Expansive Cement Stabilization of Bases

RICHARD D. BARKSDALE, Georgia Institute of Technology, and
ROBERT R. VERGNOLLE, U.S. Air Force

A soil-cement base is sometimes used in an attempt to improve the load spreading ability of the base and therefore reduce the stress level on the subgrade. However, one of the problems associated with the use of soil-cement stabilized bases is that in some instances hydration of the cement paste results in the formation of transverse and longitudinal shrinkage cracks in the base. If these shrinkage cracks in the base become sufficiently wide, reflection cracking will appear on the surfacing. In addition, a base course that has cracked does not have the load spreading ability of an intact base since the cracked blocks of the base act to some degree independently of each other.

The use of expansive cements instead of regular portland cement is a new approach to the problem of controlling shrinkage cracks in soil-cement stabilized bases. The purpose of this paper is to present some of the results of a laboratory study performed to determine if any benefits from the standpoint of cracking result from using an expansive cement as compared to using Type I portland cement. The soil investigated was a clayey, micaceous silty sand typical of many of the residual soils found in the upper soil horizon of the Piedmont area of Georgia.

•A BASE course should be constructed to have sufficient rigidity or depth to spread the load out in order to reduce to an acceptable level the magnitude of rutting in the subgrade and eliminate the possibility of a bearing capacity failure. The base should also be compacted to a sufficient density so that it will not undergo serious permanent deformation. As wheel loads move past a point on the pavement surface, the bituminous surfacing is repeatedly flexed back and forth so that points in the top and bottom of the surface layer are alternately subjected to tensile and compressive radial strains. If the strain level is sufficiently high the pavement surfacing will crack due to fatigue, sometimes forming a chicken-wire pattern of cracks on the surface after a certain number of wheel repetitions. Recent research (1) indicates that in some instances increasing the thickness of the base course while keeping the stiffness constant reduces the vertical stress on the subgrade sufficiently to reduce the amount of rutting. Increasing the thickness, however, may have practically no effect on the tensile strain in the surfacing and therefore does not reduce the possibility of a surface failure. In at least some instances, increasing the stiffness of the base by means of effective stabilization while keeping the thickness constant reduces the chances for a fatigue-type failure by reducing the tensile strain in the surfacing. The stress on the subgrade is also apparently reduced.

Soil-cement base stabilization is one method that can be used to increase the stiffness of the base and hence reduce both the possibility of rutting in the subgrade and a fatigue-type failure of the surface course. One of the problems associated with the

Paper sponsored by Committee on Soil-Portland Cement Stabilization and presented at the 47th Annual Meeting.

use of soil-cement stabilized bases is that when used with some soils hydration of the cement paste results in the formation of transverse and longitudinal shrinkage cracks in the base. If these shrinkage cracks become sufficiently wide, reflection cracking will appear on the surfacing. In addition, a base course that has cracked does not have the load-spreading ability of an intact base since the cracked blocks of the base act to some degree independently of each other. The most important factors affecting the amount of shrinkage cracking in portland cement-stabilized bases appear to be (a) physical-chemical soil characteristics, (b) amount of cement used in stabilization, (c) compaction moisture content, (d) degree of compaction, and (e) method and time of curing.

The use of expansive cements instead of regular portland cement is a new approach to the problem of controlling shrinkage cracks in soil-cement stabilized bases. The purpose of this paper is to present some of the results of a laboratory study performed to determine if any benefits from the standpoint of cracking result from using an expansive cement as compared to Type I portland cement. The soil investigated is a residual, micaceous, clayey silty sand found in the upper soil horizon of the Piedmont area of Georgia.

EXPANSIVE CEMENTS

Some practical applications of shrinkage-compensated and self-stressing expansive cements have been investigated during the last twenty years in France, the USSR, and the United States (2, 3, 4). Expansive cements and expansive cement concretes have been used on an experimental basis for pressure pipes, one- and two-way slabs, highway pavement test sections, grouts, and as structural members in buildings. However, the use of expansive cements as an engineering material is still in the developmental stage.

