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# CONSTRUCTION OF CEMENT STABILIZED SUB-BASE/BASE


National Rural Roads Development Agency
Ministry of Rural Development
Government of India

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# Cement Stabilized Subgrade, Sub-base and Base Courses

## 1.0 Introduction

Substantial length of the existing low volume rural roads in India is unpaved. Heavy rainfall and floods affect almost all these roads frequently. The unpaved roads are severely damaged due to flood, currents and wave action. This situation needs maintenance of these roads every year/ frequently. These adverse effects together with possibly inadequate compaction significantly impair the durability of these roads. The ultimate effect is comparatively low subgrade strength and eventually higher pavement thickness if paved roads are to be constructed. On the basis of this context, some treatment of locally available materials has become necessary for satisfactory and economic construction of roads in these regions. Cement stabilized bases or lime stabilized sub-bases may be provided for the construction of rural roads for low volume/ light traffic. An increasing emphasis has been placed on the use of stabilized pavement materials in recent years. Through the use of stabilizing agents, low-quality materials can be economically upgraded to the extent that these may be effectively utilized in the pavement structure. Stabilized pavement materials are generally incorporated into the pavement structure as base courses and sub-bases.

### 1.1 What is Soil-Cement?

Soil-cement is a highly compacted mixture of soil/aggregate, cement and water. It is widely used as a low-cost pavement base for roads, residential streets, parking areas, airports, shoulders, and materials-handling and storage areas. Its advantages of great strength and durability combine with low first cost to make it the outstanding value in its field. A thin bituminous surface is usually placed on the soil-cement to complete the pavement.

Soil-cement is sometimes called cement-stabilized base, or cement-treated aggregate base. Regardless of the name, the principles governing its composition and construction are the same.

### 1.2 Cement Stabilisation

The hydrated products of cement bind the soil particles, the strength developed depending on the concentration of cement and the intimacy with which the soil particles are mixed with cement. A high cement content of the order of 7-10% can produce a hard mass having a 7-day compressive strength of 20 $kg/cm^2$ or more, and this usually goes by the term soil-cement. However, a smaller proportion of 2-3% cement can improve the CBR value to more than 25, and the material goes by the term "cement-modified soil", which can be advantageously used as sub -base/base for rural roads.

Cement stabilization is ideally suited for well graded aggregates with a sufficient amount of fines to effectively fill the available voids space and float the coarse aggregate particles. General guidelines for stabilization are that the plasticity index should be less than 30 for sandy materials. For fine-grained soils, soils with more than 50 percent by weight passing 75µm sieve, the general consistency guidelines are that the plasticity index should be less than 20 and the liquid limit (LL) should be less than 40 in order to ensure proper mixing. A more specific general guideline based on the fines content is given in the equation below which defines the upper limit of PI for selecting soil for cement stabilization.

Cement is appropriate to stabilize gravel soils with not more than 45 percent retained on the no. 4 sieve. The Federal Highway Administration recommends the use of cement in materials with less than 35 percent passing no. 200 sieve and a plasticity index (PI) less than 20. Based on this system, soils with AASHTO classifications A-2 and A-3 are ideal for stabilization with cement, but certainly cement can be successfully used to stabilize A-4 through A-7 soils as well. The Portland cement Association (PCA) established guidelines to for stabilizing a wide range of soils from gravels to clays.

## 1.3 Application

Generally, granular soils free of high concentration of organic matter not greater than 2%, or deleterious salts (sulphate and carbonate not greater than 0.2%) are suitable. A useful rule for soil selection is that the plasticity modulus (product of Pl and fraction passing 425 micron sieve) should be less than 250 and that the uniformity coefficient should be greater than 5.

## 1.4 Factors Affecting Soil Cement Stabilization

During soil cement stabilization the following factors are affecting.

a) Type of soil: Cement stabilization may be applied in fine or granular soil, however granular is preferable for cement stabilization.

b) Quantity of cement: A large amount of cement is needed for cement stabilization.

c) Quantity of water: Adequate water is needed for the stabilization.

d) Mixing, compaction and curing: Adequate mixing, compaction and curing is needed for cement stabilization.

e) Admixtures: Cement has some important admixtures itself which helps them to create a proper bond. These admixtures pay a vital role in case of reaction between cement and water.

## 1.5 Advantages of Cement Stabilization

a) It is widely available.

b) Cost is relatively low.

c) It is highly durable.

d) Soil cement is quite weather resistant and strong.

e) Granular soils with sufficient fines are ideally suited for cement stabilization as it requires least amount of cement.

f) Soil cement reduces the swelling characteristics of the soil.

g) It is commonly used for stabilizing sandy and other low plasticity soils. Cement interacts with the silt and clay fractions and reduces their affinity for water.

## 1.6 Disadvantages of Cement Stabilization

a) Cracks may form in soil cement.

b) It requires extra labour.

c) The quantity of water must be sufficient for hydration of cement and making the mixture workable.

## 2.0 Selection of Stabilizer

The selection of the stabilizer is based on plasticity and particle size distribution of the material to be treated. The appropriate stabilizer can be selected according to the criterion shown in Table 1. Some control over the grading can be achieved by limiting the coefficient of uniformity to a minimum value of 5, however, it should preferably be more than 10. If the coefficient of uniformity lies below 5, the cost of stabilization will be high and the maintenance of cracks in the finished road would be expensive. If the plasticity of soil is high there are usually sufficient clay minerals which can be readily stabilized with lime. Cement is more difficult to mix intimately with plastic material but this problem can be alleviated by pre-treating the soil approximately 2 percent lime.

**Table 1: Guide to the Type of Stabilization likely to be Effective**

| **Stabilized Material** | **Soil Properties** | | | | | |
|---|---|---|---|---|---|---|
| | **More than 25% passing the 0.075 mm sieve** | | | **Less than 25% passing the 0.075 mm sieve** | | |
| | **PI<10** | **10<PI<20** | **PI>20** | **PI<6 PP<60** | **PI<10** | **PI>10** |
| Cement | Yes | Yes | * | Yes | Yes | Yes |
| Lime | - | Yes | Yes | No | * | Yes |
| Lime- Pozzolana | Yes | - | No | Yes | Yes | * |

### 2.1 Requirement of cement for different types of soils

Stabilisation with cement is resorted to for soils and other locally available materials which do not respond to lime treatment and when comparatively higher and faster development of strength and durability characteristics are needed, especially for waterlogged and high rainfall areas. Granular and sandy soils are most suitable for cement stabilisation. By way of broad guidelines, the requirements of cement content for different soil types are as under.

