PCA Portland Cement Association

SOIL-CEMENT Information

Properties and Uses of Cement-Modified Soil

"Cement-modified soil," usually referred to as CMS, is a term used to describe a soil or aggregate that has been treated with a relatively small proportion of portland cement. The objective of the treatment is to amend undesirable properties of problem soils or substandard materials so that they are suitable for use in construction. The amount of cement added to the soil is less than that required to produce a hardened mass (soil-cement[1,2]) but is enough to improve the engineering properties of the soil. For the small quantities of cement generally used, CMS becomes caked or slightly hardened. However, it still functions essentially as a soil or aggregate, although an improved one.

In-place mixing for cement-modification of clay subgrade at Denver International Airport.

Laboratory and field work on CMS indicate that the relatively small quantities of cement bind the soil grains together to form small conglomerate masses of new soil aggregates. In addition to the cementing reaction, the surface chemistry of clay particles, in clay soils or clay fraction of granular soils, is improved by cation exchange phenomenon. As a result, the modified soils have lower plasticity (cohesiveness), lower volume change characteristics, and greater strength than untreated soils.

The degree of modification increases with greater amounts of cement. Therefore, for a given soil, a cement content can be selected that will provide a material meeting the specified level of modification, expressed in terms of plasticity, strength, or other criteria.

Field and laboratory tests show that changes in the physical characteristics of a soil by cement modification are permanent. The soil does not revert to its original state, even after many cycles or years of weathering and service.

Cement-modified soils are usually classified into two groups according to the predominant grain size as follows.

Cement-modified silt-clay soils (soils containing more than 35% silt and clay*). The general objective is to improve soils that are otherwise unsuitable for use in subgrades or subbase layers. Specific objectives may be to decrease plasticity and volume change characteristics, to increase the bearing strength, or to provide a stable working platform on which pavement layers may be constructed.

Cement-modified granular soils (soils containing less than 35% silt and clay*). The usual objective is to alter substandard materials so that they will meet requirements specified for pavement base or subbase layers.

These two applications are discussed separately in this publication.

Cement-Modified Silt Clay Soils

Properties

Cement-modification improves the properties of certain silt-clay soils that are unsuitable for use in subgrade construction. The objectives may be to decrease the soil's cohesiveness (plasticity), to decrease the volume change characteristics of an expansive clay, to increase the bearing strength of a weak soil, or to transform a wet, soft subgrade into a surface that will support construction equipment.

Examples of the improvement of properties of silt-clay soils are given in the following discussion.

*Combined silt and clay defined as material passing a No. 200 sieve.

Plasticity Index and Other Index Properties. The plasticity index (PI)[3] is a measure of a soil's cohesive properties and is indicative of the amount and nature of clay in the soil. Soils with a high PI may be difficult to work with in construction because of their instability and stickiness when wet.

High PI soils also have potential for detrimental volume changes during wetting and drying, which can lead subsequently to pavement roughness. As shown in Table 1, the PI is an important indicator of soil expansion characteristics. While other factors (shrinkage limit and colloid content) are also shown as indicators, the PI alone is often taken as a simple index. Experience has shown that soils with PI's less than about 15 to 18 usually cause no problems; highly expansive soils will have much higher PI's.

Table 2 gives examples of the effect of cement-modification on three clay soils. The substantial reduction of PI's and increase in shrinkage limits* indicates not only an improvement in the volume change characteristics but also modification of the soils into more stable and workable materials. In many cases, reducing the PI to a value in the range of 12 to 15 serves as the criteria for selecting a cement content.

The in-service permanence of cement modification has been demonstrated by laboratory and field investigations. An example of the effect of freezing and thawing on plasticity properties as measured on laboratory mixtures is given in Table 3.[6] After 60 cycles of freezing and thawing the properties of the cement-modified soil showed no tendency to increase or revert back to those of the untreated soil. In fact, the PI's after 60 cycles of freezing and thawing were less than the values after 7 days of moist curing. This is attributed to additional hydration of the cement during the 60 thaw cycles. The results of one study,[7] shown in Table 4, indicate that after six years the modification was still effective. Another study[8] investigating the properties of 11 cement-modified subgrades after 45 years of service showed that the improvements in soil properties (PI, shrinkage limit, and gradations) were permanent.

*The shrinkage limit indicates how much moisture (percent) the soil can absorb without swelling; the higher the value, the less expansive the soil is.

Table 1. Relation of Soil Index Properties and Probable Volume Changes for Highly Plastic Soils

Data from index tests[1]			Estimation of probable expansion[2] percent total volume change (dry to saturated condition)	Degree of expansion
Plasticity Index (ASTM D4318)	Shrinkage limit, percent (ASTM D427)	Colloid content (percent minus 0.001 mm) (ASTM D422)		
>35	<11	>28	>30	Very high
25-41	7-12	20-31	20-30	High
15-28	10-16	13-23	10-20	Medium
<18	>15	<15	<10	Low

Adapted from Reference 4.
[1]All three index tests should be considered in estimating expansive properties.
[2]Based on a vertical loading of 1.0 psi. For higher loadings the amount of expansion is reduced, depending on the load and on the clay characteristics. In service, much less expansion would occur because these extremes of moisture variation would not take place.