An expansive cement may be produced by adding a small percent of free lime, magnesium oxide, or calcium sulfate to portland cement (3). If certain forms of these compounds are used (or excessive amounts) expansion of the cement may not occur until after the paste has hardened, resulting in serious cracking and disintegration of the concrete. To help control the reaction, gypsum is often used as a stabilizing agent in the mixture. The most commonly used expansive compound is calcium sulfoaluminate ($C_4A_3SO_3$). When this compound comes in contact with water, hydration occurs, resulting in an increase in absolute volume of the hydrate. If enough of the expansive compound is used a net expansion of the entire mass results.

Expansive cements having desirable properties increase in volume during the initial stages of curing and then shrink as the hardening of the paste continues. The amount of expansion during curing can be controlled by varying the chemical composition of the expansive cement. If during curing a specimen of expansive cement is prevented from expanding, either by internal or external restraint, compressive stresses are set up in the specimen. These stresses are later partially relieved during shrinkage. When the composition of the cement is such that expansion just offsets shrinkage, the cement is often referred to as "shrinkage compensated."

"Self-stressing" expansive cements are of such a chemical composition that, after curing, expansion of the paste exceeds shrinkage. If restraint is provided (such as that given by a reinforcing bar placed in a concrete beam) as the expansive cement cures, expansion is resisted by the reinforcing steel. As a result, a tensile stress is induced in the reinforcing steel and a compressive stress in the concrete. As curing continues, shrinkage cracks do not open up in the concrete member since the chemically prestressed concrete remains in compression. Theoretically, the same concepts can be applied in stabilizing soil bases with expansive cements.

SAMPLE PREPARATION AND TESTING PROCEDURE

Soil specimens were stabilized using both Type I portland cement and an expansive cement sold under the trade name, ChemComp. A comparison was then made between the difference in the amount of cracking, strength, and general appearance during and after curing of specimens.

The soil was classified using the Unified Soil Classification system as a residual, rusty-brown, well-graded, micaceous silty sand. The liquid limit of the soil was 52 percent and the plasticity index was 16 percent. The Standard Proctor optimum moisture content was 29 percent and the corresponding maximum dry density was 89.5 pcf. A summary of the soil properties is given in Table 1.

The soil, cement, and water were carefully proportioned and then mixed in a Read Standard Grant mixer. Specimens were prepared using 3, 6, 9, and 12 percent cement contents by weight at moisture contents of 3 percent below, 3 percent above, and at Standard Proctor optimum for the unstabilized soil.

Beam specimens 6 by 6 by 18 in. were prepared in a steel mold by compacting the soil-cement mixture in 2-in. layers using a modified Rainhart mechanical compactor. The same compaction energy level was used as in the Standard Proctor compaction test (12,400 ft-lb/cu ft). After compaction, the specimens having moisture contents of 3 percent below and 3 percent above optimum moisture content were wrapped in Saran and cured for 6 days. The Saran wrap was then removed and the specimens cured for an additional day. The beam specimens prepared at optimum moisture content were cured for 7 days with no provision for moisture retention in the specimen. Since the moisture in the specimens was allowed to evaporate freely, this condition of curing should simulate very poor field curing.

The 7-day curing period consisted of subjecting the upper surface of each beam specimen to a temperature of 105 F and a negative temperature differential between the top and bottom of 40 F for approximately 8 hr each day during the 7-day curing period; no attempt was made to control the humidity of the air surrounding the specimens. During the remaining portion of the day the specimens were kept at room temperature that varied between approximately 70 F and 80 F. The 40 F temperature differential was used to simulate a thermal gradient during curing similar to that which might exist in the base course of a pavement system during the warm summer months in Georgia. No moisture was added to the specimens during curing. After curing, the specimens were then fully exposed to the weather to determine the durability of the

TABLE 1

PROPERTIES OF THE MICACEOUS SILTY SAND

Liquid limit, %	52
Plastic limit, %	36
Plasticity index, %	16
Optimum moisture content, Standard Proctor, %	29
Specific gravity	2.71
Grain size, percent passing U.S. standard sieve no.	
4	100.0
10	97.0
40	70.0
60	55.0
100	41.0
200	27.0
Approximate mineral analysis of fines	
Kaolinite (%)	60
Biotite mica (%)	40
Note: An undetermined percentage of biotite mica had weathered to form vermiculite.	
Volume change	
Swell, %	27.4
Shrinkage, %	3.0
Total volume change, %	30.4
Soil classification	
Bureau of Public Roads Classification system (revised)	A-2-7
Unified Soil Classification system	SM

specimens. Unless otherwise noted, during curing the specimens were restrained by steel forms at the ends and also up the sides for about one-half the height of sample.

