# Guide to Cement-Treated Base (CTB)

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PCA
Portland Cement Association

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**Abstract:** Cement-treated base (CTB) is a mixed-in-place or central-plant-produced material consisting of soil/aggregate, cement, and water that creates a strong and durable stabilized roadway base. This guide to CTB discusses its applications, benefits, design, construction, testing, and performance.

**Keywords:** cement-treated base, CTB, pavement, subgrade, soil/aggregate, pavement structure, portland cement, pavement design, mixed-in-place, pugmill, moisture-density relationship, compressive strength, mix design, Tube Suction Test, processing, scarification, pre-wetting, reflective cracking, soil-cement.

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**Cover photo:** Plant-mixed CTB project in South Georgia. Courtesy of Mr. Dwane Lewis, Technical Services Manager, Georgia Department of Transportation. (IMG24044)

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**WARNING:** Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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# 1 Introduction

## Definition

Cement-treated base (CTB) is a general term that applies to an intimate mixture of native soils and/or manufactured aggregates with measured amounts of portland cement and water that hardens after compaction and curing to form a strong, durable, frost resistant paving material. Other descriptions such as soil-cement base, cement-treated aggregate base, cement-stabilized roadbed, and cement-stabilized base are sometimes used.

CTB can be mixed in place using on-site materials, or mixed in a central plant using selected material (often manufactured aggregates). Mixed-in-place CTB is compacted after blending, and CTB mixed in a central plant is hauled to the placement area in dump trucks and placed on the roadway using a grader, paver, or Jersey-type spreader. A bituminous wearing course or portland cement concrete is placed on top of the CTB to complete the pavement.

## Performance with CTB

While the concept of stabilizing soils and aggregates for pavement purposes has been around for more than a century, engineered CTB was first used in 1935 to improve the roadbed for State Highway 41 near Johnsonville, South Carolina. Today, thousands of miles of CTB pavements in every state in the United States and in all the Canadian provinces are providing good service at low maintenance costs.

CTB is widely used as a pavement base for highways, roads, streets, parking areas, airports, industrial facilities, and materials handling and storage areas. The structural properties of CTB depend on the soil/aggregate material, quantity of cement, curing conditions, and age. Typical properties of CTB material are shown in Table 1.

***Table 1. Properties of CTB***

| Property | 7-Day values |
|---|---|
| Compressive strength | 300 – 800 psi (2.1 – 5.5 MPa) |
| Modulus of rupture | 100 – 200 psi (0.7 – 1.4 MPa) |
| Modulus of elasticity | 600,000 – 1,000,000 psi (4,100 - 6,900 MPa) |
| Poisson's ratio | 0.15 |

The advantages of CTB are many:

- CTB provides a stiffer and stronger base than an unbound granular base. A stiffer base reduces deflections due to traffic loads, which results in lower strains in the asphalt surface. This delays the onset of surface distress, such as fatigue cracking, and extends pavement life (see Figure 1.1).
- CTB thicknesses are less than those required for granular bases carrying the same traffic because the loads are distributed over a large area (see Figure 1.2). The strong uniform support provided by CTB results in reduced stresses applied to the subgrade. A thinner cement-stabilized section can reduce subgrade stresses more than a thicker layer of untreated aggregate base. Subgrade failures, potholes, and road roughness are thus reduced. CTB's slab-like characteristics and beam strength are unmatched by granular bases that can fail when interlock is lost. Figure 1.3 is a core of completed CTB showing the tightly bound soil/aggregate.
- A wide variety of in-situ soils and manufactured aggregates can be used for CTB. This eliminates the need to haul in expensive select granular aggregates.

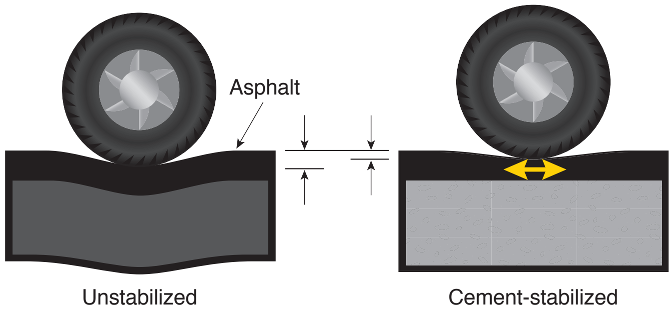


*Figure 1.1. Unstabilized bases have high deflection due to low stiffness, which results in high surface strains and eventual fatigue cracking. The higher stiffness provided by cement-stabilized bases produces lower deflections, resulting in lower surface strains and longer pavement life.*

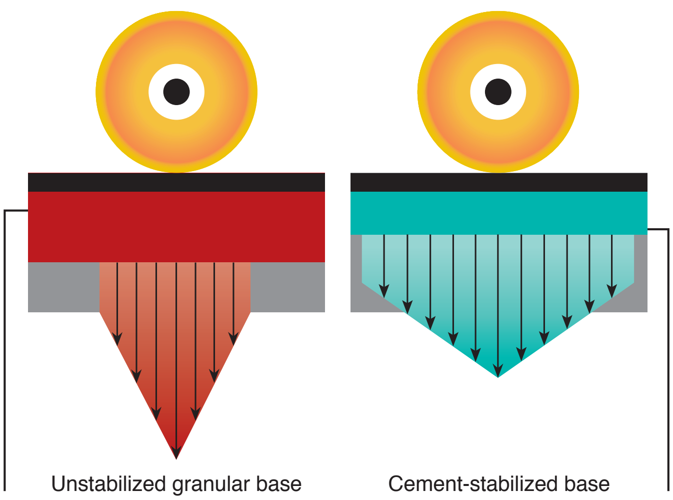


*Figure 1.2. Soils/aggregates in cement-stabilized bases are tightly bound together by cement. The entire mass is hardened into a slab with enough rigidity and strength to spread loads over a large area of the subgrade. Unstabilized granular bases concentrate loads on a small area.*

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*Figure 1.3. Pavement core proves strength of CTB. Even in severe climates the strength of CTB increases due to continued cement hydration.*