For heavy clays/black cotton soils (PI more than 30), two stage stabilization may be adopted i.e. the clay is treated with lime in the first stage to reduce plasticity and to facilitate pulverization, whereas in the second stage, the resulting soil is stabilised with cement.

**Table 2: Requirements of cement content for different soil types**

| **Soil Type** | **Required Cement Content** |
|---|---|
| Sands/Sandy Soils/Soil Gravels | 3-5 percent |
| Silts/Silty Clays of Low PI (less than 15) | 4-8 percent |
| Clays/Black Cotton Soils | 8-15 Percent |

## 3.0 Specifications and Test Requirements for Stabilized Materials

### 3.1 General Requirement

The pavement performance of a stabilized road will be largely governed by the gradation and the type of soil/granular material used for the purpose of stabilization. The quality of material to be stabilized should meet the minimum standard set out in specifications. Stabilized layers constructed from such material are likely to perform satisfactory even if, it is affected by carbonation during its life time. Materials which do not comply with the requirements given in the specifications can be stabilised but more additive will be required and the risk from cracking and carbonation will increase. The strength of stabilised materials can be evaluated many ways, of which most popular are the Unconfined Compressive Strength (UCS) test and the California Bearing Ratio (CBR) test.

## 3.2 Stabilization with Cement

### 3.2.1 Requirement for soil modification/subgrade improvement

Cement stabilised materials can be used for soil modification or improvement of subgrade soil. It is recommended from economic consideration that mix in-place methods of construction be used for subgrade improvement and only granular materials and silty cohesive materials be used. The assumption being that more clayey materials would be more effectively stabilized with lime). The main requirements for cement modification or stabilization of subgrade soil are summarised in Table 3.

**Table 3: Soil Characteristics for Cement Modified Soil/Improved Subgrade/Capping Layer**

| **Properties** | **Specified Value** |
|---|---|
| Liquid Limit (%) | <45 |
| Plasticity Index | <20 |
| Organic Content (%) | <2 |
| Total SO4 content | 0.2 % Max |
| Minimum Laboratory CBR at specified density (%) | 15 |
| Minimum cement content (%) | 2* |
| Degree of pulverisation (%) | >60 |
| Temperature for mixing | More than 100 C |
| Time for completing compaction | hrs. Max |

*In case of better mechanical equipment for spreading of cement, for breaking clods and blending is used, the minimum percentage of cement for stabilisation could be 0.5 percent. However extensive lab testing must be done to arrive at this minimum percentage. Sample at site of blended loose soil be collected and remoulded in lab to confirm that the desired CBR can be achieved.

### 3.2.2 Requirement for bound sub base/bases

The material used for cement treatment shall be soil including gravel and sand, lateritic soils, sandy silty material, crushed slag, crushed concrete, brick metal, granular material, kankar, laterite, brick aggregate, crushed rock, metallic slag or fly ash, pond ash or any locally available materials/industry wastes or any combination of these as approved by the Engineer etc., stabilised with either cement or lime-fly ash-cement or lime-fly ash, etc. may be allowed for use as capping layer over weak subgrade, as sub-base and base layer of pavement. The main requirements of stabilized layers for different layers of a pavement structure as indicated above are summarised in Table 4.

Gradation for cement bound materials as per MORD specifications Table 400.5 can be adopted. For use in a sub-base course, the material shall have a grading shown in Table 5, and a uniformly coefficient (Cu)* not less than 5, capable of producing a well closed surface finish. For use in a base course, the material shall be sufficiently well graded to ensure a well-closed surface finish and have a grading within the range given in Table 5. If the material passing 425 micron sieve is plastic, it shall have a liquid limit not greater than 45 percent and a plasticity index not greater than 20% determined in accordance with IS:2720 (Part5).However, thickness of different stabilized layers, selection/choice for adoption of a particular grading and strength requirements of these layers are to be decided on the basis of pavement design and with specific approval of the Engineer-in-Charge.

**Table 4: Material Characteristics for Cement Modified Granular Materials**

| **Properties** | **Specified Value** |
|---|---|
| Liquid Limit (%) | <45 |
| Plasticity Index | <20 |
| Organic Content (%) | <2 |
| Total SO4 content (%) | 0.2 |
| Water absorption of coarse aggregate | <2% (If this value is >2% the soundness test shall be carried out on the materials delivered to site as per IS 383) |
| 10 percent fines value when tested as per BS 812(III)Minimum cement content (%) | >= 50 KN |

**Table 5: Grading Limits of Materials for stabilization with cement**

| **IS Sieve** | **Percent by Weight Passing Within the Range** |
|---|---|
| | **Sub-Base / Base** |
| 53.0 mm | 100 |
| 37.5 mm | 95-100 |
| 19.0 mm | 45-100 |
| 9.5 mm | 35-100 |
| 4.75 mm | 25-100 |
| 600 micron | 8-65 |
| 300 micron | 5-40 |
| 75 micron | 0-10 |

## 3.3 Mix Design

Mix design should be worked out to specify the amount of cement to be added to obtain the required strength in terms of 7-day Unconfined Compressive Strength (UCS) and/or durability test under alternate wet-dry conditions. Pulverisation of soil clods, mixing of pulverised soil with the required amount of cement, compaction and curing of the compacted layer are important construction operations. The mix shall be designed for a minimum laboratory 7 days unconfined compressive strength of 3.00MPa for use in base course and not less than 1.7 MPa for sub-base.

## 4.0 Construction Operations

### 4.1 Procedure of Stabilization

The construction of stabilized road pavement layers follows the same basic procedures whether the stabilizing agent is cement, lime or other hydraulic binder. The procedures can be divided in to two main groups:

1) Mix-in-Place stabilization 2) Plant-mix stabilization

### 4.1.1 Mix-in-Place Stabilization

The main advantage of the mix-in-place procedure is its relative simplicity and hence it is particularly suitable or work in remote areas where plant mixing could prove logistically difficult. Its disadvantages are not obtaining efficient mixing i.e. good distribution of the stabilizer, constructing thicknesses of more than 200 mm and of poor levels. In this process the material is stabilized in-situ which requires the stabilizing agent to be spread before or during the pulverisation and mixing of the soil and stabilizer. This is generally carried out with a purpose made machine although for small scale work in remote areas agricultural machinery can be adapted for use. In-situ stabilization involves the following operations:

- Fixing the type and dosage of Stabilizing agent/cement considering the properties of soil
- Preparation of ground to be stabilized
- Mixing of cement with soil/aggregate
- Compaction and Finishing
- Joint Construction
- Curing of the compacted soil

#### 4.1.1.1 Preparation of ground to be stabilized

This involves:

- Placing imported material to be stabilized on the formation
- The material then has to be graded to approximately the required levels
- Plough to loosen the material, one or two passes is normally sufficient.