Table 2. Effect of Cement Treatment on Properties of Clay Soils

Soil No.	Cement Content, percent	Plasticity Index	Shrinkage Limit, percent
1	none	30	13
	3	13	24
	5	12	30
7	none	36	13
	3	21	26
	5	17	32
10	none	43	14
	3	24	24
	5	16	31

Additional data on a total of 11 clay soils are given in Reference 5.

Table 3. Permanence of Improvement of Cement-Modified Illinois Clay

	0	2		4		6	
Tests made after...	7 days	7 days	60 Cycles F-T	7 days	60 Cycles F-T	7 days	60 Cycles F-T
Liquid Limit	49	48	49	45	47	45	45
Plastic Limit	18	23	29	25	34	31	32
Plasticity Index	31	25	20	20	13	14	13
Shrinkage Limit	18	20	20	27	24	26	27

Table 4. Permanence of Cement-Modified Soil[1]

	Plasticity Index
Raw soil	29
Lab mixture, 7 percent cement by vol.	15
Field mixture after construction, 7 percent cement by vol.	11
Field mixture after 6 years of service, 7 percent cement by vol.	5 to 11

[1]An A-7 clay from Comanche County, Oklahoma.

Expansion. A direct measure of the expansive properties of soils, as opposed to the index tests discussed previously, is afforded in the soaking and swelling portion of the California Bearing Ratio (CBR) test.[9] In this test, a "percent swelling" value of 4 (roughly corresponding to a PI of 20) is an approximate borderline between expansive soils and those that would usually not be troublesome. Highly expansive soils will have much higher values than 4% swell.

Small quantities of cement have a greater effect on reducing swell or expansion than they do on improving the index properties discussed in the previous section. Since the latter are only indices, the CBR swell test is a better, more direct measure of this soil property.

Fig. 1 shows the effect of the addition of cement to a moderately expansive AASHTO Class A-7-6 (16) clay soil. Three percent cement reduced the expansion, as measured in the CBR test, from 3.9 to 0.15%. The reductions are dramatic with very low cement contents.

Reduction in swell of a highly expansive clay from California is shown in Fig. 2.[10] The laboratory specimens were molded at standard maximum density and optimum moisture content and cured in high humidity for 7 days before being saturated. Expansion on saturation was reduced from a high value of about 11% to less than 1% with the addition of 2% cement. Thus, the highly expansive clay was changed to a relatively nonexpansive material.

With most soils, excessive volume changes can be controlled by compacting the subgrade at a moisture content 1 to 3 percentage points above optimum moisture as determined by AASHTO T-99 or ASTM D698. Cement treatment of the upper

