily The base at this location was reconstructed

A four mile section of this project was primed with tar in March 1937 and soon afterwards "blow-ups" occurred in 23 places These "blow-ups" were characterized in a few cases by cracking and shattering of the base for the full depth and approximately two linear feet, but in most places only the top 2 in were visibly affected by shattering although there was one crack completely through the base Shattered portions of the base were removed and easily patched with soil-cement mixture There has been no recurrence of this trouble nor has it appeared on any other project

A failure due to improper construction occurred in a section of road one half mile long after the base had been surfaced and under traffic for a short time The surfacing shoved and it was discovered that the top of the cement stabilized base was soft for a depth of 1 in No serious trouble has developed from this failure and it has been necessary to patch only a few square yards

A contract was awarded at 48 cents per square yard for the cement stabilized base and 18 cents per square yard for the bituminous surfacing for 7 8 miles of Route 92 near Union, S C Specifications for this work are similar to those on the Hampton project The soil consists mostly of disintegrated granite which gives very excellent results in the laboratory durability tests and only 5 per cent by weight of cement was used with it However, the cement content was increased to 8 per cent when red clay soil was encountered The contractor

used equipment and methods similar to those on the Hampton project but obtained a much better riding surface Progress has been slow due to adverse weather conditions but approximately 4 8 miles have been completed In one week a total of 11,500 ft was built

The highway department constructed with its own forces several miles of cement stabilized roads These projects consisted of 1 8 miles on U S Route 178 between Saluda and Greenwood, approximately 0 5 mile in the Town of Estill, 0 5 mile at Clemson and 0 25 mile near Greenville Regular mixed-in-place procedure was followed Compacted depths varied from 4 to 6 in depending on traffic, and cement contents were varied to suit the soil encountered

The project between Saluda and Greenwood was the repair of a bituminous surfaced road which has always given trouble due to bad subgrade and inferior top soil base The old surface treatment was broken by scarifying and included in the mix Cement was applied at the rate of 7 per cent by weight and the theoretical compacted thickness was 6 in The cement stabilized base was covered with a ½ in bituminous mat As no detour was available, it was necessary to construct the road in half width sections

This project has not been in use long enough to judge the adequacy of the stabilization, but it is believed that it will furnish a severe test as the subgrade is very plastic clay, unstable in wet weather, and traffic over it is very heavy with a large proportion of trucks A portion of this project was stabilized with another material in order to compare the economy and durability of the two methods as there is a considerable mileage of bituminous surfaced road which could be repaired if either method proves economical and durable

Contracts have been let for 13 more miles of cement stabilized roads and bids have been requested on this type as an alternate to others on 15 3 miles

The preliminary laboratory durability tests and the moisture density control test used by this department vary in some particulars from the procedure adopted by the Portland Cement Association The optimum moisture content for compaction of laboratory specimens and field mixtures is determined by the Proctor method with the exception that the tamper is applied to the soil with more force than is obtained with the 12 in free drop This additional force was adopted because it appeared that in some instances the 12 in drop gave an optimum moisture content so high that the particles were lubricated and the mix cracked during final rolling At present, a definite standard has not been adopted because the compacting force is varied for different soils depending on the clay content and other characteristics Tests will be correlated with field results and the laboratory method adjusted so that laboratory densities will check with field densities

Laboratory durability tests consisting of alternate wetting-drying and freezing-thawing are conducted on cycles similar to those used by the Portland Cement Association but due to the large construction program it has been necessary to reduce the quantity of laboratory work and the size of the samples The procedure used is to make one Proctor specimen at each cement content, cure it in the moist room for 7 days and then saw it into four approximately equal parts parallel to the long axis Wetting-drying tests are performed on one of these specimens and freezing-thawing on the other One is used for moisture determination for the initial dry weight of the freezing-thawing specimen and the other is retained as a reserve

In determining losses all loose material is removed from the specimen after each

cycle by brushing with a rather soft bristle brush Brushing with a stiff bristle wire brush apparently causes greater losses than actually occur from the disintegrating forces of the durability tests and specimens made with sandy soil and low cement contents can be entirely destroyed by vigorous brushing

Much remains to be learned about designing and constructing this type of road The work to date has shown that adequate preliminary field soil surveys and laboratory tests as well as thorough field control are essential to the successful construction of cement stabilized roads

## AN EXPERIMENTAL SOIL-CEMENT ROAD IN ILLINOIS

By V L Glover

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During September, 1936, a soil-cement road, the first to be constructed in Illinois, was built near Rockford, Winnebago County The preliminary tests were made jointly by the Division of Highways, Springfield, and the Portland Cement Association, Chicago Construction work was done by the Winnebago County Highway Department The section was 6,000 ft long and the soil-cement surface was 18 ft wide and 6 in thick The section was entirely experimental and was constructed at approximately the same time that several other experimental sections were under way in the middle west

Preliminary soil samples were taken before the grading work was completed It was believed that they would be sufficiently representative of the soils involved in the project that the field control information could be satisfactorily based upon the test data for these samples and that the construction work could be started as soon as the tests were completed

### LABORATORY SOIL TESTS

Except for a few minor changes, the laboratory tests were made in accordance with the recommended procedure outlined in the Portland Cement Association Progress Report on Laboratory Investigation of Soil-Cement Mixtures, dated May 1, 1936

*Physical Test Constants and Grain Size* The test data in Table 1 indicated that with the exception of a short section of clay loam on the north end of the project, the soil would classify as a sandy loam, and as an A-2 subgrade material grading to either the A-3 or A-4 groups

These data also showed that the soils represented by Samples 36-2282, 36-2283, and 36-2285 were very similar but that Sample 36-2285 had the highest liquid limit and plasticity index Therefore, it was recommended that the laboratory control tests be confined to this last named sample because previous tests indicated that the cement required increased as the liquid limits and plasticity indices increased It was decided, however, to conduct the complete control tests on all of the samples taken

*Moisture-Density Tests* The optimum moisture content-maximum density data determined for each soil sample and for each soil sample combined with 4, 6, and 10 per cent cement, by weight, are shown in Table 2 The selection of these percentages of cement was based upon a comparison of the data shown in Table 1 with similar data for soils previously tested and for which complete soil-cement data had been obtained

The curves plotted from the data secured by these tests are shown in Figures 1 to 5, inclusive An inspection of these curves appears to establish a lack