#### 4.1.1.2 Initial Preparation

This involves excavating down to the in-situ material to be stabilized or placing imported material on the formation. The material to be stabilized then has to be graded to approximately the required levels. After which it is usually necessary to plough to loosen the material one or two passes is normally sufficient.

Before construction of any stabilised layer and before any transported material for stabilisation is dumped on the road, the underlying layer should be investigated to establish whether there is any damage, voids, wet spots or other defects. Any defects to the layer should be rectified with the material of having similar properties with the native material before the stabilised layer is constructed. Where the stabilised layer is constructed on the floor of a pavement excavation or on the top of an existing pavement layer i.e. where the underlying layer has not been reworked or reconstructed, the floor of the excavation or top of the existing pavement layer should first be watered and the compaction of the layer should be carried when layer become moist or comes at OMC. The material to be stabilised should be placed, or in the case of existing pavement layer, scarified to the full depth specified, broken down and watered if necessary and mixed to achieve a homogenous layer. Any oversize material should be removed. Normally maximum size of aggregate is 30mm.

**Figure 1: Initial preparation of soil**

### 4.1.1.3 Spreading the Stabilizer

Spreading the stabilizing agent at the required dosage rate can be carried out manually or by machine. When manual methods are used bags of stabilizer are spotted at a set spacing, they are then broken open and the stabilizer raked across the surface as uniformly as possible. The uniformity of the layer of stabilizer spread over the surface, before the mixing operation, determines the uniformity of the mixed material produced.

Mechanical spreaders automatically monitor the required amount of stabilizer to be spread on the surface of the soil. Their use results in a much more uniform spread of stabilizer over the surface than can be achieved by hand spreading. The equipment need to be calibrated before use to ensure that the correct rate of spread is achieved and subsequently checked at regular intervals to ensure that the rate of spread remains within specified tolerances.

**Figure 2: Spreading the Cement**

**Figure 3: Dry mixing of Cement**

### 4.1.1.4 Addition of Water

lf it is necessary to add water to bring the moisture content to the required value this can either be done as part of the mixing operation or after the material has been prepared prior to the addition of the stabilizer. To ensure a thorough distribution of the added water, it is; preferable to add water as part of the mixing operation. Water added during the mixing process should be through a spray system such that it is added in a uniform manner over the required area and uniformly to the required depth. Where the mixing plant does not enable water to be added or where it is not possible to add enough water during mixing it should be added to the prepared material using a spray system that enables the amount to be controlled over the whole area. The material to be stabilised should then be mixed prior to the addition of the cement stabiliser to ensure the distribution of the water throughout the layer.

**Figure 4: Addition of water**

### 4.1.1.5 Mixing Soil, Water and Stabilizer

Robust mixing equipment of suitable power for the layer being processed is required to pulverise the soil and blend it with the stabilizer and water. The most efficient of the machines available carry out the operation in one pass, enabling the layer to be compacted quickly and minimising the loss of density and strength caused by any delay in compaction. Multi pass machines are satisfactory, provided the length of pavement being processed is not excessive and each section of pavement can be processed within an acceptable time.

The plasticity of the material is overriding factor in the ability of mixing plant to mix the soil with stabilizer. A review of work showed that all plastic soil could be satisfactorily mixed with cement using the plant. For cohesive soils a factor of the plasticity index of the soil multiplied by the percentage of the fraction of the soil which was finer than 425 micron in particle diameter may be used to suggest the values for the different types of mixing plant available are given in Table 6.

**Table 6: Soil Plasticity Limits for Stabilisation using Different Types of plants**

| Type of Plant* | Plasticity Index X Percentage of fraction finer than 425 micron | Normal maximum depth (mm) capable of being processed in one layer |
|---|---|---|
| Agricultural Disc harrows, Disc Ploughs, rotavators | Less than 1000 | 120-150 |
| Light duty rotavators (Less than 100 hp) | Less than 2000 | 150 |
| Heavy duty rotavators (greater than 100 hp) | Less than 3500 | 200-300 (depending on soil type and horsepower of mixer) |

*Selection of the appropriate plant should be left to the decision of Engineer-in-Charge.

Grader have been used to mix stabilized material but they are inefficient for pulverising cohesive soil and even with granular materials a large number of passes are needed before the quality of mixing is acceptable, For these reasons, the use of grader for mixing is not suggested.

Mixing is carried out in the field using Agricultural Disc harrows, Disc ploughs or rotavators. Soil having high plasticity requires more powerful mixing device and a large number of passes are needed before the quality of mixing is acceptable. The uniformity of the mix should be ensured before compaction.

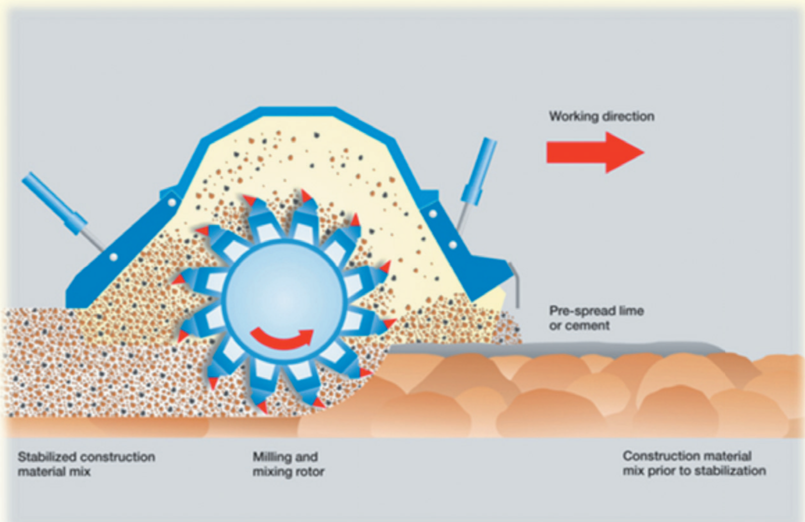


**Figure 5: In-situ mixing of soil/aggregate and stabilizer**

Figure 6 (a): In-situ mixing by using Rotavator

Figure 6 (b): In-situ mixing by Agricultural Disc Harrow

### 4.1.2 Plant-Mix Stabilization

In this process, the materials are separately batched and mixed at a mixing plant. They are then transported to the site where they are laid by a bituminous paver and compacted. The advantages of the process are the good control on proportioning of the 'materials, multi-layer work can be executed and good compacted levels are readily obtainable. The disadvantages are that output is lower than in the mix in place process, cohesive materials cannot usually be mixed and in the case of cement stabilization, the mixing plant has to be relatively close to the site so that mixing, laying and compaction can all be completed within the stipulated two-hour time limit. The process is not, therefore, applicable to small-scale projects unless there is a mixing plant near at hand.

