

# **CEMENT MODIFICATION GUIDELINES**



## **Cement Modification Guidelines**

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# CEMENT-MODIFIED SOIL (CMS)

## INTRODUCTION

Soil-cement has been used for more than 65 years primarily as a hardened base material under rigid and flexible pavements. It provides a durable pavement layer with considerable bearing strength to distribute traffic loads to weak subgrades under streets, roads, highways, airfields and parking areas. The cement content for soil-cement is based on ASTM and PCA tests for wet-dry, freeze-thaw, and brush-loss criteria.

Cement-treated soil mixtures containing less cement than that required for soil-cement have also been used for subbases under concrete pavements. In this case the cement content is generally based on a compressive strength criterion.

Another use of cement with soil is cement-modified soil (CMS). CMS is basically an improved soil and generally is unhardened in that even after compaction and hydration has occurred, the material can still be worked. The objective of CMS is to reduce the ability of the soil to retain moisture, permanently reduce the Plasticity Index (PI), and increase its strength.

CMS for soil stabilization, or more accurately, soil modification, has also been used for more than 65 years. For example, a project initiated in 1938 by the Oklahoma State Highway Department used CMS to minimize swelling of highly expansive clay soils. Testing and a follow-up report done in 1983, 45 years after initial construction, showed the soils to have improved even more than when first treated in 1938, confirming cement's ability to permanently modify and stabilize plastic clay soils. Even by using the "old" construction pulverization and mixing equipment available in 1938, the soils were successfully pulverized into a homogeneous subgrade material. Today, with modern mixers and pulverizers, any concern about inadequate or incomplete mixing can be dismissed.

CMS is not soil-cement. It modifies, improves, and stabilizes the soil through cation exchange and improves its load bearing capabilities through secondary cementation. It provides the contractor an effective working platform immediately and he can begin placing the subsequent pavement layers without a waiting period. CMS can save the contractor and the owner time and money.

The effect of cement modification on plastic soils can be compared to “lime stabilization” (more accurately modification) in its effect on the liquid, plastic, and shrinkage limits of soils. However, CMS provides other advantages as described by the report on the 1938 Oklahoma Project (Ref. 2) and the study by A.P. Christensen in a PCA report published in 1968, “Cement Modification of Clay Soils” (Ref. 6):

1. CBR values are higher (up to 400% and more)
2. Higher compressive strengths (up to 100% and more)
3. Economy:
  - a. Lime is often more expensive than cement.
  - b. Most soils require less cement for modification.
  - c. The total construction time required is less. All the processing of a given area may be completed in one day. There is no delay period required for curing or remixing.
  - d. No curing period is required as there is for lime modification.
  - e. A working platform is established immediately upon completion even if heavy rains occur afterwards.
  - f. Paving can commence immediately if desired.
4. CMS provides not only a permanent modification of the soil, but it also improves strength, plasticity index, and shrinkage limit properties. These properties improve with time.

No special equipment is required for the construction of CMS. Equipment normally used for “lime modification” is adequate, including slurry mixing and dispensing devices. A recommended procedure for processing CMS with both dry and slurry methods follows in this manual. It should be affirmed that CMS is not soil-cement, nor a base-material. It is a permanent modification intended to impart engineered properties to expansive clay soils.

# GUIDELINE CONSTRUCTION SPECIFICATIONS FOR CEMENT MODIFICATION OF CLAY SOILS

## I. DESCRIPTION

This item shall consist of treating the subgrade by scarifying, adding cement, and mixing and compacting the material to the required density. It applies to the subgrade, i.e., natural ground, embankment or existing pavement structure and shall be constructed as specified herein and in conformity with the typical sections, lines and grades as shown on the plans or as established by the Engineer.

The cement factor will be determined by laboratory testing and shall be sufficient to reduce the plasticity index (PI) to 12 or less.

## II. MATERIALS

### 1. Soil

Soil shall consist of approved materials free from vegetation or other objectionable matter encountered in the subgrade. Acceptable material shall also be used in preparation of the roadbed in accordance with this specification.

### 2. Portland Cement

ASTM C150, Type I or II Portland Cement, or that conforming to, ASTM C595 IP, Blended Cement. The contractor shall use bulk cement. All apparatus for handling, weighing and spreading the cement shall be approved by the Engineer in writing. Cement weighing and distribution equipment shall be as specified below (section III).