Soil-cement stabilized specimens 3-in. thick and 18- by 18-in. square were prepared in order to study the effect of surface area on the behavior of the specimens. Specimens were prepared at a moisture content 3 percent below optimum using both Type I portland cement and the expansive cement. The specimens were compacted in 1-in. layers using the Standard Proctor energy per unit volume. The compaction energy was supplied by a 10-lb hammer allowed to fall 18 in. The compacted specimens were wrapped in Saran and cured as previously described for 7 days.

Unconfined compression tests were performed on 2.8-in. diameter, 5.6-in. high cylindrical specimens in order to compare the difference in strength between specimens stabilized using Type I portland cement and the expansive cement. The cylindrical samples were prepared from a portion of the batch used in making the beam specimens. The same Standard Proctor compaction energy per unit volume was used in preparing the cylindrical compression samples as was used in preparing the beam specimens. The cylindrical specimens were extruded from the compaction mold, sealed in plastic bags, and stored in a moisture room at 72 F and 100 percent humidity. After 7 days of curing the specimens were then tested in unconfined compression using a loading rate of approximately 0.05 in. per minute.

TEST RESULTS

Stabilization Below Optimum Moisture Content

In the portland cement-stabilized beam specimens compacted at a moisture content of 3 percent below Standard Proctor optimum with 6, 9, and 12 percent cement contents, horizontal cracks developed on the sides of the specimens. These cracks appeared during curing about 1 in. from the top, extending horizontally about one-half

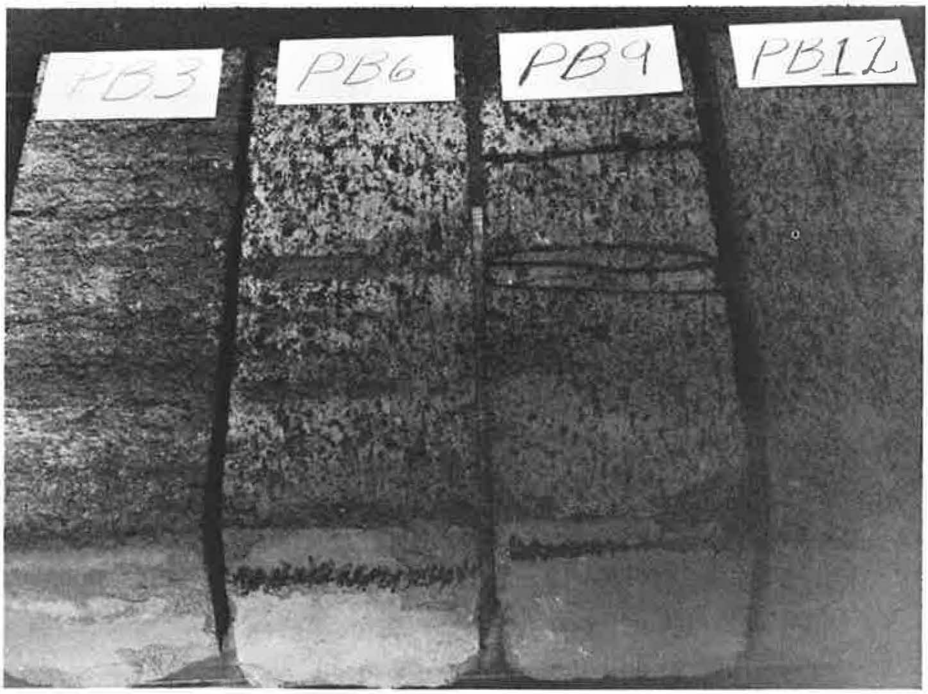

Figure 1. Soil stabilized with portland cement using 3, 6, 9, and 12 percent cement at 3 percent below optimum moisture; 7-day curing period.

the length of the specimen. The specimen having 9 percent cement content was the only one to develop surface cracks. All of these cracks can be considered to be of minor severity. The specimen having a 3 percent cement content did not crack at all, although the surface was rough and irregular due to the low cement content. Figure 1 shows the appearance and extent of surface cracking after 7 days of curing.