To ensure complete distribution of the relatively small quantities of stabilizer, mixing should be carried out in a forced action mixer and except for non-cohesive granular materials, free fall mixes of the type used for mixing concrete should not be used. If it is proposed to use a mixer other than one with a forced action preliminary trials should be made to ensure that satisfactory mixing is achieved.

Vehicles transporting the mixed material should be of sufficient number and capacity to meet both the output of the mixer and spreading and compaction operations. International standards and specifications, for plant mixed cement stabilized material require it to be spread by a bituminous paver and spreading by grader is not permitted. If graders are used for spreading, much of the advantage of plant-mix stabilization is lost as it is difficult to control levels and thicknesses of construction.

### 4.1.3 Compaction

Compaction is carried out in two stages:

- An initial rolling and trimming which may be carried out followed by a final mixing pass of the rotavator.
- Final compaction and levelling in the case of cement stabilized material must be completed within two hours of mixing.

Whatever method is used for mixing the soil with water and stabilizer material, the methods used for compaction are the same. In the case of cement stabilized materials, once the cement has begun to harden, it is important that the matrix is not disturbed; hence the requirement that compaction must be completed within two hours of mixing. The compacted density of the stabilized layer is a measure of the effectiveness of compaction and hence of its strength. The degree of compaction to be achieved in the field can be specified in two ways. In an end product specification, the density of the layer in the field is determined and compared with a specified target density. Provided that the measured field density is greater than or equal to this limit the compaction in the field is deemed to be satisfactory. The main disadvantages of an end product specification are that a large amount of site testing is required and many of the methods in use are time consuming. This means that the results of the tests may not be available in time to remedy any deficiencies in compaction.

If the base course operation is being performed in two layers, the two hour time limit will be measured from the time water and cement are added to the sand or gravel of the first layer to the time of completion of final compaction of the uppermost lift. If the target cannot meet within this time limit, it will be required to wait for the normal five days curing period before applying the next layer.

The surface of the un-compacted, partially compacted or completely compacted cement stabilized base shall be kept moist at all times until an asphaltic fog coat seal is applied.

Following compaction, before setting of the mixture, high spots on the cement stabilized base shall be removed by means of cutting blades or other equipment, in a manner to cause as little disturbance as possible to the compacted material. The excess material shall be removed to the shoulder or adjacent subgrade. Loose material shall not be left on the cement stabilized base surface. Filling low spots with cement stabilized material following compaction will not be permitted.

**Figure 7: Compaction and finishing**

**Figure 8: View of Finished Cement stabilised layer**

### 4.2 Joint Construction

- All joints shall be vertical and uniform in alignment.
- Longitudinal joints shall be formed or cut in a vertical plane to the subgrade surface, shall expose a face of thoroughly compacted material, and new material shall be spread and compacted against this face when constructing the adjacent lane or base section.
- Transverse construction joints shall be made by trimming the end of the compacted material to a straight line normal to the centreline of the roadbed and with a vertical edge in well compacted material.

### 4.3 Curing of the Compacted Soil

Proper curing is very important for three reasons:

a) It ensure that sufficient water is retained in the layer so that the hydration reactions between the stabilizer, water and the soil can continue

b) It reduces shrinkage, and

c) It reduces the risk of carbonation from the top layer

In temperate climate curing presents few problems. It is usually carried out by sealing the compacted surface to prevent the loss of water during the curing period (usually seven days) during which time all construction traffic must be kept off the stabilized material. Before spraying is started the surface should be swept free of loose material and any damp areas should be free of standing water. The following methods of curing are suggested:

a) Covering with an impermeable sheeting with joints overlapping at least 300 mm and set to prevent ingress of water.

b) Spraying with a bituminous sealing compound.

Spraying with a resin based aluminous curing compound such as is used for concrete. This has particular application where it is desirable to reduce the increase in temperature immediately under the surface which would result from the use of a black (bituminous) seal.

In a hot dry climate the need for good curing is most important but the prevention of moisture loss is very difficult. If the surface is constant sprayed and kept damp day and night the moisture content in the main portion of the layer will remain stable but the operation is likely to leach stabilizer from the top portion of the layer. If the spraying operation is intermittent and the surface dries from time to time (a common occurrence if this method is used) the curing will be completely ineffective.

Curing through spraying can be much more efficient curing system if a layer of sand 30mm to 40mm thick is first spread on top of the layer. In this case the number of spraying cycles per day can be very much less and there is a considerable saving in the amount of water used.

When the stabilized layer is to be covered by other pavement layers the construction of the upper sections will provide a very good curing seal but be taken to ensure that this work does not damage the top of the stabilized layer. During the period of time prior to the construction of the next layer some system of curing is required because this is the most critical period in terms of shrinkage in the layer.

Primer can also serve as a curing membrane but results have shown that a prime coat breaks down when it penetrates into the surface and completely loses any ability to seal it. A portion of any curing membrane must sit on the surface to achieve an effective seal If the top of the stabilized layer is sprayed lightly with water followed by an application of a viscous cutback bitumen, the loss of moisture is effectively reduced to zero. Similarly the top of the stabilized layer can be sprayed with an emulsion to achieve the same result. It is essential however that all traffic is kept off the curing membrane for several days at which time excess bitumen can be absorbed by sanding the surface.