### 3. Water

Water shall be free from substances detrimental to the hydration of the cement treatment.

## III. EQUIPMENT

1. The machinery, tools and equipment necessary for proper execution of the work shall be on the project prior to the beginning of the construction operations, and be maintained in good working order.
2. Cement shall be stored and handled in closed weatherproof containers until immediately before distribution on the subgrade. If storage bins are used, they shall be completely waterproof.
3. Cement furnished in trucks shall have the net weight of the cement certified.

4. Slurry equipment or trucks may or may not have recirculation system, and shall be equipped with dispersion plates or suitable means for distributing the cement slurry.
5. Spreader bars for distributing dry cement shall be as close to the ground as practical, but in no case shall they be greater than 18 inches above the ground. Spreader bars shall be clean and in good working order so as to produce a consistent and even distribution of cement of the subgrade.

#### IV. CONSTRUCTION METHODS

##### 1. General

It is the primary requirement of this specification to secure a completed course of treated material containing a uniform cement mixture, free from loose or segregated areas, of uniform density and moisture content, well bound for its full depth and with a smooth surface suitable for placing subsequent courses. It shall be the responsibility of the Contractor to regulate the sequence of his work, to use the proper amount of cement as required by the plans, maintain the work and rework the courses as necessary to meet the above requirements.

The roadbed shall be constructed and shaped to conform to the typical sections, lines and grades as shown on the plans or as established by the Engineer.

Pulverizing or mixing equipment will be provided to insure that the material is cut uniformly to the proper depth and which has cutters that will plane the secondary grade to a smooth surface over the entire width of the cut. The machine shall be of such a design that a visible indication is given at all times that the machine is cutting to the proper depth.

##### 2. Application

Cement should be spread only on that area where the mixing and compaction can be completed during the same working day in a timely operation.

The application and mixing of cement with the subgrade material shall be accomplished by either method herein described as "Dry Placement" or "Slurry Placement".

##### a. Dry Placement

The cement shall be spread on the grade at the rates shown on the plans or as directed by the Engineer. The cement shall be distributed at a uniform rate and in such manner as to reduce the blowing of cement by wind to a minimum. Cement shall not be applied when wind conditions, in the opinion of the Engineer, are

such that blowing cement becomes hazardous to traffic or objectionable to adjacent property owners. A motor grader shall not be used to spread the cement. (See spread rate chart on page 12)

b. Slurry Placement

When slurry placement is used, the cement shall be mixed with water to form a slurry of the solids content designated by the Engineer. The distributor truck may be equipped with an agitator which will keep the cement and water in a homogeneous suspension. Mix the required quantity of cement with water to produce a slurry free of objectionable materials and with a consistency that can be easily dispensed. Agitate the slurry continuously. Dispense slurry within 2 hours of adding water and when the roadway is at a moisture content drier than optimum. Spread the slurry uniformly by making successive passes over a measured section of the roadway at the rate directed until the required cement content is attained.

3. Mixing

The mixing procedure shall be the same for “Dry Placing” or “Slurry Placing” as described herein. The material and cement shall be thoroughly mixed by approved road mixers or other approved equipment, and the mixing shall continue until a homogeneous, friable mixture of material and cement is obtained, free from all clods or lumps. Materials shall be mixed as thoroughly as possible at the time of the cement application and brought to the proper moisture content.

If the cement-modified soil mixture contains clods, they shall be reduced in size by raking, blading, discing, harrowing, scarifying or the use of other approved pulverization methods so that when all non-slaking aggregates retained on the No. 4 (4.75mm) sieve are removed, the remainder of the soil-cement mixture shall meet the following requirements when tested dry by laboratory sieves:

Minimum Passing 1 – ½” Sieve	..... 100%
Minimum Passing ¾” Sieve	..... 85%
Minimum Passing ¼” Sieve	..... 60%

4. Compaction

Compaction of the subgrade shall begin immediately after mixing. The material shall be aerated or watered as necessary to provide the optimum moisture. Compaction shall begin at the bottom and shall continue until the entire depth of mixture is uniformly compacted. Compaction shall be in 6 to 8 inch loose lifts.