Expansive cement beam specimens were prepared using 6, 9, and 12 percent cement at a moisture content 3 percent below optimum. After 7 days of curing the 6 and 12 percent samples showed no cracks. However, the 9 percent specimen developed a surface crack in the middle one-third of the specimen during the first 24 hr of curing. When the Saran was removed from this specimen after 6 days, a very small crack was observed about 1 in. from the surface, extending horizontally from the end for about one-third the length of the specimen. Because of the apparent discrepancy between this specimen and the 6 and 12 percent specimens, another beam having 9 percent expansive cement was prepared and after 7 days of curing was observed to have no cracks. Figure 2 shows the appearance and extent of surface cracking of the original three specimens.

After 7 days of controlled curing and 21 days of exposure to natural atmospheric conditions, the original crack in the 12 percent portland cement specimen extended through the entire length of the sample. Furthermore, during exposure the 12 percent expansive cement specimen developed a crack in the same location but the crack extended for only one-half the length of the specimen. No other cracking occurred in either the portland or expansive cement-stabilized specimens. In general, after 28 days there was little difference in the surface appearance and texture among specimens stabilized with the two types of cements.

Stabilization at Optimum Moisture Content

Beam specimens were prepared using Type I portland cement and the expansive cement at the Standard Proctor optimum moisture content. The specimens were prepared at cement contents of 3, 6, 9, and 12 percent.

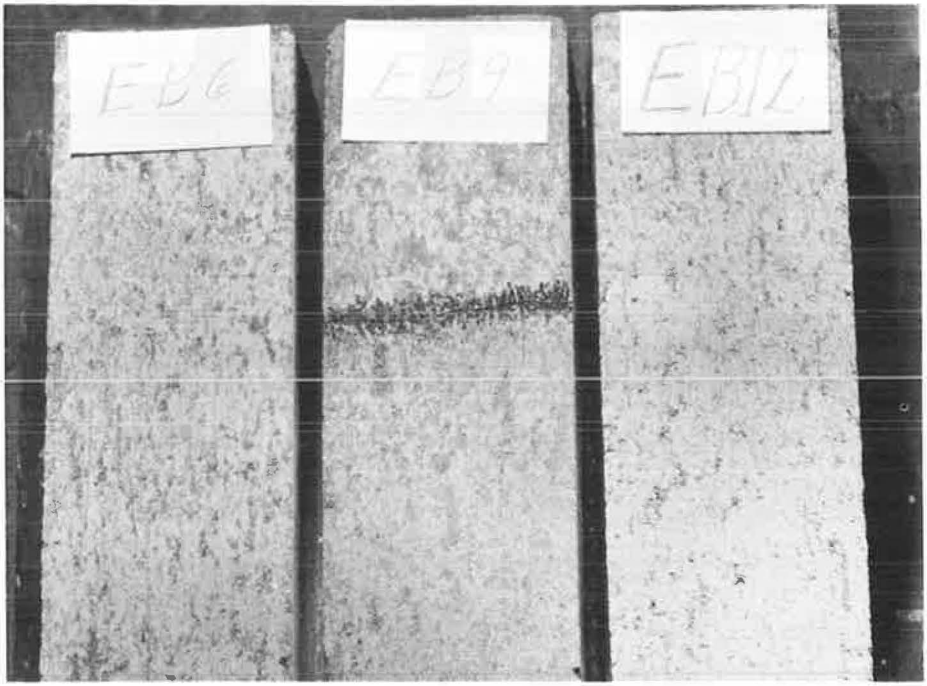

Figure 2. Soil stabilized with ChemComp cement using 6, 9, and 12 percent cement at 3 percent below optimum moisture; 7-day curing period.

The 3 percent portland cement specimen showed no cracking after 7 days. The 6 percent portland cement specimen showed very serious surface cracking concentrated near the middle of the specimen. This crack developed within the first 24 hr and became progressively worse. The 9 percent specimen also formed a surface crack within 24 hr, but it was not as wide or as deep as the crack in the 6 percent specimen. In addition, a small crack formed at one end of this specimen about 3 in. from the top extending parallel to the surface for about 3 in. The 12 percent portland cement specimen developed a crack at one end that extended along the sides parallel to the surface for a length of about 5 in. All of the specimens had a very dry and flaky surface after 7 days of exposure to the temperature differential (Fig. 3). The poor surface appearance was probably caused by improper hydration of the cement due to rapid evaporation of the water from the surface of the sample.