**Figure 9: View of curing of stabilised layer**

### 4.4 Construction Equipment's:

Road construction equipment's are found in a wide variety ranging from the very heavy equipment to portable and lighter equipment. These modern and high construction equipments make the construction job easier and quicker. For an application to be successful the appropriate equipment together with experienced persons must be planned for in advance and be readily available on site before cement stabilisation of the road is commenced with. The appropriate construction equipment required is mentioned below.

1. A road grader
2. A rotary tiller
3. A grid roller
4. A water –bowser or tanker
5. Compactors and
6. Labourers

Road Grader: With attachable ripper to loosen up the in-situ soil by ripping and to, shape the road to final road level.

Rotavator: The purpose of a rotavator is i). To break up the soil, ii). To mix the soil into a homogeneous mixture, iii). Mix in the cement and iv). Mix in the water content

Grid-Roller: To break-down any large, oversized rocks and aggregates that may be present in the loosened or transported soil

Water Bowser or Tanker: Must be fitted with a suitable sprinkler system to evenly apply the water to the soil-stabiliser mixer without creating unnecessary wet spots. The force of the sprinkler must also be controlled to be able to apply a light sprinkle of water for curing purposes.

Compactors:

To compact the cement stabilized layer to the specified compaction. The compaction rollers can consist of 6-10 tons static, steel drum rollers or 8-12 tons vibratory rollers. The steel drums of the rollers shall be equipped with water-sprinklers and brush-scrappers to prevent the pick-up of surface material and in order to scrape-off any material that is sitting fast to the steel drums.

Labourers: Sufficient labours to carry out the following tasks

a. Unloading of cement bags
b. Placing and opening of bags
c. Spreading of the cement over the earth
d. The initial setting-up of levels and placing of level pegs
e. During the preparation stage of the layer to be stabilised, the removal by hand of oversized stones, boulders or large rocks
f. Removal of the empty cement bags
g. All trimming works such as side drains, shoulders and fill slopes

### 5.0 Analysis of Rates

Standard Data for arriving unit rates for the item of cement treated soil sub-base/Base course is available under Sl no. 4.6 of MORD Standard Data book for Analysis of Rates for Rural Roads published by IRC during 2014.

## 6.0 Designs of Cement Stabilised Sub Base and Base

IRC SP-72 – 2015 "Guidelines for the Design of Flexible Pavements for Low Volume Rural Roads" has been recently published by IRC and it provides the design charts for working out design thickness for stabilised base/ sub base course based on subgrade strength CBR and various traffic categories. Design catalogues for using Cement stabilised soil sub-base and soil cement bases is given in Figure 10.

### 6.1 Stabilised Soil Sub-base

For silty clays and clayey soils, including Black Cotton Soil, treatment with lime offers an appropriate and cost effective technique which may be in the form of modification by way of reducing the PI or in the form of a stabilisation technique for attaining the need strength as per Clause 403 of MoRD Specification for Rural Roads. For soils which do not respond to lime treatment and where comparatively higher and faster development of strength and durability characteristics are needed, especially for water logged and high rainfall areas, soil stabilization with cement is most appropriate. For cement treated soil sub-base courses, the relevant specifications are contained in Clause 404. The cement content for a cement treated sub-base should be determined by mix design, yielding a 7-day unconfined compressive strength of not less than 1.7 MPa. From practical considerations, the thickness of sub-base, where provided, shall not be less than 100 mm.

### 6.2 Soil-cement base

Where hard stone has to be carted from long uneconomical leads, the use of soil-cement often offers an appropriate option. The soil-cement mix should be designed to attain a minimum laboratory 7-day unconfined compressive strength of 3 MPa. Special consideration must be given to pulverization of soil clods to the specified requirements and thorough mixing as laid down in Clause 404 of MoRD specifications for Rural Roads. For clayey soils, pre-treatment with lime may be needed before stabilization with cement. The Thickness of base shall be as per pavement design catalogue for soil cement bases but should not be less than 100 mm.

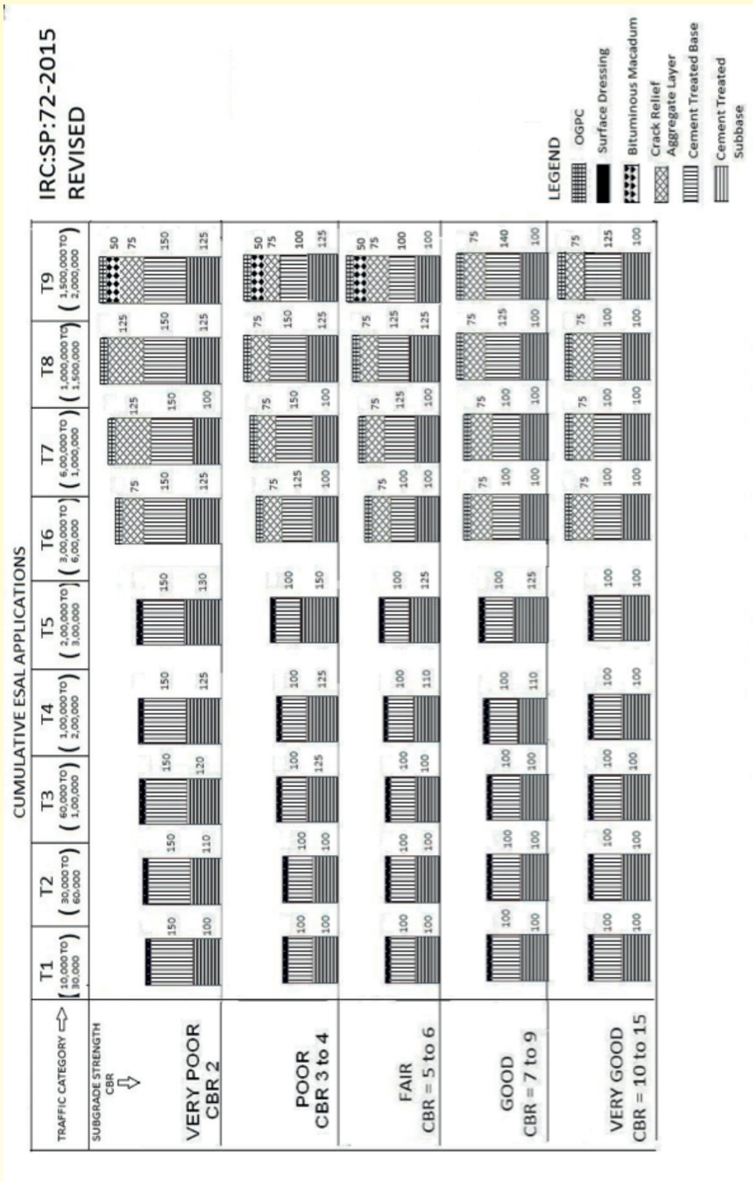


**Figure 10: Pavement Design catalogues for Cement treated bases and sub-bases**

## 7.0 Quality Assurance

### 7.1 General

During the construction process regular checks are to be made on the stabilized material to ensure that all the requirements of the specification are being met. Many of the checks carried out are merely "good housekeeping" i.e. continual supervision to ensure that the construction process allows the design objectives to be achieved in full. In addition to this there is production control tests carried out to monitor the work in progress to ensure, for example, that the correct thickness of stabilized layer is being laid and that a consistent product is being produced. Finally compliance tests are to be carried out on the finished product to demonstrate that it meets all the requirements of the specification.