The course shall be sprinkled, if necessary, and compacted to provide the density specified below as determined by the use of the Standard Proctor (ASTM D698) Moisture/Density Relationship.

<u>Description</u>	<u>Density, Percent</u>	<u>Moisture, Percent</u>
Cement-modified subgrade that will receive subsequent courses.	Not less than 95%, except when shown otherwise on the plans.	Within 2.5% of optimum unless otherwise shown on the plans.

The testing will be as outlined in Test Method ASTM D2922 and ASTM D3017 or other approved methods. In-Place Density tests shall be performed at the rate of one (1) per 300 linear feet of paving for two (2) lanes. The suitability of the stabilization shall be confirmed by Atterberg Limit testing at the rate of one (1) test per 2,500 cubic yards of processed material.

In addition to the requirements specified for density, the full depth of the material shown on the plans shall be compacted to the extent necessary to remain firm and stable under construction equipment. After each section is completed, tests for density will be made. If the material fails to meet the density requirements, it shall be reworked as necessary to meet these requirements.

Throughout the entire operation the shape of the course shall be maintained by blading, and the completed surface shall be smooth and conform to the typical section shown on the plans. Should the material, due to any reason or cause, lose the required stability, density and finish before the next course is placed or the work is accepted, it shall be recompacted and refinished at the sole expense of the Contractor.

#### V. FINISHING AND PREPERATION FOR SURFACING

After the final layer of the cement-modified subgrade has been compacted, it shall be brought to the required lines and grades in accordance with the typical sections. The completed section shall then be finished by rolling with a pneumatic tire or other suitable roller.

#### VI. MEASUREMENT

Cement treatment of the subgrade shall be measured by the square yard as shown on the typical section and for the quantity chosen by the Engineer. The quantity of cement shall be measured by the ton.

## VII. PAYMENT

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid in accordance with the following Sections.

### 1. Cement

Cement will be paid for at the unit price bid for "Cement". This price is full compensation for materials, delivery, equipment, labor, tools, and incidentals.

### 2. Cement Treatment

Cement treatment will be paid for at the unit price bid for "Cement Treatment" of the compaction method and depth specified. This price is full compensation for shaping existing material, loosening, mixing, pulverizing, providing cement, spreading, applying cement, compacting and finishing, blading, shaping and maintaining, replacing, disposing of loosened materials, processing, hauling, water, equipment, labor, tools, and incidentals.

## CEMENT-MODIFIED SOILS

### Testing for Atterberg Limits (P.L., L.L., P.I.)

1. Representative clay sample is allowed to air dry or may be placed in 140°F (60°C) (max) oven.
2. After drying, sample shall be pulverized by any suitable method to obtain an amount equal to 200 – 500 grams passing #40 (425 $\mu$ m) mesh sieve for each cement content tested.
3. Various percentages of cement, based on dry weight of soil samples, shall be added to soil and thoroughly mixed.
4. Water, sufficient to bring sample just beyond the liquid limit, shall be added and thoroughly mixed.
5. Specimens shall be placed in sealed plastic bags and stored for a period of 24 hours\* at room temperature before drying.

\*Note: Numerous tests by PCA, using various waiting periods, show that if time is a factor in determining cement content, satisfactory results can be obtained with only a 1-hour wait period. P.I.'s will be slightly lower initially than those with a 24-hour period. After a 48-hour wait period results will only be slightly better than those obtained after 24 hours.

6. After the waiting period, sample shall be dried in a 140°F (60°C) (max) oven.
7. Upon drying, sample shall be pulverized as before to obtain sufficient material passing the #40 (425 $\mu$ m) mesh sieve.
8. Liquid, plastic, and shrinkage limits shall be obtained in the standard manner, and the plasticity index calculated.

### Testing for Unconfined Compression

1. Steps 1 thru 4 shall be as for Atterberg limits except for larger quantity of material.
5. After steps 1 thru 4 are completed, specimen shall be molded immediately in accordance with ASTM D-1633. It is recommended that 3 specimens be molded for each testing period, i.e. 3 for 7 days, 3 for 28.
6. Molded specimens shall be stored in sealed plastic bags at 73.5  $\pm$  3.5°F (23.0  $\pm$  2.0°C) until the testing period (7, 28 days). Specimen shall be tested in accordance with ASTM D-1633, Method A.
7. The average compressive strength for the three (3) specimens for each testing period shall be used.