Similar specimens compacted at the optimum moisture content using the expansive cement did not develop any cracks after 7 days except for the 9 percent specimen, which developed a very small crack near one corner during the sixth day. Although the surfaces of these specimens appeared dry after 7 days of curing, they did not have the flaky appearance that the portland cement specimens had, and the samples in general were in much better condition (Fig. 4). After 21 days of exposure to natural atmospheric conditions the existing cracks in the portland cement specimens had widened, and some weathering occurred in the vicinity of the cracks in the 6 and 9 percent specimens. The specimens stabilized with the expansive cement had not undergone any additional cracking or widening by the end of 21 days of exposure. Outside of the cracking in the portland cement-stabilized specimens, both sets of specimens had about the same surface texture and appearance at the end of 21 days.

Stabilization Above Optimum Moisture Content

Portland cement beam specimens were compacted at moisture contents 3 percent above Standard Proctor optimum using cement contents of 3, 6, 9, and 12 percent.

Figure 3. Soil stabilized with portland cement using 3, 6, 9, and 12 percent cement at optimum moisture, after 7-day exposure to temperature gradient; improper curing.

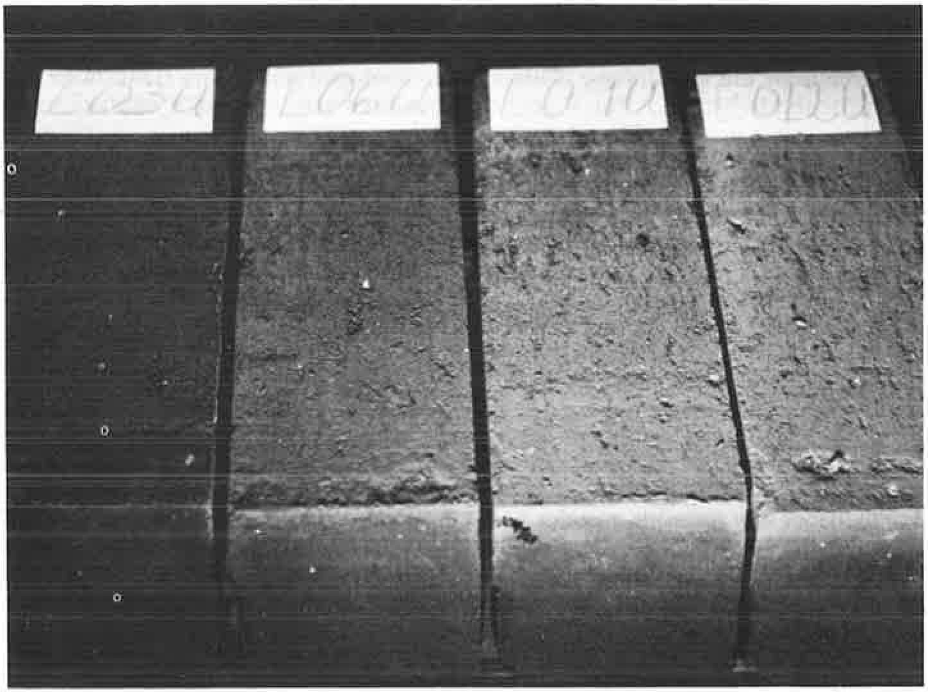

Figure 4. Soil stabilized with ChemComp cement using 3, 6, 9, and 12 percent cement at optimum moisture, after 7-day exposure to temperature gradient; improper curing.

Figure 5. Soil stabilized with portland cement using 3, 6, 9, and 12 percent cement at 3 percent above optimum moisture; 7-day curing period.

After 7 days of curing all the specimens had cracked although the location and severity of the cracking was not always the same (Fig. 5). The beam stabilized with 3 percent cement developed a very fine surface crack in approximately the center of the specimen. These cracks formed during the last days of curing, and the surface of this specimen was very rough and irregular. The 6 percent specimen developed many small cracks over its entire surface during the last day of curing. There was also a very fine horizontal crack about 1 in. from the top at one end extending along the sides for about 3 in. The 9 percent specimen showed a very small crack near its middle, and the entire surface was very flaky.