This section, therefore, describes the tests that may need to be carried out to check on the quality of the material. It also discusses the various factors that influence the choice of a particular test that is used to establish the values for parameters such as moisture content, compacted density, strength, etc., set out in the specification.

## 7.2 Preliminary Trial

As part of the quality control and in order to make a final decision on moisture content and stabilizer content, the information gained in the laboratory tests should be related to a preliminary field trial. At least 10 days before the main work begins, a trial area should be laid using the materials, mix proportions, mixing, laying and compaction plant to be used, to check the suitability of the methods, etc.

## 7.3 Sampling and Testing Frequency

Samples for checking the moisture content, strength, etc. are most conveniently taken from the laid material before compaction. Frequency of testing depends on the size of the project and the facilities available on site but regular checks should, at least, be made on the moisture content, strength and in-situ density. Whatever the frequency, sampling should be spread out over the site so as to give a representative indication of the quality of the material within a given area. In order to achieve the specification for stabilized sub-bases and road bases, it is suggested that samples at equally spaced locations along a diagonal that bisects the area to be tested may be taken. For satisfactory performance of soil stabilized road, strict quality control measures are essential. It is prudent to conduct periodic testing during construction to confirm that the properties of materials being used are within the range of value anticipated during the design. For each consignment of cement, testing should be done to check quality. Quality control tests and their minimum desirable frequency are as given in Table 8 & 9. Strict control should be excised during the mix in-place operations, with frequent checks on mixing efficiency. This can be done by trenching through the in-place material and inspecting the colour of the mixture. Unmixed streaks or layers indicate poor mixing and the material in that area should be remixed until uniformity of colour is achieved.

### 7.3.1 Tests on Cement Treated Soil Sub-Base/Base

#### 7.3.1.1 Tests prior to construction

The quality control tests to be carried out prior to construction shall be given in Table 7.

**Table 7: Quality Control Tests Prior to Construction**

| Sl No | Type of Test | Frequency |
|---|---|---|
| 1 | Quality of cement and purity of Lime (IS:1514) (if used for pre-treatment) | One test for each lot |
| 2 | Unconfined Compressive Strength Test (Is:4332 Part 5) | One test on a set of 3 specimens per Km length. |

#### 7.3.1.2 Tests during construction

The quality control tests to be carried out during construction shall be given in Table 8.

**Table 8: Quality Control Tests during to Construction**

| Sl No | Type of Test | Frequency |
|---|---|---|
| 1 | Pulverization of Soil clods | At least 3 tests daily, well spread over the day's work. |
| 2 | Placement Moisture Content (IS:2720 Part 2) | -do- |
| 3 | Insitu Density measurements (IS:2720 Part 28) | -do- |
| | | i). Average of 3 test results shall not be less than the specified degree of compaction.<br>ii). Individual test values of the degree of compaction attained shall not be less than 1 percent of the specified degree of compaction. |
| 4 | Thickness of compacted layer | At random |

### 7.4 Storage and Handling of the Stabilizer

Unless cement and lime are properly stored and used in a fresh condition the quality of the pavement layer will be substantially reduced. Cement must be stored in a sound water-tight building and the bags stacked as tightly as possible. Doors and windows should only be opened if absolutely necessary. The cement which is delivered first should be used first. According to a study it was found that even if cement is properly stored the following losses in strength will still occur:

**Table 9: Losses in cement strength**

| Age | Percentage Reduction |
|---|---|
| After 3 months | 20 |
| After 6 months | 30 |
| After 1 year | 40 |
| After 2 years | 50 |

Lime should be stored in sealed bags, tightly stacked and covered with a water proof tarpaulin. The material which has been stored for more than three weeks should be tested for available lime content before use. Lime which is older than 6 months should be discarded.

### 7.5 Control of the Moisture Content

Throughout the stabilization work, the moisture content should be maintained slightly above its specified value. This means that rapid determination of the in-situ moisture content is necessary to allow adjustments to be made so as to bring the moisture content of the stabilized material to the required value. The definitive oven-drying method is, in general, too time-consuming to be of much practical use in the field and more rapid means have to be employed. Rapid heating methods may be used, but where these are inappropriate, the calcium carbide method may be used to give rapid result. The method depends on the reaction between calcium carbide and water in the stabilized material to produce acetylene at the ambient temperature according to the equation:

$$CaC2 + 2H20 = Ca\ (OH)2 + C2H2$$

If the reaction is allowed to occur under standardised conditions in a closed container, the pressure of the acetylene generated in the container is a measure of the moisture content of the stabilized material.

Nuclear density gauges for the determination of the in-situ density of compacted materials usually include a facility for the in-situ moisture content at the same time. This method can be used to determine moisture content when construction starts and also during the processing.

### 7.6 Control of the Stabilizer Content

Whatever method of spreading the stabilizer is employed, it is important that a uniform spread rate is achieved as this will affect the uniformity of the stabilized material. If the stabilizer is placed in bags and spread by hand, the accuracy of the spotting of the bags must be checked and the manual spreading of the stabilizer should be visually assessed. If a mechanical spreader is used, metal trays or canvas sheets, one metre square, should be placed at regular intervals along the road to check the application rate.

Determination of the stabilizer content, after mixing, is in principle easy to perform but in practice is time consuming and needs to be carried out with care if meaningful results are to be obtained. Both the methods described in the codes BS: 1924: Part 2 and in ASTM D 806 involve a comparison of the calcium contents of the stabilized material, the stabilizer and the material in an un-stabilized condition. However, the method given for the determination of calcium in BS: 1924 is to be preferred. Neither method is applicable if the calcium content of the un-stabilized materials is high or variable.