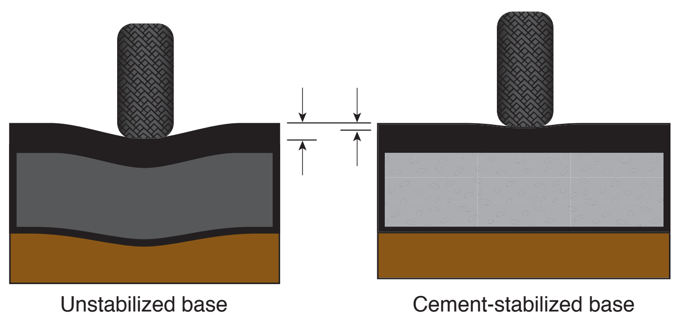


*Figure 1.4. Rutting can occur in the surface, base, and subgrade of unstabilized bases due to repeated wheel loading. Cement-stabilized bases resist consolidation and movement, thus virtually eliminating rutting in all layers but the asphalt surface.*

- The construction operation progresses quickly with little disruption to the traveling public. It can be accomplished while still maintaining traffic.
- Rutting is reduced in a CTB pavement. Loads from channelized traffic will displace unbound granular material beneath flexible surface pavements (see Figure 1.4).
- Moisture intrusion can destroy unstabilized pavement bases, but not when cement is used to bind the base. CTB pavements form a moisture-resistant base that keeps water out and maintains higher levels of strength, even when saturated, thus reducing the potential for pumping of subgrade soils (see Figure 1.5).
- CTB provides a durable, long-lasting base in all types of climates. As an engineered material it is designed to resist damage caused by cycles of wetting and drying and freezing and thawing.
- Similar to concrete, CTB continues to gain strength with age. This is especially important when considering that many pavements experience greater traffic loads and volume throughout their service life. This reserve strength accounts in part for CTB's fine performance.

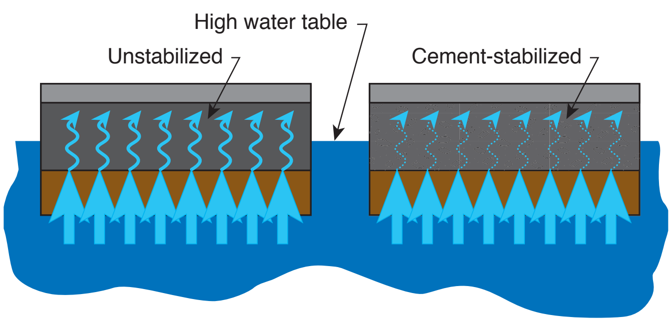


***Figure 1.5. Moisture can infiltrate unstabilized bases through high water tables or capillary action causing softening, lower strength, and reduced modulus. Cement stabilization reduces permeability, helps keep moisture out, and maintains a high level of strength and stiffness even when saturated.***

# 2 Design

## Material Requirements

Because CTB can either be constructed in place or plant mixed, the correct selection of soil and aggregate materials is important to the production of quality CTB mixes. This knowledge of the ingredients is coupled with the construction requirements and specifications for the intended project in order to ensure a CTB mix that meets the design and performance objectives. The design procedures mentioned in this document relate to all climate areas when the quality of the CTB meets requirements for aggregate and cement factor as described below, and when it is properly constructed.

The soil and aggregate materials for use in CTB may consist of (1) any combination of gravel, stone, sand, silt, and clay; (2) miscellaneous material such as caliche, scoria, slag, sand-shell, cinders, and ash; (3) waste material from aggregate production plants; (4) high-quality crushed stone and gravel base course aggregates; or (5) old flexible pavements, including the pulverized bituminous surface and stone or gravel base course.

To achieve the most economical cement factor for durable CTB, it is recommended to use soil/aggregates that provide dense, well-graded blends with a nominal maximum size not to exceed 3 inches (75 mm) in order to help minimize segregation and produce a smooth finished surface (see Figure 2.1). Gap-graded soil/aggregate mixes that are dominated by two or three sizes are not desirable for most CTB applications. There are instances where cement-treated *permeable* bases using an open or gap-graded mix are utilized under concrete pavements. The American Concrete Pavement Association has information on the design, construction, and maintenance of these stabilized drainable bases available as a Portland Cement Association (PCA) publication titled *Cement-Treated Permeable Bases for Heavy-Traffic Concrete Pavements,* IS404P.

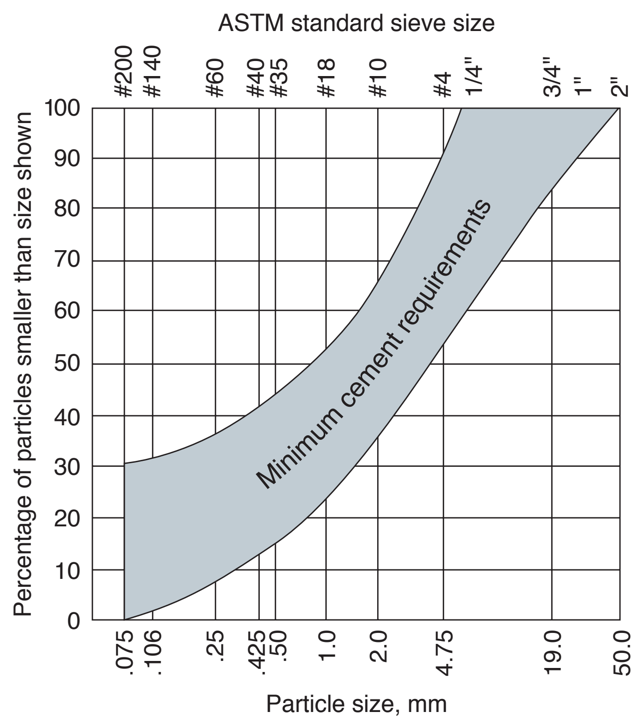


***Figure 2.1. Aggregate gradation band for minimum cement requirements.***

More coarsely graded soil/aggregate blends have been used; however, the cement content required to make durable CTB is generally greater. Up to a limit, an increase in the quantity of coarse material will reduce the cement requirement because the finer particles requiring cement to bind them together are replaced by coarser particles. The total density of the soil/aggregate material increases as the quantity of coarse material increases, but the density of the finer material decreases. Too much coarse material interferes with compaction of the matrix of finer particles. Adequate density of the fine fraction is important, for it is here that most of the cementing action takes place, forming a matrix that holds the coarser particles together.

## Pavement Design

The ability of a pavement base to carry loads depends on the strength of the base material and the thickness of the base layer. A thin, but strong base can theoretically carry the same load as a thick, but weaker base. However, the thin, strong base should be avoided because it can become brittle and fracture, resulting in potential reflection cracks in the pavement surface (see page 13 under Reflective Cracking). When selecting thicknesses for CTB pavements, a thicker base with less strength is usually preferred (see discussion of Balanced Design on page 7). Today's more powerful mixing and compacting equipment has made the job of constructing thicker CTB layers much easier and more reliable compared with equipment used years ago.