The 12 percent cement specimen had a very severe surface crack that appeared approximately in the middle of the sample within the first 24 hr of curing. This crack extended about 2½ in. down both sides of the sample and at the end of 7 days it had lengthened to almost 3½ in. Expansive cement-stabilized specimens, compacted at the same moisture content using 3, 6, 9, and 12 percent cement did not crack within the first 7 days of curing and the surfaces appeared to be much smoother than the specimens compacted with portland cement (Fig. 6).

After 21 days of exposure to natural atmospheric conditions the original cracks in the portland cement-stabilized specimens widened and all of the specimens showed a rough and flaky surface (Fig. 7). On the other hand, the expansive cement-stabilized specimens were in much better condition than the corresponding portland cement specimens after 21 days (Fig. 8), although the 3 percent specimen did weather somewhat.

Effect of Restraint and Surface Area

To study the effect of side and end restraint, two sets of soil specimens were prepared at a moisture content 3 percent below optimum using 6, 9, and 12 percent of the expansive cement. One set of specimens was allowed to expand freely during curing (except for friction developed on the bottom of the sample), while the other set was

Figure 6. Soil stabilized with ChemComp cement using 3, 6, 9, and 12 percent cement at 3 percent above optimum moisture; 7-day curing period.

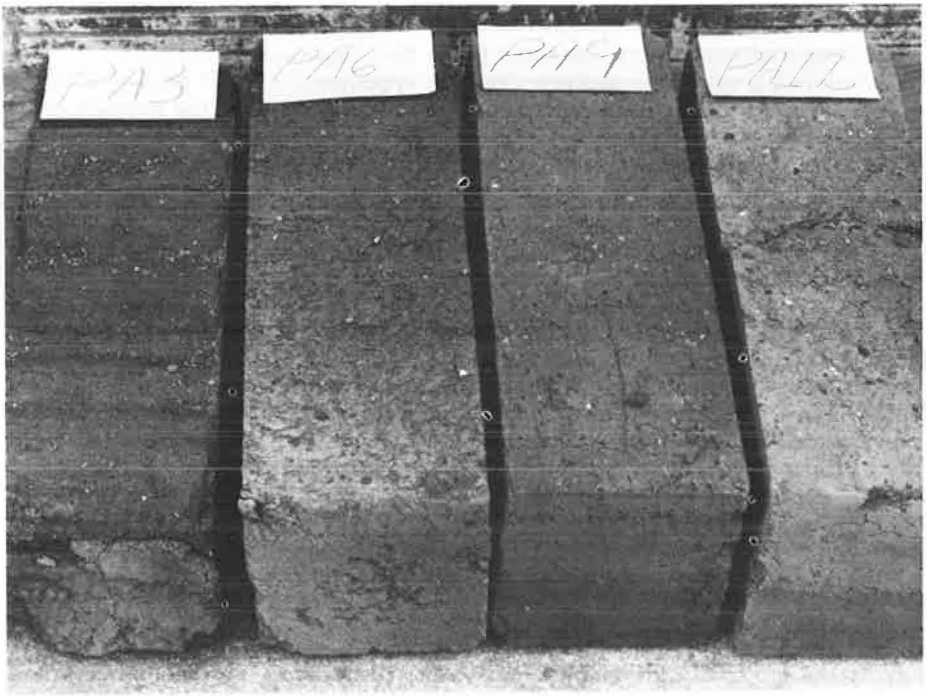

Figure 7. Soil stabilized with portland cement using 3, 6, 9, and 12 percent cement at 3 percent above optimum moisture, after 21-day exposure to atmospheric conditions.

Figure 8. Soil stabilized with ChemComp cement using 3, 6, 9, and 12 percent cement at 3 percent above optimum moisture, after 21-day exposure to atmospheric conditions.