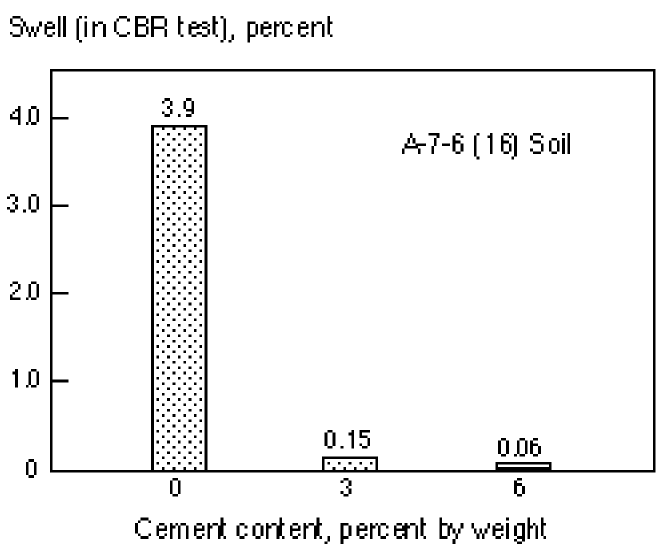

Fig.1. Effect of Cement on Swelling in the CBR Test

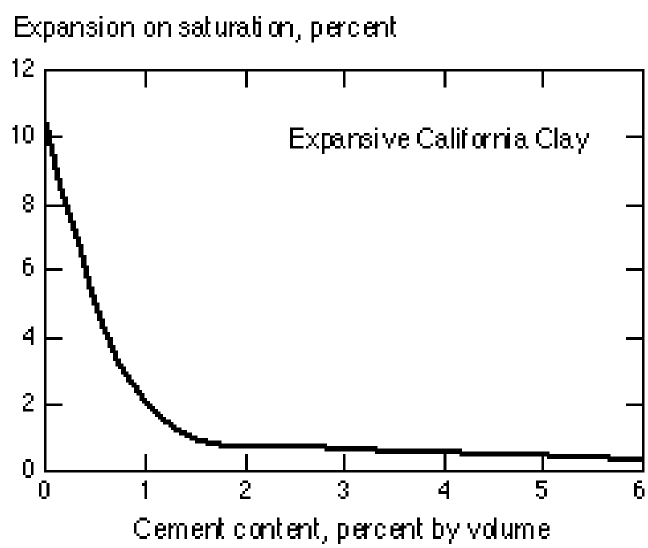

Fig. 2. Expansion versus Cement Content, Highly Expansive Clay

portion of the moisture-controlled subgrade not only prevents volume changes but produces an impermeable layer that will protect the soil below from seasonable variations in moisture content. The cement-treated layer also provides protection against subgrade drying between the time the subgrade is compacted and the subsequent layers of the pavement are placed.

Strength and Bearing Tests. The cementitious reaction between cement and clay takes place as primary and secondary processes. Hydration of the cement is regarded as the primary reaction and forms the normal cement hydration products that bind particles together. In the secondary process, the fresh calcium hydroxide formed in the primary phase reacts with the silica and alumina in the clay to form additional cementitious material. (Obviously, this secondary process does not occur with clean granular materials or concrete aggregates.) Thus, in spite of the otherwise objectionable properties of untreated clay, the clay material itself contributes somewhat to the strength development of cement-clay mixtures.

Examples of the beneficial effect of cement-modification on compressive strength are given in Table 5 for 9 clay soils. These data are from a comprehensive study[5] that also investigated other properties of cement-treated clay such as triaxial strength, cohesiometer values, plasticity indices, shrinkage limits, and so forth. Similar increases in strength were found in the results of triaxial strength tests and cohesiometer tests.

Table 5. Unconfined Compressive Strengths,* psi, of Cement-Treated Clays

Soil No.	AASHTO Classification	Cement Content, percent by wt.	No compaction delay		24-hour compaction delay	
			7-day strength	28-day strength	7-day strength	28-day strength
1	A-7-6(20)	0	56	--	--	--
		3	98	135	83	128
		5	160	233	155	207
2	A-6(8)	0	26	--	--	--
		3	316	374	243	324
		5	445	495	270	371
4	A7-6(17)	0	29	--	--	--
		3	216	277	179	238
		5	332	426	256	320
6	A-6(9)	0	28	--	--	--
		3	210	269	141	185
		5	323	414	234	302
7	A-7-6(19)	0	41	--	--	--
		3	124	149	100	133
		5	172	232	158	213
8	A-6(6)	0	26	--	--	--
		3	234	276	156	267
		5	405	452	217	346
9	A-7-6(18)	0	37	--	--	--
		3	158	202	135	192
		5	243	310	219	283
10	A-6(9)	0	54	--	--	--
		3	114	158	84	140
		5	174	234	141	205
11	A-7-6(14)	0	38	--	--	--
		3	147	186	107	137
		5	237	377	204	294

*2.8 x 5.6 in. cylinders kept damp until tested. From Reference 5.

Increases in strength as measured in the California Bearing Ratio test are shown in Fig. 3[6] for a silty clay loam. The CBR value of 2 for the untreated soil represents a relatively unstable material that would be difficult to work with during pavement construction operations. At a cement content of only 3%, the CBR value is increased to 42, which would not only provide a stable working platform but would meet CBR requirements as a subbase layer in a flexible (asphalt surfaced) pavement design.

Soil Particle Size. One of the benefits of cement-modification is that the reaction between cement and soil reduces the amount of silt and clay size particles. These fine-grained particles are a detriment to stability when the soil is in a moist or wet condition. Also, the amount and type of clay in a soil determine its expansive characteristics.

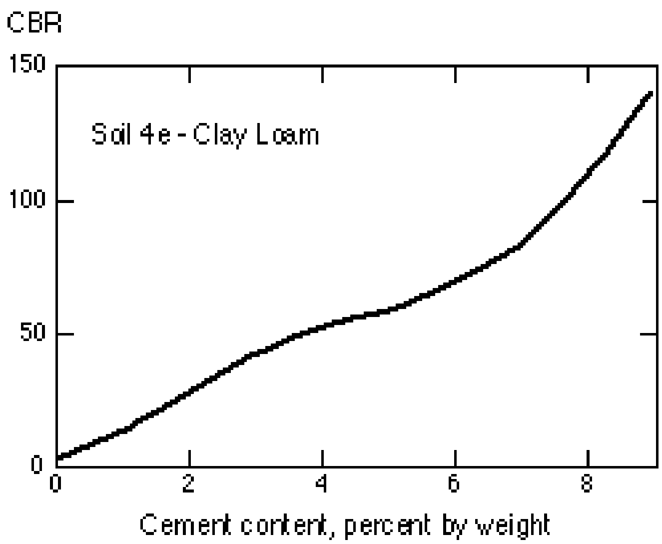

Fig. 3. California Bearing Ratio versus Cement Content

When a fine-grained soil is treated with a small amount of cement, the cement hydration products bind some of the particles together to form larger grains in the size range of fine sand particles. The result is that the treated soil contains less silt and clay and more sand, and in addition, the remaining clay has been altered chemically to become a less expansive material.