CTB possesses its own unique structural characteristics. CTB pavements are designed for both economy and long service life. The factors analyzed to determine the CTB and surface design thickness are:

1. Subgrade strength
2. Pavement design period
3. Traffic, including volume and distribution of axle weights (single- and tandem-axle loading configurations of conventional trucks)

In most cases, engineers have the option of selecting a CTB design procedure for the pavement structure. The 1993 American Association of State Highway and Transportation Officials (AASHTO) design guide for pavement structures, for example, uses a Structural Layer Coefficient to model base materials. In addition, PCA has three separate information sheets that present detailed design methods for streets and highways (PCA publication *Thickness Design for Soil-Cement Pavements,* EB068), airfields (PCA publication *Soil-Cement Pavements for Light Aircraft,* IS203), and special heavy-load areas such as container ports, log handling areas, and other heavy industrial loads (PCA publication *Thickness Design of Soil-Cement Pavements for Heavy Industrial Vehicles,* IS187).

These three PCA design procedures are based on information from several sources including research, theory, full-scale test pavements, and the performance of pavements in service. A research program conducted by PCA correlates the design information from these sources and results in a procedure developed uniquely for CTB materials.

A few 4 to 5-inch (100 to 125 mm) thick pavements have been constructed and have held up well under favorable conditions of light traffic and strong subgrade support; however, most CTB pavements in service are 6 inches (150 mm) thick. This thickness has proved satisfactory for the service conditions of secondary roads, residential streets, and light-traffic airfields.

Many miles of 7 to 9-inch (175 to 225 mm) thick pavements are in service on primary and heavy-traffic secondary roads. On interstate highways, thickness ranges from 6 to 12 inches (150 to 300 mm) have been incorporated into the total pavement structures. CTB pavements with thicknesses of 12 inches (300 mm) or more are not numerous, although a few airport projects have been built with thicknesses of up to 15 inches (375 mm). CTB thicknesses exceeding 12 inches (300 mm) are difficult to compact in one lift. For design thicknesses greater than 12 inches (300 mm) multiple lift construction is used.

CTB can also be used as a subbase layer under concrete pavements to prevent mud-pumping of fine-grained subgrade soils under wet conditions and heavy truck traffic. In addition to preventing mud-pumping, CTB provides a uniform, strong support for the pavement, provides a firm, stable working platform for construction equipment, prevents infiltration of subgrade into the subbase, prevents subbase consolidation under traffic, and provides increased load transfer at pavement joints.

## Mix Design

Designing the proper amount of water and cement for CTB is not only important to obtain a good final product, but also provides important information for quality control during construction. The PCA publication *Soil-Cement Laboratory Handbook,* EB052, provides comprehensive information on testing procedures for determining the appropriate cement content, water content, and compaction requirements for CTB materials. Research has shown that cement-stabilized materials have better strength and performance when they are fully compacted, so determining final compaction density is fundamental to the design procedure.

Compaction density is determined through the Standard Test Method for Moisture-Density Relations of Soil-Cement Mixtures (ASTM D 558). The test procedure is similar to ASTM D 698 which uses the standard compaction effort used for soil and aggregate. The ASTM D 558 test method is a common (as well as inexpensive) procedure for most construction testing labs. The test can be performed in either the laboratory or the field, and determines the maximum dry density (unit weight) for the CTB mix, and the optimum-moisture content. Figure 2.2 shows a typical compaction curve from the ASTM D 558 test method. If the mix is too dry, there is not enough moisture available to lubricate the particles into a denser formation. If the mix is too wet, the excess moisture pushes the particles apart.

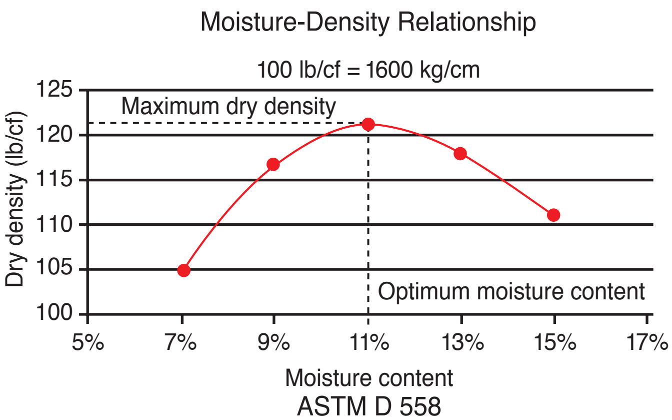


***Figure 2.2. Determining the Maximum Dry Density and Optimum Moisture Content (ASTM D 558).***

The amount of water in the mix is called the water (moisture) content, and is defined as the weight of water in the mix (expressed as a percentage of the dry material):

$$\text{water content, } w\ (\%) = \frac{\text{weight of water in mix}}{\text{weight of oven-dry CTB material}} \times 100$$

The amount of cement is normally expressed in percentage on a weight or volume basis. The cement content by weight is based on the oven-dry weight of the soil/aggregate only (cement is not included) and is expressed as:

$$\text{cement content, } c\ (\%) = \frac{\text{weight of cement in mix}}{\text{weight of oven-dry soil/aggregate}} \times 100$$

The amount of water and cement required in the mix will depend upon the project specified strength and gradation of the soil/aggregate materials. Typical specifications for most mixed-in-place and plant mixed CTB call for a minimum of 100% passing the 3-inch (75 mm) sieve, 95% passing the 2-inch (50 mm) sieve, and 55% passing the No. 4 (4.75 mm) sieve. If the blend contains more fine-grained soil, then more cement and water will be required because of the larger surface area of the finer particles.

The next step is to conduct a moisture-density test to determine the moisture content for molding the CTB specimens for compressive strength testing. Since the exact cement content is not known at this stage of the design, an assumed cement content can be chosen in conducting the test. Table 1 in PCA publication *Soil-Cement Laboratory Handbook* may be used to estimate cement content for the moisture-density test. Cement contents within a range of one or two percent will not significantly influence the results. However, once the exact cement content is established, a moisture-density test should be conducted with the established cement content in order to determine the control factors for field construction.

Using the optimum moisture content from the initial moisture-density test, a series of CTB specimens are prepared at different cement contents to determine compressive strength. Typically three cement contents are chosen (for example, 2%, 5%, and 8%). Caution should be used when cement contents exceed 8% as increased shrinkage may occur, resulting in reflection cracking. It is recommended that a minimum of two specimens be prepared for each cement content. These specimens are moist cured for 7 days, and then tested for unconfined compressive strength according to ASTM Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders (ASTM D 1633). This will give a range of strength results in which to determine the required cement content.