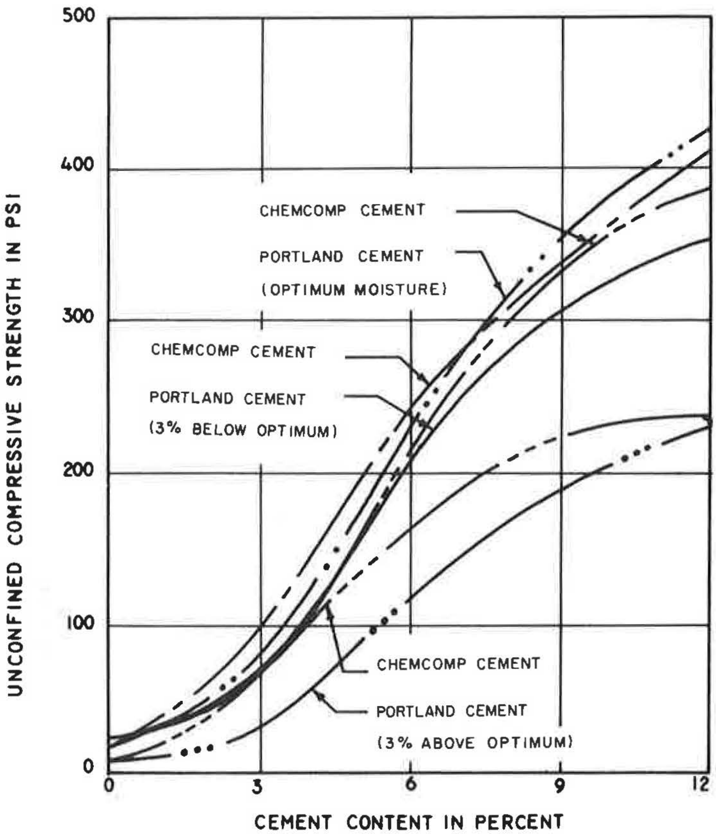

Figure 9. Comparison of unconfined compressive strength between portland cement and ChemComp cement-stabilized soil.

fully restrained from expanding on the ends, bottom, and sides by confining the sample in a steel mold. Both sets of specimens were covered with Saran wrap and cured under a temperature gradient as previously described.

Only the unrestrained specimen stabilized with 6 percent expansive cement exhibited any cracking at all. After the Saran wrap had been removed, this specimen developed two small surface cracks and one small crack 5 in. long parallel to the surface on the end of the specimen. Both the unrestrained and restrained specimens had about the same general surface appearance.

The 6- by 6- by 18-in. beam specimens tested during the main part of the experiment have a very small surface area compared to thickness. On the other hand, an actual cement-stabilized base would have a very large surface area compared to its thickness. Therefore, three 18- by 18- by 3-in. soil cement specimens were prepared at a moisture content 3 percent below optimum using a cement content of 6 percent in order to obtain an indication of the effect of the surface area to thickness ratio. These specimens have a surface area to thickness ratio six times that of the beam specimens. One specimen stabilized with expansive cement was cured with no restraint against expansion except for friction on the bottom while a second one was cured in a fully restrained condition on the ends and sides. A third specimen was stabilized with Type I portland cement and used for comparison. The portland cement specimen developed a series of fine cracks on the surface after the third day of curing. By the seventh day, the cracks had noticeably widened to approximately $^1/_{16}$ in. Neither the restrained nor unrestrained specimens stabilized using expansive cement showed cracking after the 7-day curing period.

Compressive Strength

The soil stabilized with the expansive cement and prepared at a moisture content 3 percent below optimum using 3, 6, 9, and 12 percent cement had a greater strength than the corresponding samples stabilized with portland cement (Fig. 9), with the average increase in strength about 20 percent. At optimum moisture content the strength of the expansive cement-stabilized soils was on the average about 12 percent less than that of the portland cement-stabilized samples as shown in Figure 9. The strength of the expansive cement-stabilized soils at 3 percent above optimum was greater than that of the portland cement samples with the average increase in strength about 35 percent.

DISCUSSION

In general, for the micaceous, clayey silty sand investigated, the use of an expansive cement reduces and, in some cases, eliminates the shrinkage cracking that occurs in beam specimens stabilized with Type I portland cement using 6, 9, and 12 percent cement contents. These test results indicate that as the moisture at compaction is increased the benefit of using the expansive cement over Type I portland cement appears to become greater. At water contents 3 percent below optimum only a slight amount of reduction in cracking appears to be gained by using ChemComp expansive cement. At and above optimum moisture content more benefit in terms of cracking appears to be derived from using the expansive cement for stabilizing this soil. In fact, at a moisture content 3 percent above optimum all of the soil specimens stabilized with portland cement cracked while those stabilized with the expansive cement did not develop any cracks.