An example of the change in silt-clay content of a silty clay soil is given in Fig. 4.[11] The silt-clay content of 93% in the untreated soil was reduced to 53% by the addition of 6% cement. These tests were performed using ASTM D422, which relies on sieving and sedimentation tests to determine particle sizes. As specified in the test, samples of the raw soil and hydrated cement-treated soil were subjected to grinding with mortar and pestle until aggregations of soil particles were broken up into separate grains.

Additional, similar data on the improvement of soil gradation is given in Reference 8.

Uses

Cement-modified silt-clay soils are used in pavement construction to increase bearing strength and reduce volume changes and plasticity properties of fine-grained subgrades and highway fills. Cement is also added to wet and unstable subgrades as a

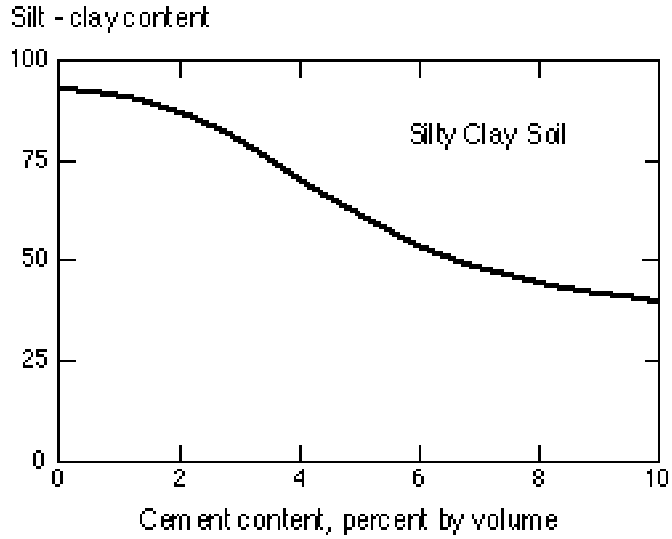

Fig. 4. Reduction in Silt-Clay Content Due to Cement Modification

construction expedient. The cement dries out the wet soil, improves the soil characteristics, and produces a firm foundation on which the pavement layers can be placed.

In the following discussion, the terms subgrades, subbases, and bases are used to describe the uses of cement-modified silt-clay soils. Fig. 5 shows the meaning of these terms.

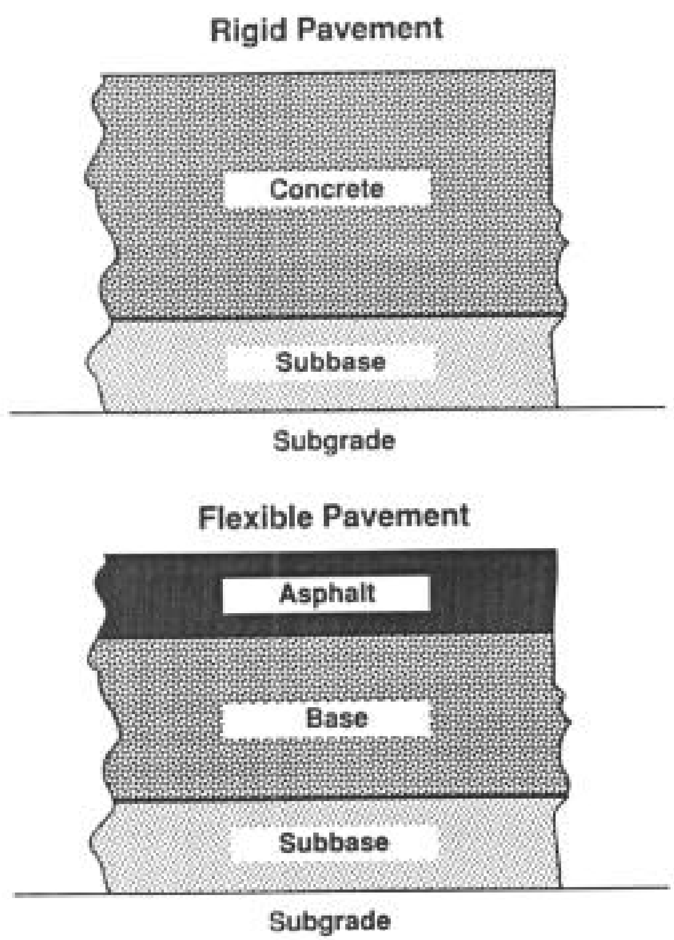

Fig. 5. Terminology Used in Rigid and Flexible Pavement Layered Systems

Subgrade Stabilization for Pavements. Poor quality subgrade soils are improved by cement modification. The primary purpose is to provide supporting power and a firm, stable working table for pavement construction. Cement-treated subgrades also provide an effective solution to the problem of fatigue failures caused by repeated high deflections of asphalt surfaces where a weak subgrade exists in the pavement structure. Field tests and experience in areas of resilient subgrades, micaceous soils for example, show a marked decrease in deflection when subgrades are stabilized with cement. Performance indicates the cost of subgrade stabilization is well worth the modest cost involved.