## Balanced Design

CTB must be strong enough to provide adequate pavement support for the current and future traffic loading conditions. In addition, CTB needs to remain hard and durable and be able to resist the volume changes or hydraulic pressures caused by freezing and thawing and moisture changes that could gradually break down the cementitious bonds.

In general, a cement content that will provide a 7-day unconfined compressive strength between 300 and 400 psi (2.1 and 2.8 MPa) is satisfactory for most mixed-in-place CTB applications. Because there is usually more coarse aggregate involved, strengths for plant mixed CTB can be as high as 800 psi (5.5 MPa). Even higher strengths may be achieved depending on project requirements. However, the main reason for limiting strength is to minimize shrinkage cracking caused by higher cement and water content. Experience has shown that high strengths can cause additional cracks to reflect through the pavement surface. The objective is to have a "balanced design," where enough cement is used so that the resulting stabilized base is strong, durable, and relatively impermeable, but not so strong that it results in other types of distress in the pavement.

## Moisture Sensitivity

A new test procedure that shows a great deal of promise for future implementation is the Tube Suction Test (TST). This test helps to identify base materials that may be particularly sensitive to moisture degradation in the field, and to determine the correct amount of cement to use for stabilization. The testing protocol, originally developed by the Texas Transportation Institute and modified by the Texas Department of Transportation (TxDOT), is described in TxDOT Test Method Tex-144-E (draft).

The concept behind the TST is to measure the movement of water in a sample of cement-stabilized material (see Figure 2.3). The test results can be evaluated to make sure that enough cement is used to "choke off" the permeability and capillarity of the specimen.

PCA currently recommends the use of the TST when working with materials that may be moisture sensitive, or when the presence of water may be especially detrimental – such as in areas with deep frost penetration.


(IMG24046)

***Figure 2.3. The Tube Suction Test measures the movement of water in cement-stabilized materials.***

# 3 Construction

## General Requirements

In CTB construction, the objective is to thoroughly mix a soil/aggregate material with the correct quantity of portland cement and enough water to permit maximum compaction. The resulting CTB must be adequately cured to provide the necessary moisture needed for cement hydration to fully harden the CTB mixture.

The fundamental control factors for quality CTB are:

1. Proper cement content
2. Adequate moisture content
3. Thorough mixing
4. Adequate compaction
5. Proper curing

The construction steps are

1. Preparation
   - Checking and calibration of equipment
   - Correcting any soft subgrade areas
   - Shaping the area to proper crown and grade

2A. Mixed-in-Place Processing
   - Spreading portland cement and mix
   - Applying water and mix
   - Compacting
   - Finishing
   - Curing

2B. Central Plant Processing
   - Mixing soil/aggregate material, cement, and water in central plant
   - Hauling and spreading
   - Compacting
   - Finishing
   - Curing


(IMG24047)

*Figure 3.1. Mixing CTB in a continuous-flow-type pugmill.*

The area to be paved must be shaped to proper crown and grade. Proper compaction is one of the fundamental requirements for CTB construction. If the subgrade is soft and cannot support the compaction equipment, adequate density will not be obtained. Therefore, soft areas should be located and made stable before CTB material is mixed or placed.

Soil/aggregate, cement, and water can be mixed in a central mixing plant, or mixed in place using traveling mixing machines. The mixing methods include:

1. Single-shaft in-place mixing equipment
2. Central mixing plants
   - Continuous-flow-type pugmill
   - Batch-type pugmill
   - Rotary-drum mixer

## Mixed-In-Place Method

Guide stakes should be set to control the width of treatment and to guide the operators during construction.

Soil/aggregate in required quantity should be distributed on an accurately graded, well-compacted subgrade in an even layer or in a uniform windrow, depending upon the type of mixing equipment to be used.

For maximum efficiency the day's work should be broken down into several adjacent sections rather than one or two long sections.

Bulk cement is normally hauled to the jobsite in bulk transport trucks. Cement is then transferred to job cement storage trucks, which are usually enclosed or fitted with canvas covers. Cement is transferred into the cement storage trucks pneumatically by a screw or belt conveyor. Prior to cement spreading, truckloads of cement are weighed on portable platform scales or at a nearby scale.

A mechanical cement spreader is attached to the dump truck. To obtain a uniform cement spread, the spreader should be operated at a constant slow speed with a constant level of cement in the hopper. The mechanical cement spreader can also be attached directly behind a bulk cement truck. Cement is moved pneumatically from the truck through an air separator cyclone that dissipates the air pressure. Cement falls into the hopper of the spreader. Skirts are sometimes used to minimize wind blown dusting (see Figure 3.2). Placing dry portland cement in an uncontrolled manner by blowing under pressure should always be avoided. Typical spread rates are shown in Table 2.

Cement is most commonly applied dry, but can also be applied in a slurry form. With a slurry application, it is important that the slurry be dispersed uniformly over the placement area so that it will not pool or run off in any manner.

Materials that contain excessive amounts of moisture will not mix readily with cement. However, granular materials can be