An actual stabilized base course is subjected to some indeterminate degree of restraint (i.e., resistance to volume change) due to friction on the bottom of the slab and edge effects on the sides, and it has a much larger surface area to thickness ratio than do the beam specimens studied. Earlier tests performed on expansive cement specimens (made of cement paste without soil) indicated that the surface area and condition of restraint has an important effect on the performance of an expansive cement specimen (3). In order to get a preliminary indication as to whether these factors are also important in the expansive cement-stabilized soil, restraint and surface area tests were performed on a limited number of specimens.

Specimens were cured with (a) no side and end restraint, (b) restraint for one-half the height of the sample, and (c) full edge restraint. These conditions of restraint should bound the actual condition of base restraint existing in an actual pavement system. The results of these tests indicate that, for the soil studied and a moisture content 3 percent below optimum, the condition of restraint apparently has only a relatively small effect upon cracking of the cement-stabilized specimens. Furthermore, the results of the surface area tests tentatively indicate that for the soil investigated the effect of the surface area to thickness ratio is also small for at least a moisture content 3 percent below optimum and a cement content of 6 percent. Therefore, the surface area and restraint tests indicate that the results of a laboratory study performed using small specimens, ChemComp cement, and the soil investigated should probably give a reasonable indication of how a similar stabilized base should perform in the field with regard to cracking. However, before definite conclusions can be made a more extensive investigation using a range in cement and water contents is required. The difference in performance between these tests and those performed previously using only expansive cement (3) may be due to the fact that the finer portion of the soil stabilized in the present study consists of hydrous aluminum silicates that probably reacted with the expansive cement. If in some soils restraint is found to be necessary, bamboo or some other type of reinforcing may possibly be used to provide internally the required restraint.

The results of this investigation are based on a study of the behavior of a somewhat limited number of beam specimens. In order to more fully understand the effect of stabilization using expansive cements, a more extensive testing program should be carried out for the soil investigated. In particular, several specimens at each cement content, cement type, and water content should be prepared in order to get a statistically

representative variation of the specimen behavior that will occur, since soils are not homogeneous. The soil used in this investigation was a plastic, micaceous silty sand. Other soils may behave differently when stabilized using an expansive cement. Furthermore, only one type of expansive cement was used in the tests, which may not consist of the optimum combination of constituents for use in stabilizing the plastic, micaceous silty sand. Further research may indeed show that the optimum combination of cement constituents varies with the physical-chemical composition of the soil to be stabilized.

CONCLUSIONS

The use of ChemComp, an expansive cement, to stabilize a plastic, micaceous clayey silty sand resulted in a definite general reduction and in some instances elimination of the shrinkage cracking that occurred using Type I portland cement. The beneficial effects of the expansive cement were particularly encouraging at a moisture content of 3 percent above Standard Proctor optimum, and also when the moisture content was at optimum and the specimens were subjected to poor curing conditions. This investigation, however, was of too limited a scope to make any detailed conclusions.

The results of these preliminary tests are encouraging and indicate that the use of an expansive cement to stabilize at least some soils under certain conditions may result in a significant reduction or even elimination of shrinkage cracking without a reduction in strength. However, further research in both the laboratory and field is needed to investigate the effects of using an expansive cement in base stabilization. In particular, additional work is needed to determine (a) the types of soils that may benefit from stabilization with an expansive cement, (b) the optimum composition and percentage of expansive cement to use with each soil, (c) the effect of different conditions of curing and temperature gradients, and (d) the effect of surface area and slab restraint. Finally, a field test section should be constructed and carefully monitored after a complete laboratory study has been made for each soil.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the National Science Foundation and the School of Civil Engineering, Georgia Institute of Technology, for the financial assistance that made this research possible.

REFERENCES

1. Barksdale, R. D., and Leonards, G. A. Predicting Performances of Bituminous Surfaced Pavements. Proc. Second Internat. Conf. on the Structural Design of Asphalt Pavements, Univ. of Michigan, Jan. 1967.
2. Mather, Bryant. Investigation of Expanding Cements, Report 1. Summary of Information Available as of 1 July 1963, Tr. No. 6-691 U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Sept. 1965.
3. Monfore, G. E. Properties of Expansive Cement Made With Portland Cement, Gypsum, and Calcium Aluminate Cement. Journal of the PCA Research and Development Laboratories, Vol. 6, No. 2, May 1964.
4. Simms, J. F. Expansive Cements for Crack Resistant Concrete. Civil Eng., June 1966.