CEMENT-SOIL STABILIZATION

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SUMMARY * OF A SYMPOSIUM PRESENTED AT THE SEVENTEENTH ANNUAL MEETING, HIGHWAY RESEARCH BOARD

Studies of stabilization of soil with cement have advanced in 1937 with the construction of test sections by a number of highway departments and with the continuation of research by the Portland Cement Association The information which is presented here was obtained from reports submitted by.

- M D Catton, Development Department, Portland Cement Association
- V L Glover, Engineer of Materials, Illinois Department of Public Works and Buildings
- T R Perry, Bituminous Engineer, Iowa State Highway Commission
- M D VanWagoner, State Highway Commissioner, and Mr W S Housel, Research Consultant, Michigan State Highway Department
- F V Reagel, Engineer of Materials, Missouri State Highway Comm
- Guy H Larson, Assistant Materials Engineer, State Highway Commission of Wisconsin
- W H Mills, Testing Engineer, South Carolina State Highway Department

With minor exceptions methods developed by the Portland Cement Association were followed by the several States in the preliminary laboratory investigations for determining the quantity of cement for stabilizing the soil The thicknesses of the treatments ranged from 4 to 6 in although most of the work has been 6 in thick The mixed-in-place method using disc harrows, quack grass diggers or road machines was used in all experiments, but a traveling mixing plant was used in Missouri and South Carolina on some work Compaction of the mixture at optimum moisture content was secured with sheepsfoot rollers The final finish was obtained by blading the sur-

* The complete papers, which will be published separately, may be secured from the Highway Research Board face and compacting loose material with smooth wheel or pneumatic tired rollers Density determinations of the finished base compared very favorably with laboratory densities obtained by the Proctor method.

Curing of some type was generally used, but in South Carolina and on a portion of the work in Illinois there was no attempt to retain or supply moisture to the finished base Wet earth, wet straw, special curing paper or bituminous materials have been used. In most sections, however, shrinkage cracking occurred in spite of the curing A bituminous wearing surface was applied to most of the sections soon after construction

The initial 500-ft experiment constructed in South Carolina in December 1933 is still in excellent condition and the four other test sections which were constructed in July 1934 have proved entirely satisfactory One of these sections was removed in 1937 on account of new construction work but the others are still under traffic In the Fall of 1935, the Proctor principle of soil compaction was used for the first time on the 15-mile experiment near Johnsonville

PORTLAND CEMENT ASSOCIATION

In 1935 the Development Department of the Portland Cement Association started a laboratory research project to develop basic information on soil-cement mixtures Samples of soil types ranging in classification from A-2 to A-8 were obtained from 16 States

Moisture density relations of raw soil and soil-cement mixtures were first determined, then the durability and stabil-

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ity of mixtures of soil and various quantities of cement was obtained on specimens compacted at optimum moisture content and stored in the laboratory for 7 days prior, to the start of the test It has since been found desirable to simulate field conditions more nearly by storing laboratory specimens in air of high humidity

The durability tests were alternate wetting-drying and alternate freezingthawing The wetting-drying cycle consisted of drying the specimens in an oven at 160° F for 42 hours and immersing them in water for 5 hours The freezingthawing specimens after complete capillary absorption of moisture were placed in the refrigerator at a temperature of -15° F for 20 hours They were then removed and thawed in the moist room on saturated felt pads for 24 hours Losses in weight and changes in volume were determined Based on results obtained, the soils in this series were grouped into three classifications depending on their actions with cement Work on a few unusually bad subsoils of limited occurrence were not included in these groups

Durability specimens made with soils of Group 1 and with 4 to 6 per cent of cement by dry weight showed negligible losses in 12 cycles of wetting-drying and freezing-thawing Volume and moisture changes in these specimens were also quite small Soils in Group 2 were decidedly hardened with 6 to 8 per cent of cement, losses in the durability test were small and moisture and volume changes were reduced to a minimum The soils in Group 3 generally contained considerable clay but 10 per cent of cement hardened them appreciably and the durability tests showed reasonably low losses and volume change