Subbase for Flexible and Soil-Cement Pavements. Cement-modified silt-clay soils have been used in flexible pavement systems. Generally, the subgrade soil is treated with enough cement to provide a firm foundation for compacting the base course above it. A soil-cement base constructed on top of the cement-modified subbase may be made of the same material treated with sufficient cement to produce hardened soil-cement, or it may be hardened soil-cement[1,2] built with granular borrow soil.

Subbases for Concrete Pavements. Where heavy weights and volumes of truck traffic are anticipated, cement-modified silt-clay soils are <u>not</u> recommended for use as a subbase because they do not meet the requirements of a non-pumping subbase material. If subgrade problems exist, they may be improved by cement modification. Then an untreated granular or fully hardened granular soil-cement should be utilized as a subbase if the concrete pavement is to carry heavy truck traffic—see Reference 12 for subbase material requirements.

Adding cement in slurry form to clay subgrade for concrete parking lot in Texas.

For light-traffic facilities, a subbase is not required and the concrete may be constructed directly on a properly prepared subgrade if it is capable of supporting construction equipment and is not highly expansive. Otherwise, the subgrade may be made suitable by cement modification.

Base Course for Flexible Pavements. Cement-modified silt-clay soils are <u>not</u> recommended for use as pavement bases. Small quantities of cement do not improve silt-clay soils sufficiently to make them satisfactory as base materials. The most effective means of utilizing such soils for base materials is to add sufficient cement to make fully hardened soil-cement. See References 1 and 2.

Correcting Unstable Subgrade Areas. Sometimes, localized soft spots of very wet and unstable subgrades are encountered unexpectedly during construction. In addition to the difficulty of operating construction equipment, adequate compaction of base and subbase layers placed on top of these soft areas may not be possible.

These areas may be corrected by cement modification. Cement is spread and mixed into the soil to the best extent possible. If the material is too wet or cohesive to use a travelling mixer, it may be processed by several passes of a disc harrow or motor patrol using its scarifier teeth. Then the material is compacted to whatever density can be achieved. The drying action of the cement and its hydration for two or three days will stabilize the area sufficiently so that construction may proceed.

Construction

For silt-clay soils that are not excessively cohesive or wet, the construction operations are essentially the same as those for soil-cement and cement-treated base courses.[2] However, some additional effort may be required in the pulverization and mixing operations.

Wet cohesive soils may require disking to cut in the cement and do the initial mixing before a rotary mixer is used. If the soil is dry, prewetting and allowing the water to soak in, may facilitate pulverization.

Also in contrast to normal soil-cement construction, there is no time limit between mixing and compacting; although all the operations are completed in the same day. Applying an asphalt cure coat is usually not required.

Typical construction steps are given below, although they may vary somewhat depending on the wetness and cohesiveness of the soil.

- Shape the area to crown and grade.
- If necessary, prewet dry soils to aid pulverization, or dry wet soils by aeration with disc harrow or rotary mixer with its hood open.
- If necessary to aid subsequent pulverization, scarify full depth with disc harrow, grader scarifier teeth, or other equipment.
- Distribute cement in dry form with mechanical spreader or in slurry form from distributor truck equipped with agitation system.
- Mix with travelling rotary mixer, adding water if necessary, until a homogeneous, friable mixture is obtained that will meet the specified pulverization requirements. (In very wet cohesive soils, initial mixing may be done with several passes of a disc harrow until the material becomes friable enough to use a rotary mixer.)
- Compact with tamping (sheepsfoot) roller.
- Complete surface compaction with appropriate type of roller.

- With grader, shape area to final crown and grade.
- Seal surface with pneumatic-tire roller sufficiently light in weight to prevent hair-line cracking.

Experience has shown that pulverization requirements (the allowable amount of unpulverized lumps and clods in the mix) for cement modified soils need not be as strict as those for fully hardened soil-cement construction. Specifications of different agencies vary somewhat. In Oklahoma, field and lab studies[13] showed the following requirements were suitable: 95% minimum passing 1-inch sieve and 60% minimum passing No. 4 sieve.

Based on experience in North Central Texas, a specification initially was developed by the North Central Texas Council of Governments as follows: 100% passing 1-1/2-inch sieve, 75% passing 3/4-inch sieve, and 45% passing No. 4 sieve; these are minimums. Current specifications require 100% passing 1-1/2-inch and 60% passing No. 4 sieve.