## GUIDELINE CONSTRUCTION PROCEDURES FOR SLURRY APPLICATION

1. Cut the subgrade to approximate final grade.
2. Moderately scarify the subgrade to the approximate required depth of treatment. Scarify using a motor grader with short teeth, or other appropriate means.
3. Distribute the slurry evenly across the site. The slurry may be agitated, and should be dispensed as soon as practical, but no longer than 60-90 minutes after water is added to the cement.
4. Thoroughly mix the slurry into the subgrade using a rotary mixer, disc, or other appropriate means. If necessary, make passes at various angles across the site to facilitate breaking up large clods.
5. Process the subgrade to the required depth using an approved rotary mixer. Add water as necessary to achieve optimum moisture and for ease of pulverization. Continue processing until gradation requirements have been met.
6. Compact the cement-modified subgrade to the specified density and moisture with sheepsfoot, pneumatic or other approved compaction equipment.
7. After proper compaction has been achieved, blade the subgrade to finished grade within the specified tolerances.
8. Seal the surface by rolling with a pneumatic roller.
9. Proceed with paving construction as soon as practical, or as directed by the Engineer.

## GUIDELINE CONSTRUCTION PROCEDURES FOR DRY APPLICATION

1. Cut the subgrade to approximate final grade.
2. Thoroughly scarify the subgrade to the approximate required depth of treatment. Scarify using a motor grader with short teeth, or other appropriate means.
3. Spread the dry cement at the prescribed rate.
4. Mix the cement into the subgrade using a rotary mixer, disc, or other approved methods. If possible, make passes at various angles across the site to facilitate breaking up large clods.
5. Add water for mixing.
6. Process the subgrade to the required depth using an approved rotary mixer until the required gradation has been achieved.
7. If necessary, continue adding water during the mixing process to reduce dusting, and to ease in pulverization and to obtain optimum moisture.
8. Compact the cement modified subgrade to the specified density and moisture with sheepsfoot, pneumatic or other approved compaction equipment.
9. Blade the subgrade to finished grade within the specified tolerances.
10. Seal the surface by rolling with a pneumatic roller.
11. Proceed with paving construction as soon as practical, or as directed by the Engineer.

## REFERENCES

1. Roberts, J.D., "Performance of Cement-Modified Soils: A Follow-Up Report," Transportation Research Record, No. 1089, pp 81-86, Transportation Research Board, National Research Council, Washington D.C., 1986.
2. Oklahoma State Highway Department, "Report on FAP-215FG" (unpublished report, Central Laboratory), Oklahoma City, OK, 1944.
3. Prusinski, J.R., PE and Bhattacharja, S., Ph.D, "Cement Stabilization of Clay Soils: A State-of-the-Art Synopsis", 1997.
4. Hopkins, T.C., Hunsucker, D.Q., and Beckham, T., "Long-Term Performance of Flexible Pavements Located on Cement-Treated Soils," Transportation Research Board, Bulletin No. 1440, Transportation Research Board, Washington D.C., 1994.
5. Portland Cement Association, "Properties and Uses of Cement-Modified Soil," Report No. IS411.01P, Skokie, IL, 1992.
6. Christensen, A.P., "Cement Modification of Clay Soils," (RD002.01S), Portland Cement Association, 1969.

Table 1

CEMENT SPREAD REQUIREMENTS POUNDS PER SQAURE YARD

COMPACTED DEPTH, INCHES

Percent Cement By Volume	5	6	7	8
3.0	10.6	12.7	14.8	17.0
3.5	12.4	14.8	17.3	19.8
4.0	14.1	16.9	19.7	22.6
4.5	16.0	19.1	22.2	25.4
5.0	17.8	21.2	24.7	28.2
5.5	19.4	23.3	27.2	31.0
6.0	21.1	25.4	29.6	33.8
6.5	22.9	27.5	32.1	36.6
7.0	24.7	29.6	34.6	39.5
7.5	26.5	31.7	37.0	42.3
8.0	28.2	33.8	39.5	45.1