*Table 2. Cement Spread Requirements*

| Percent cement by weight | | Percent cement by volume | Cement spread requirements in pounds per square yard (kg/m$^2$) for compacted thicknesses | | | | |
|---|---|---|---|---|---|---|---|
| 115 pcf (1842 kg/m$^3$) | 125 pcf (2002 kg/m$^3$) | | 5 in. (125 mm) | 6 in. (150 mm) | 7 in. (175 mm) | 8 in. (200 mm) | 9 in. (225 mm) |
| 2.5 | 2.3 | 3.0 | 10.6 (5.7) | 12.7 (6.8) | 14.8 (7.9) | 17.0 (9.1) | 19.1 (10.2) |
| 2.9 | 2.7 | 3.5 | 12.4 (6.6) | 14.8 (7.9) | 17.3 (9.3) | 19.8 (10.5) | 22.3 (11.9) |
| 3.4 | 3.1 | 4.0 | 14.1 (7.5) | 16.9 (9.1) | 19.8 (10.5) | 22.6 (12.1) | 25.5 (13.6) |
| 3.8 | 3.5 | 4.5 | 15.9 (8.5) | 19.1 (10.2) | 22.2 (11.8) | 25.4 (13.6) | 28.7 (15.4) |
| 4.2 | 3.9 | 5.0 | 17.6 (9.4) | 21.2 (11.3) | 24.8 (13.3) | 28.2 (15.1) | 31.8 (17.0) |
| 4.7 | 4.3 | 5.5 | 19.4 (10.3) | 23.3 (12.4) | 27.2 (14.6) | 31.0 (16.5) | 35.0 (18.7) |
| 5.2 | 4.7 | 6.0 | 21.2 (11.3) | 25.4 (13.6) | 29.6 (15.8) | 33.9 (18.1) | 38.1 (20.4) |
| 5.6 | 5.1 | 6.5 | 21.9 (11.7) | 27.5 (14.7) | 32.1 (17.1) | 36.6 (19.6) | 41.2 (21.9) |
| 6.0 | 5.6 | 7.0 | 24.7 (13.2) | 29.6 (15.8) | 34.6 (18.5) | 39.5 (21.1) | 44.4 (23.7) |
| 6.5 | 6.0 | 7.5 | 26.5 (14.2) | 31.7 (16.9) | 37.0 (19.8) | 42.3 (22.5) | 47.6 (25.4) |
| 7.0 | 6.4 | 8.0 | 28.2 (15.1) | 33.8 (18.0) | 39.5 (21.1) | 45.1 (24.1) | 50.8 (27.2) |
| 7.4 | 6.9 | 8.5 | 30.0 (16.0) | 36.0 (19.2) | 42.1 (22.4) | 48.0 (25.6) | 54.2 (28.9) |
| 7.9 | 7.2 | 9.0 | 31.8 (17.0) | 38.1 (20.4) | 44.6 (23.7) | 50.8 (27.2) | 57.6 (30.7) |
| 8.4 | 7.7 | 9.5 | 33.5 (17.9) | 40.2 (21.5) | 47.1 (25.1) | 53.6 (28.6) | 59.8 (31.9) |
| 8.9 | 8.2 | 10.0 | 35.2 (18.8) | 42.3 (22.5) | 49.5 (26.5) | 56.4 (30.1) | 62.0 (33.4) |

mixed effectively with moisture contents slightly above optimum.

Procedures for applying water and mixing will depend on the type of mixing machine used. A thorough mixture of soil/aggregate, cement, and water must be obtained. Uniformity of the mix is easily checked by digging trenches or series of holes at regular intervals for the full depth of treatment and inspecting the color of the exposed mixture. Uniform color and texture from top to bottom indicate a satisfactory mix; a streaked appearance indicates insufficient mixing.

(IMG24048)

*Figure 3.2. In mixed-in-place construction, cement is uniformly distributed over the area to be processed.*

**Single-shaft traveling mixing equipment.** CTB construction with single-shaft traveling mixers varies depending on the type equipment used. Some equipment can thoroughly mix the CTB in a single pass (see Figure 3.3). Other equipment requires more than one mixing pass. However, the basic principles and objectives are the same.

Shaping the roadway and scarification are the first steps of preparation. The larger mixers can scarify as well as mix an existing pavement surface and tough soil/aggregate material. For smaller equipment the soil/aggregate may need to be loosened with a scarifier. Pre-wetting the soil/aggregate is common practice. Applying water at this stage of construction saves time during actual processing operations because most of the required water will already have been added to the soil/aggregate when cement is spread. Pre-wetting prevents cement from sifting to the bottom of the mix by causing it to adhere more readily to the soil/aggregate particles. Moisture should be applied uniformly during pre-wetting. Evaporation losses are reduced by incorporating this

(IMG24049)

*Figure 3.3. Mixing CTB in place using a single-shaft traveling mixer.*

moisture into the mix. After scarifying and pre-wetting, the loose soil/aggregate is shaped to crown and grade.

Cement is spread by a mechanical cement spreader. Then the mixer picks up the soil/aggregate and cement and mixes them in place. Water, supplied by a tank truck, is usually applied to the mixture by the spray bar mounted in the mixing chamber, or water may be applied ahead of the mixer by water pressure distributors. The soil/aggregate and cement must be sufficiently blended when water contacts the mixture to prevent the formation of cement balls. The number of mixing passes depends on the type of mixer, the soil/aggregate characteristics and its moisture content, and on the forward speed of the mixer.

## Central-Plant Method

Revolving-blade pugmills can be used for mixing non-plastic to slightly plastic soil/aggregate materials. Rotary-drum mixers are suitable for mixing coarse, non-plastic soil/aggregate materials. With batch-type pugmills and rotary-drum mixers, materials are batch weighed, mixed, and placed into haul trucks. With continuous-flow-type pugmills, materials are individually metered by weight or volumetrically prior to entering the pugmill mixing operation. Each plant must be calibrated to make sure proper quantity of material is entering the mixer.

The continuous-flow-type pugmill plant is the most common (see Figure 3.1). The plant setup is typified by a hopper or bulkhead feeder system containing the soil/aggregate, a cement silo, surge hopper and feeder, main feeder belt, and revolving-blade pugmill mixer.

Cement is usually metered onto the soil/aggregate main feeder belt just prior to entering the pugmill. Water is metered and added by means of spray bars mounted above the pugmill. The mixed material is discharged into a holding hopper and then into haul trucks.

(IMG24050)

*Figure 3.4. Twin-shaft pugmill mixing chamber thoroughly mixes the CTB.*

There are three types of cement feeders in common use:

1. Auger or screw-type feeder
2. Belt feeder
3. Rotary-vane feeder

Each requires a surge tank or hopper for proper operation. The surge tank maintains a constant head of cement above the meter.

The calibration of a continuous-flow central plant is a relatively simple operation. First, the soil/aggregate is run through the plant for a short period and is collected and weighed. Then the cement meter is operated while soil/aggregate that is being run through the plant is collected and weighed. Adjustments are made until the correct proportion is attained. The speed of the cement meter is thus synchronized with the speed of the main feeder belt.

At the plant, additional moisture is added to compensate for moisture loss during transporting and spreading.

CTB is usually paid for on a weight basis. Haul trucks of mixed material are usually weighed on a nearby scale.

The mixed material is placed on a moist subgrade without segregation and is spread by an aggregate spreader, or by two spreaders operating side by side, or by an automatic string-line-controlled subgrader.

(IMG24051)

*Figure 3.5. Soil/aggregate spreading operation working in staggered position across roadway to minimize longitudinal cold joints.*

## Compaction, Finish, and Cure

Compaction starts immediately after the CTB material has been mixed or spread. While vibratory-steel-wheel rollers are most common, many types of compaction equipment may be used to obtain adequate densification.