All processing in an area is completed in one day. Thus, an all-weather working platform is provided with no waiting period. The operation of construction equipment to place base or subbase courses, or concrete pavement can commence at any time.

Cement-Modified Granular Soils

Cement has been used to improve bearing values of granular base and subbase materials, to reduce their plasticity or swell characteristics, to prevent consolidation, and to produce a firm working table as a subbase. With the rapid depletion of acceptable granular materials for use as bases and subbases, it becomes ever more important to conserve the remaining limited supply of acceptable materials. Submarginal granular materials, cement-modified to improve their bearing values and reduce their plasticity, will meet specifications for acceptable base and subbase materials. Consequently, the limited supply of acceptable materials can be conserved. The resulting product, however, is still primarily a granular base material with all the characteristics of that type construction.

Properties

Specifications for pavement base and subbase course materials place limits on the amount of fines and the plasticity (cohesiveness or stickiness) of the fines in granular materials. Excessive fines can lead to loss of stability, susceptibility to frost action, and mud-pumping under traffic loads.

The following discussion gives examples of the improvement of the properties of substandard granular soils by the addition of cement.

Plasticity Index. One common and simple way of measuring the improvement of a granular material containing an excessive amount of clay is by the reduction in its plasticity characteristics as measured by the plasticity index (PI).[3] This index is a significant indicator of soil behavior; the higher the PI, the more plastic the soil will be and the more unsuitable it will be for use in construction. Typically, specifications for base courses limit the PI to about 6 along with a maximum fines content (No. 200 sieve) of 10 or 12. For subbase courses, somewhat more fines are permitted with maximum PI's of 6 to 10.

An example of the effect of cement on reducing the PI of a clayey gravel is shown in Fig. 6.[14] For this substandard material, a cement content of about 3 or 4% by weight would reduce the PI sufficiently to meet specifications. The figure also shows the permanence of the PI reduction as measured in the field over a 10-year period.

California Bearing Ratio (CBR). Fig. 7 shows the increase in CBR values obtained for the same clayey gravel represented in Fig. 6. To explain the CBR value, it is based on a load bearing strength index test[9] made by measuring the force required to penetrate a compacted material by a 3 sq in. piston. The highest quality base course materials will have CBR's in the range of 70 to 90 while suitable subbase materials will have lower values down to about 20. Flexible pavement design procedures of some agencies specify a minimum CBR for each layer; for example, 80 for the base course, 30 for the second layer (subbase), and 15 for a third layer (select material).

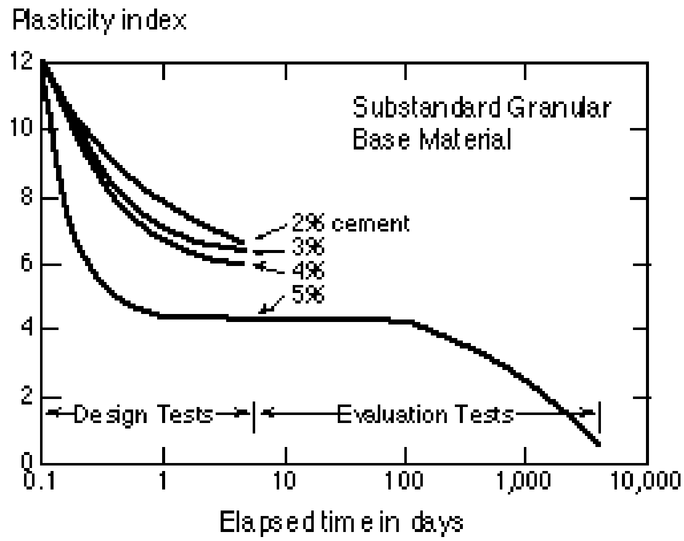

Fig. 6. Reduction in Plasticity Index Due to Cement Content and Time

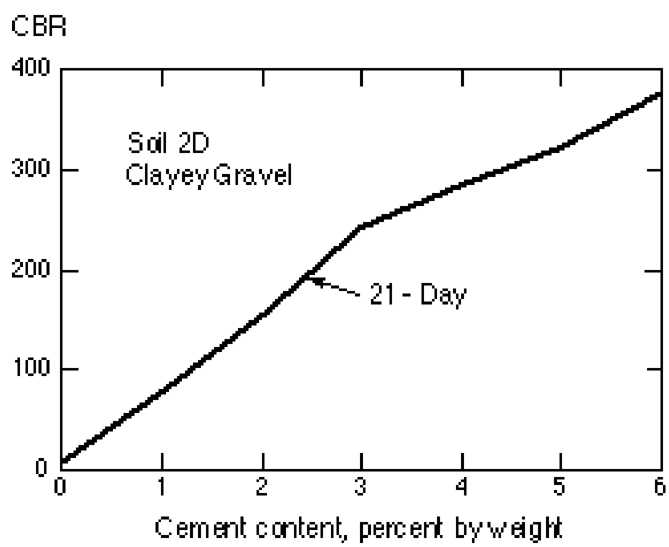

Fig. 7. California Bearing Ratio versus Cement Content

The raw material (0% cement) represented in Fig. 7 has a CBR of only 10 due to the excessive clay content, which upon saturation during the test, significantly weakens the material. As shown in the figure, a small amount of cement increases the CBR to a level that is adequate for base and subbase courses.