The relation of the Liquid Limit, Plastic Limit and Clay Content were compared with durability results and the following is quoted from Mr Catton's report

"At the present time, no effort has been made to draw sharp lines between soil characteristics and treatment requirements However, the following general conclusions are justified regarding characteristics of soils falling in Treatment Group 1 or 2

- "1 The liquid limit must be below 50
- "2 The plasticity index must be below 25
- "3 The clay content must be below 35
- "4 The percentage of solids at maximum density must be 60 or greater
- "5 The soil must possess a "regular" moisture density curve

"If a soil meets the above specifications, it is evident that it can be effectively hardened by the addition of a reasonable amount of cement The cement required to harden the soil effectively will be approximately the same as that producing effective hardening in a similar soil in the same treatment group

"All the laboratory results obtained to date 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 Specimens prepared and tested in the laboratory have shown substantial durability when subjected to severe durability tests"

ILLINOIS

The Illinois section near Rockford in Winnebago County was 6000 ft long 18 ft wide and 6 in thick Ten per cent of cement by volume was used Durability tests on samples of soil with this quantity of cement showed very low losses

The project was divided into eight sections varying from 500 to 900 ft in length The average time required to spread and mix the cement, apply the water, and compact and finish the surface was 2 hr for 100 ft The scarifying and pulverizing operations were carried on when there was no actual processing in progress, although these operations together with the curing, turn-arounds, and incidentals increased the total time involved Mixing of dry cement was accomplished with disc harrows supplemented by blading Water was added in two lifts due to the depth of the treatment Sheepsfoot rollers compacted the mix at optimum moisture content

The last 700-ft section was given a surface application after compaction of pea gravel applied at the rate of 25 lb per sq yd The surface was then wetted slightly and compacted with trucks, after which it was rolled with an 8-ton roller Considerable loose gravel remained on the surface after this rolling

The following is quoted from Mr Glover's report

"Within two days after the first two increments were completed, hair checking appeared on the surface and it was supposed that these were caused by the rapid and excessive drying out which resulted from lack of curing, therefore, all other increments were cured for seven days In spite of this, transverse cracks and some hair checking appeared on these increments within three days after completion

"When examined in December 1936, approximately three months after completion, the interval between transverse cracks was about 15 ft on all increments except that covered with gravel, on that increment, the interval was about 30 ft At that time, longitudinal cracking was apparent in only one increment, where a continuous crack, at approximately the centerline, extended through the entire length of the increment, a distance of about 800 ft

"When examined in April 1937, scaling and pitting had developed, but aside from being somewhat rough, the surface was in fair condition. In order to protect the surface and to provide a better riding surface, all but 400 ft of the project was given a bituminous surface treatment in August 1937"

The total cost exclusive of cement was \$0 281 per square yard

Conclusions as given by Mr Glover are

"(a) Preliminary samples on which the job control data are to be based should never be taken until the grading operations have been completed

"(b) Extreme care should be exercised in taking the samples on which the job control data are to be based The locations at which the samples' are taken should be carefully selected and a sufficient number of samples secured to represent satisfactorily the soil types and variations within these types"

IOWA

During the summer of 1937 a project totaling 16 miles in length was constructed on Primary Road No 40 in Wayne County by the Iowa State Highway Commission The section chosen for the experiment was thought to be typical of a great many miles of gravel surfaced roads of that state, and the material in the road consisted of a mixture of soil and gravel which contained approximately 15 per cent clay

The base was 26 ft wide and 4 in thick with 10 per cent of cement by weight The cement content was based on determinations of density, strength, wetting and drying, bearing, and moisture losses

Cement was spread in two layers over the pulverized soil from a Buckeye spreader attached to the rear of a truck but other construction operations were similar to those used on other projects of this type

It was noted that care must be exercised in rolling the final surface with a smooth steel tired roller as the soil picks up if the surface is too wet