Adequate compaction at the edge of the pavement is extremely important. With plant-mixed and spread CTB, one method that permits proper edge compaction is to blade shoulder material up against the spread CTB to confine it. The shoulder material then provides the support for edge compaction.

If mixing or spreading has been carefully done, the compacted CTB should be smooth and at grade, and minimum finishing should be required. If needed, the surface is shaped, moistened, and re-rolled to tighten the surface. The finished surface should be dense and free of cracks, ridges, and loose material.

When CTB is placed as a subbase layer under a concrete pavement, most contractors use electronically controlled equipment operating from an accurately placed reference wire or string line for grade control. Initially, the CTB is placed slightly high and after compaction is trimmed to grade and finish rolled.

(IMG24052)

*Figure 3.6. Vibratory steel-wheel rollers typically used to compact CTB.*

Compacted and finished CTB contains sufficient moisture for adequate cement hydration. The newly constructed base should be kept moist (by lightly watering or misting) for a 7-day period, or a moisture-retaining cover or curing compound can be placed over the CTB soon after completion to retain the moisture and permit the cement to hydrate. If the road will have an asphalt surface, a bituminous prime-coat can be applied at any time, as this will act as a curing membrane. The finished CTB surface is kept moist until the curing compound is applied. At the time of application, the CTB surface should be free of all dry, loose, and extraneous material.

Construction joints are formed by cutting back into the completed work to form a true vertical face. Special attention should he given to joint construction to ensure a vertical joint, adequately mixed material, and compaction up against the joint.

A thorough discussion on CTB construction and field inspection procedures can be found in the PCA publications *Soil-Cement Construction Handbook,* EB003 and *Soil-Cement Inspectors Manual,* PA050.

## Surfacing

A concrete or bituminous surface should be placed on the completed CTB as soon as practical. Although it is not unusual for several weeks to elapse between completion of the CTB and placement of the wearing course, it can be placed immediately provided the CTB is stable (does not rut or shove) under construction traffic. The time required for this can range from 4 to 48 hours. The type and thickness of surfacing depend on traffic volume, availability of materials, cost, and local practices. Local experience and practice will dictate the specific details of construction. Good construction practices such as thorough cleaning of the base course, should always be followed when the surfacing is placed.

Traffic can be placed on the CTB in the same time frame, as long as repeated applications of heavy trucks are not involved. In many cases with low-volume roads, traffic is allowed to run on the compacted base until the project is ready for surfacing. For conditions where heavy truck traffic is involved, up to 7 days may be required to make sure the base has gained sufficient strength for a high volume of heavy trucks.

## Reflective Cracking

CTB will shrink naturally while curing. With properly designed pavements, and good construction procedures, the resulting cracks in the base will not significantly affect pavement performance. In some cases larger cracks in the base layer can result in stress concentrations, and the cracks may reflect from the base into the surface. This does not normally affect pavement roughness, but may influence the overall appearance of the pavement.

Usually proper construction procedures, crack minimization strategies, and maintenance sealing, if necessary, can eliminate requirements for significant maintenance due to reflective cracking. Newer techniques such as microcracking or using a stress absorbing interlayer have been very successful. A well designed and properly maintained CTB will normally outlast several asphalt overlays, providing decades of low maintenance service.

More information on control of reflective cracking in CTB can be found in the following PCA documents:

*Reflective Cracking in Cement-Stabilized Pavements,* IS537 (4-page Information Sheet).

*Minimizing Cracking in Cement-Treated Materials for Improved Performance,* RD123 (40-page Research Report).

*Microcracking,* LT299 (8-page brochure).

# 4 Suggested Construction Specification for Cement-Treated Base

## 1. GENERAL

**1.1 Description.** Cement-treated base (CTB) shall consist of soil/aggregate, portland cement, and water proportioned, mixed, placed, compacted, and cured in accordance with these specifications; and shall conform to the lines, grades, thicknesses, and typical cross sections shown in the plans.

These suggested specifications cover construction of CTB course, also referred to in some areas as soil-cement base, cement-treated aggregate base, cement-stabilized base, and other names.

**1.2 Caveat.** These specifications are intended to serve as a guide to format and content for normal CTB construction. Most projects have features or requirements that should be incorporated in the project documents.

## 2. REFERENCED DOCUMENTS

**American Society for Testing and Materials (ASTM) with corresponding American Association of State Highway and Transportation Officials (AASHTO) designations:**

<u>ASTM</u>

C 150 Specification for Portland Cement (AASHTO M 85)

C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete (AASHTO M 148)

C 595 Specification for Blended Hydraulic Cements (AASHTO M 240)

C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete (AASHTO M 295)

C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars (AASHTO M 302)

C 1240 Specification for Silica Fume Used in Cementitious Mixtures (AASHTO M 307)

D 558 Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures (AASHTO T 134)

D 977 Specification for Emulsified Asphalt (AASHTO M 140)

D 1556 Density and Unit Weight of Soil in Place by the Sand-Cone Method (AASHTO T 191)

D 2167 Density and Unit Weight of Soil in Place by the Rubber Balloon Method

D 2922 Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth) (AASHTO T 310)

## 3. SUBMITTALS

**3.1 Submittal Requirements.** The contractor shall submit the following to the engineer at least 30 days before start of any production of CTB:

**3.1.1 Certifications.** Certifications for portland cement and supplementary cementitious materials as required by the engineer.

**3.1.2 Specifications.** Manufacturers' data and specifications for equipment including capacities to be used in mixing, hauling, placing, and compacting CTB.

**3.1.3 Plant Layout.** If central-plant mixing, submit layout of plant location showing mixing plant, cement and aggregate storage, and water supply.

3.1.4 Proposed CTB Mix Design. If the proposed mix design is developed by the contractor or there is a suggested change to the mix design, it must be submitted to the engineer for approval at least two weeks prior to CTB construction. This mix design shall include details on soil gradation, cementitious materials, compressive strengths, and required moisture and density to be achieved during compaction.

## 4. MATERIALS

**4.1 Soil/aggregate.** "Soil/aggregate" may consist of (1) any combination of gravel, stone, sand, silt, and clay; (2) miscellaneous material such as caliche, scoria, slag, sandshell, cinders, and ash; (3) waste material from aggregate production plants; (4) high-quality crushed stone and gravel base course aggregates; or (5) old flexible pavements, including the bituminous surface and stone or gravel base course.