Table 6 shows the permanence of the CBR increase. After many cycles of laboratory freeze-thaw tests, the CBR values did not decrease; in fact, the value at 4% cement increased substantially due to additional cement hydration during the thaw cycles.

Sand Equivalent (SE). Some agency specifications for granular base and subbase courses include a requirement for a minimum Sand Equivalent value.[15] This is determined by a test developed to detect the presence of undesirable clay-like materials in soils and aggregates. The method tends to magnify the volume of clay in a sample somewhat in proportion to its detrimental effects. Clean crushed stones and sands have SE values of about 80; very expansive clays have SE values of 0 to 5. A western state highway agency specifies a minimum SE of 30 for base course materials.

The sand equivalent of a material can be increased by the addition of a small quantity of cement. Data from tests made by the Utah Department of Transportation on a soil having a PI of 11 and having 33% passing the No. 200 sieve are shown in Table 7.[16] This material containing 2% cement would meet the SE requirement. Incidentally, the PI was correspondingly reduced from 11 to 0 for the material containing 3% cement.

Resistance R-Value. Some agencies make use of the Resistance R-Value test,[17] also called the Hveem Stabilometer test, to determine the stability of a material used as a roadway base, subbase, or subgrade. An R-Value of about 78 is considered equivalent to a good crushed stone. Some agencies specify an R-Value of 72 for base course materials.

An example of how the addition of cement increases the R-Value is shown in Table 8. The data are for a Colorado sand classified by the AASHTO system as an A-2-4, primarily a fine sand with an appreciable quantity of silt and clay making it somewhat marginal in stability. The R-Value of 65 for the untreated sand increased to 89 with the addition of 3% cement—a stability level suitable for a base or subbase layer.

Triaxial Compression. The triaxial compression test[18] is used by a few state highway agencies for pavement design or to classify an aggregate's suitability for use in pavement construction. The test is used to determine the shearing resistance of a material, which is the sum of two components—internal friction and cohesion.

A clean granular material derives most of its strength from internal friction, (particle to particle contact resists shearing movement) while the cohesion component of strength is very low or zero. Dirty granular materials have some cohesion but have lower total strength because the fine silt and clay particles, when wet, act as a lubricant decreasing the internal friction.

When cement is added, both cohesion and internal friction are substantially increased. An example for a dirty bank-run gravel is shown in Fig. 8,[19] where the vertical scale represents cohesion and the angle ϕ is the internal friction. This increase in stability due to the addition of cement would modify the substandard or marginal material to one of acceptable quality.

Field Load Tests. Data on the load-carrying capacity of cement-modified granular soils have been determined by tests[20] of outdoor test panels. Fig. 9 shows the increase in plate bearing value of a 7-in.-thick base with increasing cement contents. At 1.5% cement the load bearing capacity was approximately doubled. Panels were tested each spring for a period of five years. Data from these tests also show the substantial increase in load-carrying capacity obtained even at the very low cement contents. Some loss in load-carrying capacity occurred at the lower cement contents after exposure to freezing and thawing. However, after five years of exposure,

Table 6. Permanence of Bearing Value of Cement-Modified Granular Soil[1]

	CBR (percent)
Raw soil	43
2 percent cement by weight, age 7 days	255
2 percent cement by weight after 60 cycles of freeze-thaw	258
4 percent cement by weight, age 7 days	485
4 percent cement by weight after 60 cycles of freeze-thaw	574

[1]A-1-b(0) disintegrated granite from Riverside County, Calif.

Table 7. Sand Equivalent Values of Cement-Modified Soil

Percent Cement by Weight	Sand Equivalent
0	11
1	18
2	36
3	59

Table 8. R-Values of Cement-Modified Granular Soil[1]

	R-Value
Raw soil	65
Lab mixture	
3 percent cement by weight	89
5 percent cement by weight	93

[1]Colorado A-2-4 fine sand.