### 7.7 Routine Strength Determinations

Continuous monitoring of the strength of processed material is required to ensure that the specified strength is being achieved. Representative samples of the full depth of mixed material should therefore be taken from the site immediately prior to compacting the material. As stated previously, the frequency of sampling should be related to the size of the processed area and its structural importance. In the case of cement stabilized materials, preparation of the test specimens should be completed within two hours of mixing.

The moisture content to be used for the preparation of the test specimens will clearly be that of the mixed material and precautions should be taken to ensure that no drying out of the material occurs between taking the samples and completing the preparation of the test specimens.

The density at which the test specimens are to be compacted depends on the density requirements of the specification and various methods which are in use. The test specimens should be prepared at the same density as the compacted material in the field. This has some logic because it means that there should be no differences in strength, which can be attributed to differences of density, between the laboratory test specimens and the strength of the material in the field. The difficulty is that an immediate measure of the in-situ density is required and this can only be achieved if nuclear density gauges are used.

## 8.0 Precautions to be taken while using Stabilized Materials

### 8.1 General

The two major problems that arise with the use of stabilized materials in road pavement layers are cracking and the long -term durability of the material. The extent to which either of these is a problem is intimately related to the purpose of the stabilized layer in the road pavement as a whole and it is, therefore, difficult to divorce the two factors. However, in this Chapter the problems that can arise are discussed.

### 8.2 Cracking in Stabilized Layers

Many factors contribute to the cracking and crack -spacing of stabilized pavement layers. Some of them are listed below:

a) Tensile strength of the stabilized material;

b) Shrinkage characteristics;

c) Volume changes resulting from temperature or moisture variations;

d) The subgrade restraint;

e) Stiffness and creep of the stabilized material, and

f) External loadings such as those caused by traffic.

As in the case of compressive strength, the tensile strength of stabilized materials takes time to develop. On the other hand, stabilized material in a road pavement layer, will be subject to volume changes from at least one of the factors listed above as soon as it is compacted. Cracking in stabilized layers due to changes in temperature or moisture content cannot, therefore, be avoided and must be accepted as inevitable although steps can be taken to reduce the effect. Cracking may also occur as a result of fatigue failure due to trafficking and is an entirely separate phenomenon from the initial cracking due to environmental changes.

Cracks in stabilized layers used at capping and sub-base level are unlikely to cause significant problems but at base level the cracks may be reflected through the surfacing. The existence of cracks in a road surface may be assumed to indicate need for remedial action. The consequences of not doing so, may range from no problems at all to loss of interlock or to eventual failure when the stabilized layer has been reduced to unconnected blocks. Cracks may also permit ingress of water leading to weathering of materials at crack faces, de-bonding between pavement layers, or deterioration of moisture-susceptible layers beneath the stabilized layer.

### 8.3 Primary Cracking

Cracks appear in cement-stabilized materials as a result of shrinkage and temperature fluctuations. The initial crack pattern is dependent on the early strength of the material and the properties of the material used. Materials which have low strength, normally also contain a higher proportion of plastic fines. The stabilized materials with lower strength and with high proportion of plastic fines have frequent but narrow cracks. Whether or not these frequent but fine cracks prove to be a problem depends to a large extent on the mechanical interlock at the face of the cracks. If the interlock is good the material performs satisfactory and the cracks are sufficiently fine for them not to be reflected through the pavement layer above. However, the lower strengths of these stabilized materials mean that they are generally only suitable for use in the lower layers of the road where cracking is less of a problem anyway.

On the other hand, stabilized materials with high strength criteria and which have little, if any, plastic fines have fewer but wide cracks. These cracks are often wide enough for them to be reflected through the surface. In order to restrain the propagation of lateral reflective cracks, such materials therefore have to be covered with a greater thickness of construction material than would otherwise be required.

The temperature at which the material is laid also plays a part in the type of crack pattern that is produced. Layers placed in cooler weather tend to develop fewer and narrower cracks as there is less thermal shrinkage. The stabilized layer may subsequently be in compression, apart perhaps from prolonged cold spells, so that cracks remain closed with good load transfer. Fewer cracks develop when the temperature difference between day and night during construction is not large, as thermal warping is reduced.

Lime- stabilized materials are also subjected to cracking for the same reasons. However, the effects are not so pronounced; if the cracks occur before unreacted lime in the layer has been used up, either in pozzolanic reactions or by carbonation, the continuing pozzolanic reaction of the lime can result in self- healing (autogenous healing) of the cracks.

Given that cracking is inevitable, the ideal condition is for materials to have low early strength which lead to numerous fine cracks but high long- term strengths which mean good mechanical interlock at the face of the cracks. As lime is slower to react than cement, this is another reason for favouring lime, provided it can achieve high long- term strengths.

Another possibility is to use secondary additives to modify the hardening action of the cement to reduce its early strength without affecting its long-term strength.

## 8.4 Traffic Associated Cracks

Quite separately and much more importantly than the primary transverse cracks, cracks may appear in stabilized bases of inadequate strength or inadequate construction thickness in relation to the traffic and the sub-grade strength. Such cracking takes the form of "map" cracking which, in extreme cases, causes the stabilized material to deteriorate into small slabs with poor load transfer. Once started, deterioration is likely to continue until the stabilized base becomes little more effective than granular sub-base.

When extensive cracking has developed as a result of the combined action of free water and traffic, then it often results in the "pumping" to the surface of fine material from the underlying pavement layers where it is deposited in the cracks. The fines discolour the surface along the cracks making them clearly visible.

Unlike the primary cracking, the appearance of traffic-associated cracks is not inevitable. It should not occur if the road pavement has been properly designed to take account of the traffic likely to be encountered during the design life of the road.

## 8.5 Durability of Stabilized Materials

The failure of stabilized materials by disintegration into a loose mass is not common. It is most likely to be due to deficiency either in the amount of stabilizer, deficiency in the quality of the stabilizer, or deficient compaction or curing. These problems should not occur if a good standard of preliminary testing for suitability and of quality control are maintained.