The soil/aggregate shall not contain roots, topsoil, or any material deleterious to its reaction with cement. The soil/aggregate as processed for construction shall be such that 100% passes a 3-inch (75 mm) sieve, at least 95% passes a 2-inch (50 mm) sieve, and at least 55% passes a No. 4 (4.75 mm) sieve.

**4.2 Portland Cement.** Shall comply with the latest specifications for portland cement (ASTM C 150, ASTM C 1157, or AASHTO M 85) or blended hydraulic cements (ASTM C 595, ASTM C 1157, or AASHTO M 240).

**4.3 Water.** Shall be free from substances deleterious to the hardening of the CTB material.

**4.4 Pozzolans.** If used, pozzolans including fly ash, slag, and silica fume shall comply with the appropriate specifications (ASTM C 618, AASHTO M 295 for fly ash; ASTM C 989, AASHTO M 302 for slag; and ASTM C 1240, AASHTO M 307 for silica fume).

**4.5 Curing Compounds.** Curing compounds shall comply with the latest specifications for emulsified asphalt (ASTM D 977, AASHTO M 140) or liquid membrane-forming compounds for curing concrete (ASTM C 309, AASHTO M 148).

**4.6 Sand Blotter.** Sand used for the prevention of pickup of curing materials shall be clean, dry, and non-plastic.

## 5. EQUIPMENT

**5.1 Description.** CTB may be constructed with any machine or combination of machines or equipment that will produce completed CTB material meeting the requirements for gradation, cement and water application, mixing, transporting, placing, compacting, finishing, and curing as provided in these specifications.

**5.2 Mixing Methods.** Mixing shall be accomplished in a central mixing plant or in place, using single-shaft or multiple-shaft mixers. Agricultural disks or motor graders are not acceptable mixing equipment.

**5.3 Cement Proportioning.** The cement meter for central-plant mixing and the cement spreader for in-place mixing shall be capable of uniformly distributing the cement at the specified rate. Cement may be added in a dry or slurry form. If applied in slurry form, the slurry mixer and truck shall be capable of completely dispersing the cement in the water to produce uniform slurry, and shall continuously agitate the slurry once mixed.

**5.4 Application of Water.** Water may be applied through the mixer or with water trucks equipped with pressure-spray bars.

**5.5 Compaction.** The processed material shall be compacted with one or a combination of the following: tamping or grid roller, pneumatic-tire roller, steel-wheel roller, vibratory roller, or vibrating-plate compactor.

## 6. CONSTRUCTION REQUIREMENTS

### 6.1 General

6.1.1 Preparation of Subgrade. Before CTB processing begins, the area to be paved shall be graded and shaped to lines and grades as shown in the plans or as directed by the engineer. During this process, any unsuitable soil/aggregate or material shall be removed and replaced with acceptable material. The subgrade shall be firm and able to support without yielding or subsequent settlement the construction equipment and the compaction of the CTB hereinafter specified. Soft or yielding subgrade shall be corrected and made stable before construction proceeds.

6.1.2 Mixing and Placing. CTB material shall not be mixed or placed when the soil/aggregate or subgrade is frozen, or when the air temperature is below 40°F (4°C). Moisture in the soil/aggregate at the time of cement application shall not exceed the quantity that will permit a uniform and intimate mixture of the soil/aggregate and cement during mixing operations, and shall be within 2% of the optimum moisture content for the CTB mixture at start of compaction.

The operation of cement application, mixing, spreading, compacting and finishing shall be continuous and completed within 2 hours from the start of mixing. Any CTB mixture that has not been compacted and finished shall not be left undisturbed for longer than 30 minutes.

## 6.2 Central-Plant-Mixed Method

6.2.1 Mixing. CTB shall be central-plant mixed in an approved continuous-flow or batch-type pugmill, or rotary-drum mixer. The plant shall be equipped with metering and feeding devices that will add the soil/aggregate, cement, and water into the mixer in the specified quantities. If necessary, a screening device shall be used to remove oversized material greater than 3 inches (75 mm) from the raw soil/aggregate feed prior to mixing. Soil/aggregate and cement shall be mixed sufficiently to prevent cement balls from forming when water is added.

The mixing time shall be that which is required to secure an intimate, uniform mixture of the soil/aggregate, cement, and water.

Free access to the plant must be provided to the engineer at all times for inspection of the plant's operation and for sampling the CTB mixture and its components. If the actual quantities of the mix vary more than 3% by weight of the specified quantities, the engineer may require such changes in the plant operation as will provide the required accuracy.

6.2.2 Handling. The CTB mixture shall be transported from the mixing plant to the paving area in trucks or other equipment having beds that are smooth, clean, and tight. Truck bed covers shall be provided and used at the engineer's discretion to protect the CTB material during transport from moisture variations due to weather conditions. Any CTB material wet excessively by rain, whether during transport or after it has been spread, will be subject to rejection.

The total elapsed time between the addition of water to the mixture and the start of compaction shall be the minimum possible. Haul time shall not exceed 30 minutes, and compaction shall start as soon as possible after spreading. In no case shall the total elapsed time exceed 45 minutes between the addition of water to the soil/aggregate and cement and the start of compaction.

The contractor shall take all necessary precautions to avoid damage to completed CTB by the equipment.

6.2.3 Placing. Immediately prior to placement of the CTB material, the receiving surface shall be in a moist condition. The mixture shall be placed without segregation at a quantity per linear foot (meter) that will produce a uniformly compacted layer conforming to the required grade and cross section. The mixture shall be spread by one or more approved spreading devices. Not more than 60 minutes shall elapse between placement of CTB material in adjacent lanes at any location except at longitudinal and transverse construction joints.

## 6.3 Mixed-in-Place Method

6.3.1 Preparation. The surface of the soil/aggregate to be processed into CTB shall be at an elevation so that, when mixed with cement and water and re-compacted to the required density, the final elevation will be as shown in the plans or as directed by the engineer. The material in place and surface conditions shall be approved by the engineer before the next phase of construction is begun.

6.3.2 Pulverization. Before cement is applied, initial pulverization or scarification may be required to the full depth of mixing.

For cohesive soils with a plasticity index greater than 20, the soil shall be damp at the time of pulverizing to reduce dust and aid in processing.

For slurry application of cement, initial pulverization shall be performed to provide a method to uniformly distribute the slurry over the soil without excessive runoff or ponding.

6.3.3 Application of Cement. The specified quantity of cement shall be applied uniformly in a manner that minimizes dust and is satisfactory to the engineer. If cement is applied as slurry, unless an approved retarding admixture is used, the time from first contact of cement with water to application on the soil/aggregate shall not exceed 60 minutes. The time from slurry placement on the soil/aggregate to start of mixing shall not exceed 30 minutes.