For curing, the completed base was primed with tar on the morning following completion During construction the temperatures ranged from 90° F to 102° F and an average of 1100 linear feet of completed base was constructed per day of 14 hours A bituminous wearing mat type was applied to the completed base

The cost of the completed base including curing was \$0 393 per sq yd

Mr Frank L Davis, who was in charge of the project believes that quack grass diggers are excellent for mixing, that with proper equipment, cement in bulk instead of bags would be profitable, that water should be distributed with power driven equipment to obtain uniform application, that two sheepsfoot rollers should be used so as to compact the mix at the optimum moisture content before the moisture evaporates, that only track type tractors should be used to pull sheepsfoot rollers as pneumatic tired tractors pack the soil unevenly, that compaction planes occurring during final compaction can be removed with a fine spike tooth harrow, and that the base should be sprinkled with water about five hours before application of bituminous curing material

MICHIGAN

This report deals particularly with the laboratory investigation and field control of the experimental project near Cheboygan

Based on the preliminary survey, the soils were classified into ten groups for preliminary laboratory work Subsequent tests showed that four classifications would have been sufficient The tests of Michigan Highway Department and the Portland Cement Association were in substantial agreement although the methods used varied in some respects By comparing the grading of the samples with the ideal grading for maximum density, it was found that variations in density could be predicted from the grading curves, poorly graded material giving lower densities From these tests the conclusion is drawn that variation in texture and grading is so accurately reflected in the compacted density that the routine density tests may be the most practical basis of designing the stabilized mixture

The mixtures were proportioned by absolute volume, the cement content being expressed as a percentage of the absolute volume of soil plus cement The void characteristics of the soil-cement mixtures were determined in order to obtain some practical criterion of design which would accurately reflect the properties of the stabilized mixture, particularly with respect to durability Durability tests followed the general procedure outlined by the Portland Cement Association The author states that the durability tests indicate that a cement-voids ratio of 15 per cent may produce a mixture as durable as present requirements indicate is essential

Samples compacted in the field agreed much better with the density of the road than the preliminary samples The addition of clay to a very sandy soil in which the organic matter was high improved the durability considerably but whether this improvement was due to additional fines which were needed to increase density or to correcting the acidity was not clearly determined

Final rolling by an ordinary steam roller caused displacement of the top inch which resulted in flaking or breaking away of the top surface

The following statements are quoted from Mr Housel's paper

"Since completion of the project the road has been subjected to one year of weathering with practically no traffic Several inspections have been made and observations will be continued Some sections are in quite satisfactory condition while others show signs of excessive scaling and disintegration "

Conclusions The experience indicates some rather definite relations based on void characteristics of the soil which may be applied to the design of soil-cement mixtures The cement-voids ratio appears to be a controlling factor in producing a durable stabilized mixture Studies must be made of the physical chemistry of soils to determine the effect of chemical composition including such factors as hydrogen ion concentration

While a thorough investigation of soils should be made preliminary to construction, it appears to the writer that the durability tests can scarcely be considered feasible on regular construction projects and should be replaced by much shorter routine tests Study of moisturedensity relations requires much less time ~ . . . -

and might be supplemented by a compression test or something similar as routine procedure In addition, it appears that the difficulty of representative sampling necessitates control of compaction by field control tests conducted in the field in conjunction with each day's work

MISSOURI

Three experimental projects have been constructed by the Missouri Highway Department

The first, 15 miles long, was constructed in the Fall of 1936 in Moniteau County The soil consisted of A-4 loam, 'A-6 clay and A-7 clay loam The Portland Cement Association recommended 12 per cent cement by compacted volume The road was 22 ft wide and 6 in thick compacted

The pulverized soil was protected from rain with Sisalkraft paper Cement was applied from bags spotted along the road at regular intervals Straw was spread over the completed surface as a protection from freezing and to reduce the moisture loss

Rain delayed construction considerably and the temperature dropped below freezing the night after completion of 12 of the 14 sections