It is reported that the most common type of failure of stabilized layers is the peeling-off of surface dressings from stabilized layers. This is usually due to failure of top of the layers itself rather than any of the shortcomings of the surface dressing. The surface of the layer tends to disintegrate under traffic, the most likely cause of which is considered to be as a result of overstressing of the surface layer during the compaction of the stabilized material at the time of construction. This induces a series of shallow shear planes in the surface layer and result in a sharp falling-off density of the material towards the upper surface. Overstressing is most prevalent with uniformly graded non-cohesive sands. It can be avoided if special care is taken with the compaction and if towed vibrating rollers are used.

A survey of known causes of lack of durability of stabilized layers confirmed that the most common problem was surface disintegration of the primed layer during construction and scabbing of the seal in service due to an inadequate bond with the stabilized material. These problems are a result of inadequate compaction and curing and are more likely to occur in hot, dry climates. Apart from the problem of surface disintegration, long-term durability may also be impaired by the effects of sulphates and by carbonation.

## 8.6 Control of Reflective Cracking in Cement Stabilized Pavements

Although the potential exists for reflection cracking when a cement-stabilized base is used in a pavement structure, proper construction and design techniques can minimize the potential that the pavement will be adversely affected. Proper construction practices to minimize drying, pre-cracking soon after construction, and designing for stress relief are all valid methods that will reduce or eliminate the formation of reflection cracks in cement-stabilized bases.

There are several factors as discussed in the previous chapter, which contribute to the cracking in a cement-stabilized base/sub-base. With regard to material characteristics, the type of soil, cement content, degree of compaction and curing, and temperature and moisture changes directly influence the degree of shrinkage.

There are a number of preventative measures and design concepts that can be used to minimize shrinkage cracking in the cement-stabilized base, and to reduce the potential that base cracks will reflect through the asphalt surface. Methods of controlling reflective cracking include proper construction and curing of the stabilized base, reduction of crack size through the use of "pre-cracking", and relief of stress concentrations through the use of flexible layers in the pavement structure.

A cement-stabilized base provides excellent support for asphalt surfaces. The stabilized base material is stronger, more uniform and more water resistant than an un-stabilized base. Loads are distributed over a larger area and stresses in the subgrade are reduced. However, cement-stabilized bases can also be the source of shrinkage cracks in the stabilized base layer, which can reflect through the asphalt surface. The cracks that develop are not the result of a structural deficiency, but rather a natural characteristic of cement-stabilized bases. The surface cracks tend to follow the same pattern as the cracks in the base, and are referred to as "reflection" cracks.

In most cases, reflection cracks are narrow (less than 3 mm) and will not adversely affect the performance of the pavement. However, wider cracks can result in a rough riding surface and deterioration of the pavement. The wide cracks create an environment for water infiltration and subsequent pumping of the underlying subgrade.

Several factors contribute to the cracking and crack spacing in a cement stabilized base which include material characteristics, construction procedures, traffic and restraint imposed on the base by the subgrade. With regard to material characteristics the primary cause of cracking is due to drying shrinkage of the cement stabilized base. The degree of drying shrinkage is affected by the type of soil, degree of compaction and curing, cement content, temperatures and moisture changes.

Cement stabilized fine grained soils e.g. clays exhibit greater shrinkage than cement stabilized granular soils. Although stabilized clay soils develop higher total shrinkage than granular soils, the cracks are typically finer and more closely spaced often of hairline variety spaced 0.6 to 3.0 m apart. The granular soils generally produce less shrinkage but develop larger cracks typically spaced at 3.0 to 6.0 m apart.

Fine grain grained soils have large surface area than granular soils and typically require higher moisture content for compaction purposes. In addition, cement content for fine grained soils are generally 2 to 5 percent higher than granular soils in order to achieve adequate durability and strength. Both these factor contribute to higher moisture contents for stabilized fine grained soils and consequently higher drying shrinkage.

The effect of compaction on shrinkage characteristics of cement stabilized material plays an important role. A well compacted mixture exhibits reduced shrinkage potential, because the soil/aggregates particles are packed tightly together resulting in reduced voids. It has been reported that compacting cement stabilized soil at modified proctor effort, reduces shrinkage significantly as compared to stabilized soil compacted to standard proctor density. The reason for the same can be attributed to the fact that the optimum moisture contents at modified proctor compaction are typically less than at standard proctor compaction which helps to reduce shrinkage. The least amount of shrinkage is obtained for the stabilized material at the highest density and lowest moisture content.

Cement hydration contributes less to shrinkage than does many other factors. In fact, for soils that exhibit volume change without cement, increasing cement will decrease total shrinkage. However, excessive amounts of cement can exacerbate cracking in two ways: First, increased cement contents cause greater consumption of water during hydration, thus increasing drying shrinkage. Also, higher cement levels cause higher rigidity and excessive strength (both tensile and compressive).

## 8.7 Methods of controlling reflective cracking

Methods of controlling reflective cracking basically fall into the two categories:

- Pre-cracking
- Providing for stress relief at the base-surface interface

Pre-cracking: Minimizing crack width with proper construction and curing procedures, as discussed in the previous sections, will eliminate much of the potential for wide cracks. Another method to reduce crack width is a relatively new procedure called "pre-cracking", where hundreds of tiny micro-cracks develop instead of single transverse cracks. The method has been successfully tried on several projects in the United States. The procedure involves several passes of a large vibratory roller over the cement-stabilized base one to two days after final compaction. This introduces a network of closely spaced hairline cracks into the cement-stabilized material, which acts to relieve the shrinkage stresses in the early stages of curing, and provides a crack pattern that will minimize the development of wide shrinkage cracks. In addition, since the pre-cracking is performed shortly after placement, the "micro- cracking" will not impact the pavement's overall structural capacity as the cracks will heal and the cement-stabilized material will continue to gain strength with time.

Stress Relief: Another method of reducing the potential for reflection cracking is to relieve the stress concentrations that result from cracks in the cement-stabilized base. The following three methods have been successfully used to reduce the stresses that cause reflection cracks:

1) A bituminous surface treatment (chip seal) between the stabilized base and the asphalt surface. The additional flexibility of the surface treatment layer will help to reduce stress concentrations. This surface treatment also provides an excellent temporary surface during construction for traffic control.
2) A geo-textile between the stabilized base and surface, or between the asphalt binder and wearing courses. Similar to the surface treatment, the geo-textile provides flexibility and acts to intercept cracks without letting them pass through the material.
3) A 50 mm to 100 mm layer of unbound granular material between the stabilized base layer and the asphalt surface. This use of a "sandwich" or "inverted" pavement design adds additional structure to the pavement, and will prevent the propagation of cracks through to the surface layer.


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