6.3.4 Mixing. Mixing shall begin as soon as possible after the cement has been spread and shall continue until a uniform mixture is produced. The final mixture shall be pulverized such that 100% passes the 3-inch (75 mm) sieve, at least 95% passes the 2-inch (50 mm) sieve, and at least 55% passes the No. 4 (4.75 mm) sieve.

The final pulverization test shall be made at the conclusion of mixing operations. Mixing shall be continued until the product is uniform in color, meets gradation requirements, and is at the required moisture content throughout. The entire operation of cement spreading, water application, and mixing shall result in a uniform soil/aggregate, cement, and water mixture for the full design depth and width.

**6.4 Compaction.** CTB material shall be uniformly compacted to a minimum of 98% of maximum dry density based on a moving average of five consecutive tests with no individual test below 96%. Field density of compacted CTB material can be determined by the 1) nuclear method in the direct transmission mode (ASTM D 2922, AASHTO T 310); 2) sand cone method (ASTM D 1556, AASHTO T 191); or rubber balloon method (ASTM D 2167). Optimum moisture and maximum dry density shall be determined prior to start of construction and also in the field during construction by a moisture-density test (ASTM D 558 or AASHTO T 134).

At the start of compaction, whether central-plant-mixed or mixed-in-place, the moisture content shall be within 2% of the specified optimum moisture. No section shall be left undisturbed for longer than 30 minutes during compaction operations. All compaction operations shall be completed within 2 hours from the start of mixing.

**6.5 Finishing.** As compaction nears completion, the surface of the CTB shall be shaped to the specified lines, grades, and cross sections. If necessary or as required by the engineer, the surface shall be lightly scarified or broom-dragged to remove imprints left by equipment or to prevent compaction planes. Compaction shall then be continued until uniform and adequate density is obtained. During the finishing process the surface shall be kept moist by means of fog-type sprayers. Compaction and finishing shall be done in such a manner as to produce a dense surface free of compaction planes, cracks, ridges, or loose material. All finishing operations shall be completed within 4 hours from start of mixing.

**6.6 Curing.** Finished portions of CTB that are traveled on by equipment used in constructing an adjoining section shall be protected in such a manner as to prevent equipment from marring, permanently deforming, or damaging completed work.

After completion of final finishing, the surface shall be cured by application of a bituminous or other approved sealing membrane, or by being kept continuously moist for a period of 7 days with a fog-type water spray that will not erode the surface of the CTB. If curing material is used, it shall be applied as soon as possible, but not later than 24 hours after completing finishing operations. The surface shall be kept continuously moist prior to application of curing material.

For bituminous curing material, the CTB surface shall be dense, free of all loose and extraneous materials, and shall contain sufficient moisture to prevent excessive penetration of the bituminous material. The bituminous material shall be uniformly applied to the surface of the completed CTB. The exact rate and temperature of application for complete coverage, without undue runoff, shall be specified by the engineer.

Should it be necessary for construction equipment or other traffic to use the bituminous-covered surface before the bituminous material has dried sufficiently to prevent pickup, sufficient sand blotter cover shall be applied before such use.

Sufficient protection from freezing shall be given the CTB for at least 7 days after its construction or as approved by the engineer.

**6.7 Construction Joints.** At the end of each day's construction a straight transverse construction joint shall be formed by cutting back into the completed work to form a true vertical face.

CTB for large, wide areas shall be built in a series of parallel lanes of convenient length and width meeting approval of the engineer. Straight longitudinal joints shall be formed at the end of each day's construction by cutting back into completed work to form a true vertical face free of loose or shared material.

Special attention shall be given to joint construction to ensure a vertical joint, adequately mixed material, and compaction up against the joint. On mixed-in-place construction using transverse shaft mixers, a longitudinal joint constructed adjacent to partially hardened CTB built the preceding day may be formed by cutting back into the previously constructed area during mixing operations.

**6.8 Traffic.** Completed portions of CTB can be opened immediately to low-speed local traffic and to construction equipment provided the curing material or moist-curing operations are not impaired, and provided the CTB is sufficiently stable to withstand marring or permanent deformation. The section can be opened up to all traffic after the CTB has received a curing compound or subsequent surface, and is sufficiently stable to withstand marring or permanent deformation. If continuous moist curing is employed in lieu of a curing compound, the CTB can be opened to all traffic after the 7-day moist curing period, provided the CTB has hardened sufficiently to prevent marring or permanent deformation.

**6.9 Surfacing.** Subsequent pavement layers (asphalt concrete, bituminous surface treatment. or portland cement concrete) can be placed any time after finishing, as long as the CTB is sufficiently stable to support the required construction equipment without marring or permanent distortion of the surface.

**6.10 Maintenance.** The contractor shall maintain the CTB material in good condition until all work is completed and accepted. Such maintenance shall be done by the contractor at his own expense.

Maintenance shall include immediate repairs of any defects that may occur. If it is necessary to replace any processed material, the replacement shall be for the full depth, with vertical cuts, using either fresh cement-treated material or concrete. No skin patches will be permitted.

## 7. INSPECTION AND TESTING

**7.1 Description.** The engineer, with the assistance and cooperation of the contractor, shall make such inspections and tests as deemed necessary to ensure the conformance of the work to the contract documents. These inspections and tests may include, but shall not be limited to:

1. Obtaining test samples of the CTB material and its individual components at all stages of processing and after completion.
2. Observing the operation of all equipment used on the work. Only those materials, machines, and methods meeting the requirements of the contract documents shall be used unless otherwise approved by the engineer.

All testing of processed material or its individual components, unless otherwise provided specifically in the contract documents, shall be in accordance with the latest applicable ASTM or AASHTO specifications in effect as of the date of advertisement for bids on the project.

## 8. MEASUREMENT AND PAYMENT

**8.1 Measurement.** This work will be measured:

1. In square yards (meters) of completed and accepted CTB base course as determined by the specified lines, grades, and cross sections shown on the plans.
2. In tons (tonnes) or cwt of cement incorporated into the CTB base course in accordance with the instructions of the engineer.

**8.2 Payment.** This work will be paid for at the contract unit price per square yard (meter) of CTB base course and at the contract unit price per ton (tonne) or cwt of cement furnished, multiplied by the quantities obtained in accordance with Section 8.1. Such payment shall constitute full reimbursement for all work necessary to complete the CTB base course, including watering, curing, inspection and testing assistance, and all other incidental operations.

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