This project was allowed to stand without surface treatment until the middle of the Summer of 1937 During this time no base weakness developed, however considerable surface scaling occurred approaching pot-holes in some spots particularly at "turn-arounds" These holes were fairly successfully hand-patched with soil-cement mixtures A light surface treatment was not effective in correcting the surface defects that developed and a later bituminous drag treatment was necessary to give the section good riding quality

Two miles of cement-soil stabilization in Franklin County were included in an extensive study of soil stabilization in

1937 The subgrade consisted almost entirely of the Union Silt Loam of the A-4 \cdot group One-half of the project was constructed by the road mix method and a travelling mixing plant was used for the other Cement was varied from 6 to 8 per cent by compacted volume

Approximately one quarter mile sections could be processed each day with the road mix method Sisalkraft paper was used for curing a section approximately 150 ft long, and the remainder was plimed with tar on the day following construction

For the section mixed with the travelling mixing plant the material was first scarified and pulverized The soil was windrowed to the center of the road and protected against inclement weather with Sisalkraft paper Cement was emptied on top of the windrowed material Sufficient water was added in the pug mill to raise the moisture content slightly above The mixture was disthe optimum charged from the pug mill directly into the spreading machine which distributed the materials over the undisturbed subgrade Immediately behind the finishing machine the mixed material was sheepsfooted in short stretches Final shaping was done with a motor grader and final compaction was secured with a 7-ton roller

Straw was used for curing although Curcrete was used for experimental purposes Due to hot weather and heavy local traffic, the straw was not effective Where Curcrete was used there was slightly less early checking and cracking but after several weeks there was no apparent difference between the sections

It was found necessary to place a drag treatment on this section because of bad raveling which took place before the seal coat work began The riding surface was wavy due to the short sections finished

Another project 5 miles long in St Clair County was constructed by contract between September 18 and October 15, 1937 The longest section processed in one day was 1600 ft and the averaged length was 1313 ft The soils varied from A-2 with 14 per cent clay to A-6 with 28 per cent clay A considerable portion of the road consisted of the remains of a failed oil mat surface which could not be entirely removed and portions of the bituminous treatment were included in the mix A 14-in gang plow proved to be very satisfactory on this project for loosening the road bed and for mixing

Exclusive of the cost of cement which was \$ 025 per square yard for each percent of cement used, the cost of these sections were as follows

	Per square yard
Route 5 Monitcau County	\$ 34
Route 100, Franklin	
Road Mix	15
Machine Mix	.27
Route 13, St Clair County	.20

The following conclusions are quoted from Mr Reagel's report

"The costs as given are reasonable and in the range of what one can expect to pay for a reliable base in the low cost program

"Some surface treatment to provide a wearing course is required before putting the road under traffic

"The results obtained do not appear to justify the extra cost of the machine mixing as carried on here

"In the processing it developed that proper care and provision could eliminate the objectionable conditions that develop on "turnarounds" Another development in processing indicates that the use of gang plows in turning over the material during the discing and mixing operations is more effective in preparation of the material and in uniform mixing than the "Orchard Cultivators"

"With good organization it appears that a complete crew of men and equipment will complete, as an average, one quarter mile per working day"

WISCONSIN

Half of the Wisconsin Project consisting of 3.3 miles in Adams County was built in the Fall of 1936 and half in the early Summer of 1937 The soil on this project is very sandy and uniform in size Durability and strength tests showed that 20 per cent cement was not enough to stabilize this soil, due to a deficiency in fine material and to the presence of an excessive amount of organic matter. The addition of clay showed marked advantages and it was decided to add 20 per cent of clay and 10 per cent of cement by dry weight to the section constructed in 1936 and 8 per cent cement to that constructed in 1937

The clay was first placed on the top of the sand, then pulverized and partially mixed with the sand Cement was spread on the surface Mixing was done with quack grass diggers and the mix was compacted at optimum moisture content by a sheepsfoot roller The correct moisture content in this very friable soil was very important With a moisture content of 93 per cent the soil was dry and crumbly, with 10 to 11 5 per cent compaction was good, but 123 per cent moisture resulted in sponginess and a tendency of the soil to peel and stick to the smooth roller