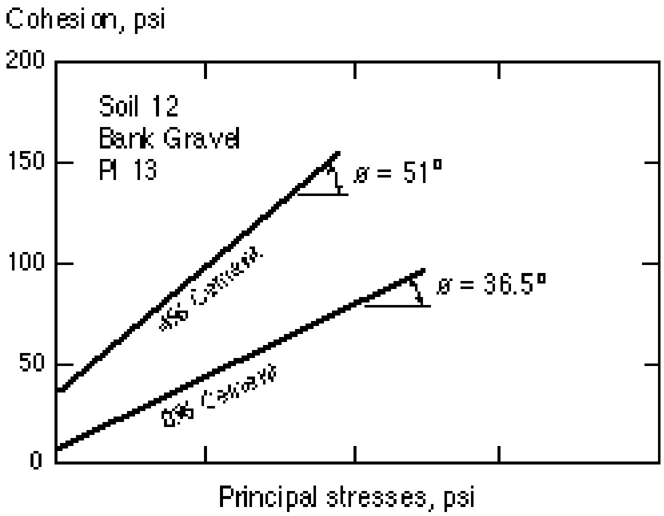

Fig. 8. Change in Triaxial Compressive Strength due to the Addition of Cement

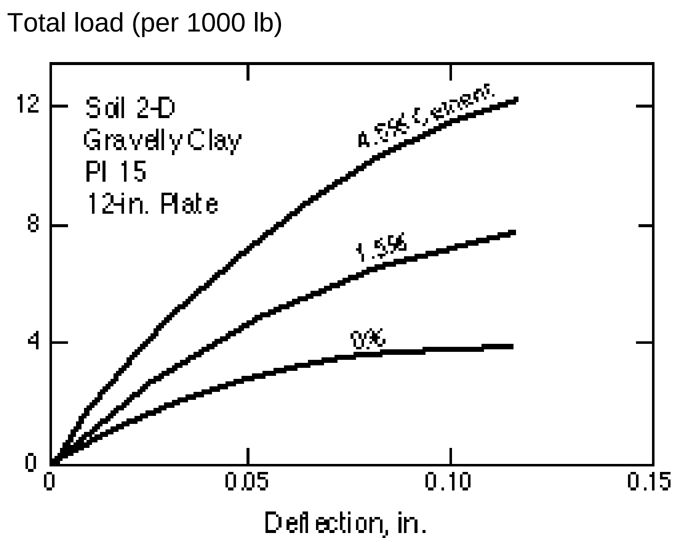

Fig. 9. Bearing Capacity versus Cement Content

even for cement contents as low as 1.5%, the cement-modified materials were still able to support considerably more load than the untreated material.

Uses

Substandard granular soils can be modified with portland cement to reduce or eliminate plasticity and to increase their bearing values to a point where they are acceptable for use as pavement base or subbase.

By the addition of relatively small quantities of portland cement, these substandard materials are improved and made usable. The resultant product, however, is still primarily a granular material rather than a fully hardened soil-cement material.

In the following discussion, the terms "base" and "subbase" are used to describe the uses of cement-modified granular soils in flexible and rigid pavement systems. Fig. 5 on page 5 shows the meaning of these terms.

Base Course for Flexible Pavement. Cement-modified granular soils have been used extensively as pavement bases for highways and streets. For these uses the materials to be treated should require only a small degree of improvement to meet specification requirements. Cement-modified granular bases are always covered with a bituminous wearing surface.

Shoulders. CMS has also been used to construct shoulders for highway pavements. The addition of cement prevents consolidation of the shoulder adjacent to the pavement edge and helps to eliminate dangerous "drop-offs." Like CMS pavement bases, CMS shoulders are always surfaced with bituminous material.

Subbase for Concrete Pavements. Cement-modified granular soil subbases are used to:

1. Prevent consolidation of the subbase under heavy traffic,
2. Increase the bearing capacity of the subbase,
3. Provide a firm support for paving operations; this is especially important when a slip-form paver is used, and
4. Prevent intrusion of subgrade soil into the granular subbase.

The use of cement-treated granular soil as subbase is recommended where good quality granular subbase materials do not exist or are very expensive. Substandard granular subbase materials can be treated with just enough cement to reduce the PI and/or upgrade the materials sufficiently to meet standard subbase specifications, such as AASHTO M 155 or ASTM D 1241.

Granular materials to use for cement-modified subbases under concrete are restricted to AASHTO Soil Classification Groups A-1, A-2-4, A-2-5, and A-3.

Subbase for Flexible Pavements and Soil-Cement Bases. Cement-modified granular soils have been used as subbases for flexible pavements and soil-cement bases. Projects have been built in Texas, Utah, Arizona, California, and other states.

Usually the existing soil is treated with cement to serve as the subbase. Sufficient cement to produce a firm, stable subbase is used, and a granular material, either untreated or cement-treated, is placed upon this to form the base.

Mixing cement-modified granular material in a central plant for a road subbase in Kansas.

Construction

With a few exceptions, these base and subbase courses are constructed in essentially the same manner as soil-cement and cement-treated base courses.[2] The steps include:

- For initial preparation, shape the area to crown and grade and correct any soft subgrade areas.
- Add specified amounts of cement and water, and mix thoroughly; this is done in a central mixing plant or with mix-in-place equipment (travelling rotary mixer).
- Compact, finish to grade and crown.

In contrast to normal soil-cement construction, there is no time limit between mixing and compacting. The material usually is spread and compacted the same day it is mixed. Often, it is not cured, although curing with a moist spray is suggested to provide maximum benefit from the cement.

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