A short section of road processed with the same cement but with no clay could not be compacted with the sheepsfoot roller, and it was necessary to resort to a cleatless crawler tractor and lighter equipment

In finishing it was found better to shave high spots and waste the material than to try to fill low places

For curing the finished surface was covered with damp sand one inch deep which was left in place for 7 to 10 days The average section processed per day was 513 ft in 1936 and 728 ft in 1937

The following is a quotation from Mr Larson's report

"There was some shrinkage after final compaction of the road, as evidenced by the formation of shrinkage cracks noticed at intervals of approximately 25 ft upon the removal of the sand covering Also, there was some scaling and spalling of the surface attributed to improper finishing and attempting to patch or fill low spots The clay could not be completely pulverized with the equipment available, and small clay balls were apparent in the surface of the road It was, therefore, deemed advisable in this case to protect the surface from abrasion with a light bituminous armor coat The section processed in the fall of 1936 came through the winter in good shape It is rather early to make any comment as to ultimate service behavior of either section "

SOUTH CAROLINA

Since the experiments described in Vol 16, Proceedings of the Highway Research Board, the South Carolina Highway Department has built 184 miles of cement stabilized base Approximately 153 miles were constructed by contract and the remaining 31 miles by the department's forces All of this work has been surfaced with a bituminous wearing course one-half to three quarter inches thick

One project approximately 0.5 miles long was designed to give information on the minimum quantity of cement which would satisfactorily stabilize the red clay typical of soil found in a large area of the State According to usual laboratory tests 9.5 per cent cement by compacted volume was required for stabilization This quantity was reduced to 7.5 per cent for one section and 6.5 per cent for another There have been no failures during the six months the project has been exposed to traffic

In the winter of 1936 a 10-mile project was constructed by contract A travelling mixing plant was used and compaction and finishing were performed as usual The soils varied from almost pure fine sand to clay loam containing 25 per cent clay Eight per cent of cement was used with the sandy soil and 10 per cent with the heavier clay soil The bid prices were \$0 495 per sq yd for base and \$0 18 for the surfacing

A four mile section on this project was

primed with tar in March 1937 and soon afterward "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 for approximately 2 lineal ft, but in most places only the top 2 in were visibly affected 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 the road 0 5 miles 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 to a depth of about 1 in No serious trouble has developed from this failure and it has been necessary to patch only a few square yards

The department recently repaired a 18 mile section of bituminous surfaced road in which the top-soil base material was bad The bituminous surfacing was broken by scarifying and included in the soil-cement mixture This project is being observed with great interest as there is a considerable mileage of bituminous surfaced roads which could be repaired if this method proves satisfactory

CONCLUSIONS

Based on the information presented in these reports, it appears that cement-soil mixtures give promise of real merit as a road construction material Studies should be continued both in the laboratory and in the field to improve and simplify the laboratory and field methods now used

Adequate preliminary laboratory investigation prior to construction and positive and accurate control during construction are essential

DISCUSSION ON CEMENT-SOIL STABILIZATION

MR A A LEVISON, Blaw-Knox Company. Would equipment that would efficiently and rapidly pulverize the natural soil which is to be treated with the cement stabilization be useful in this type of construction?

MR MILLS There is a great opportunity for improvement in the equipment all the way through from pulverization to compaction During most of the experiment we used equipment that we could get easily and we were not satisfied with any of it

MR LEVISON. That is a very interesting response but it does not quite agree with the reaction from other sources which is to the effect that this type of construction has as one of its chief advantages economy, and the thought has been presented that to load work of that type up with expensive machinery would not be economical unless work was done in exceedingly long stretches, say contracts for 40 or 50 miles

MR MILLS We believe that we must keep the construction cost as low as possible, and expensive equipment might increase the cost too much However I believe it is true that there is an opportunity for other equipment that can compete satisfactorily with the equipment that we now have

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