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A Comprehensive Review of the Principles of Soil Stabilization Techniques for Roads

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***Abstract-* With limited finances available, the biggest challenge in the developing countries like India is to provide a complete network of road system, particularly in providing connectivity to remote villages. The cost of road construction using conventional construction materials and methods has been increasing by leaps and bounds year after year. Therefore there is a need to resort to one of the suitable low-cost road construction methods by effectively utilising locally available materials and adopting Soil Stabilization Techniques. Thus the objectives of soil stabilized road construction are: (a) to affect economy in the initial construction cost of the lower layers of the pavement such as subgrade and sub-base course, and (b) possibility to upgrade the pavement structure to higher specification at a later stage by resorting to the stage – construction of the pavement to meet the growing needs of the road traffic. Thus construction of roads using the different Soil Stabilization Techniques proves to be economically viable alternatives to the costly constructions. This paper aims at carrying out an exhaustive review of the principles of the various Soil Stabilization Techniques generally employed in the construction of roads in the context of a country like India.**

***Index terms-* Concrete, Soil Stabilization Techniques, Road Construction, Mechanical Soil Stabilization, Soil-Cement Soil Stabilization, Soil-Lime Soil Stabilization, Soil-Bitumen Soil Stabilization**

I.INTRODUCTION

The term 'Soil Stabilization' means, improvement of the stability or bearing power of the soil by the use of controlled compaction, proportioning and or the addition of suitable admixture or stabilizers. Soil Stabilization deals with physical, physico-chemical and chemical methods to ensure that the stabilized soil serves its intended purpose as pavement component material. The basic principles of Soil Stabilization may be stated as:

- Evaluating the properties of given soil and assessing the deficient property due to which the soil is considered weak
- Deciding the appropriate method of supplementing the deficient property by an effective and economical method of stabilization
- Designing the soil mix for the intended stability and durability, resorting to suitable procedure including addition of selected stabilizers, mixing, spreading, and by adequate compaction.

Soil Stabilization may result in any one or more of the following changes:

- Increase in the strength characteristics
- Modification in some of the undesirable properties of the soil, such as high plasticity, swelling, etc.
- Change in chemical properties
- Retaining desired minimum strength even after subjecting the stabilized soil to soaked condition.

Based on the above principles, the various techniques of Soil Stabilization may be grouped as given below. Densification by suitable method of compaction is common to all these techniques.

- Proportioning and mixing different materials
- Using cementing agent
- Using modifying agent
- Using water-proofing agent
- Using water repelling agent
- Using water retaining agent
- By heat treatment
- By chemical stabilization

II. RESULTS AND DISCUSSIONS

A. MECHANICAL SOIL STABILIZATION

Principles and Applications: Correctly proportioned materials (aggregates and soils) when adequately compacted to get a mechanically stable layer, the method is called mechanical stabilization. Thus the two basic principles in this method of stabilization are:

1. Proportioning
2. Compacting

If a granular soil containing negligible fines is mixed with a certain proportion of fine or binder soil, it is possible to increase the stability. Similarly the stability of a fine grained soil could be considerably improved by mixing a suitable proportion of granular materials to get a suitable gradation.

The principle of mechanical soil stabilization has been successfully applied in the construction of sub-base and base courses of low volume roads. The method has also been used as surface course for low cost roads such as village roads when the traffic and rainfall are low

B. MIX DESIGN

The factors to be considered in the design of mix are gradation, density, index properties and stability. Of these factors, gradation and proportioning are important factors to be taken care at initial stage of mix design. The other properties can be tested on the selected mixes.

Gradation: The particle size distribution that gives maximum density is generally aimed at. The theoretical gradation for maximum density is given by:

$P = 100 (d/D)^n$

Where,

P = percent finer than diameter ‘d’ (mm) in the material

D = diameter of largest particle, mm

n = gradation index, which have values ranging from 0.3 to 0.5 depending upon the shape factor of the coarser fractions of materials

Proportioning: When two or more different types of materials are available at nearby location of the road project, it is possible to achieve much superior properties by mixing these materials in certain proportions, than those of individual materials. The principle is to aim at achieving a desirable grain size distribution of the selected mix such that there is a substantial increase in dry density resulting in improved strength and durability.

The following three methods have been in common use:

1. Rothfutch’s method
2. Triangular Chart method
3. Laboratory methods on trial mixes

The first two are graphical methods and the third one is by trial and error. Specified set of Laboratory tests are conducted on different trial mixes. Rothfutch’s method of proportioning is explained here in detail.

Proportioning of Materials by Rothfutch’s Method:

First, sieve analysis of the different selected soils is to be carried out in the laboratory (by wet sieving except in case of cohesionless sand or aggregates). The results of the grain size distribution are tabulated giving the different sieve sizes and the cumulative percentages passing each sieve, ranging from 0 to 100%.

The ‘desired gradation’ is to be decided either based on recommended grain size distribution tables or by using a theoretical equation assuming an appropriate value of gradation index, n.

On a plain graph paper, the cumulative percentages passing various sieves ranging from 0 to 100% are plotted to natural scale on the Y-axis. The X-axis is to represent different particle sizes, but not to any specified scale, to be plotted later. The point representing 100% passing located on the Y-axis represents maximum size of the set of sieves used in the sieve analysis, through which 100% of all the selected materials will pass. A sloping straight line of convenient slope is drawn from this 100% passing point on the Y-axis, to a point corresponding to 0% passing, lying on the X-axis. The smallest sieve size that will be made use of, will be near this point on the X-axis, before the 0% passing. This sloping line represents the ‘balancing straight line’ of the desired gradation of the mixed aggregates.

Using the grain size distribution table, the cumulative % passing any particular sieve size is selected and a line is drawn parallel to the X-axis so that, the line intersect the sloping line at a point and from that point of intersection, a line parallel to the Y-axis is drawn to intersect the X-axis. This point on the X-axis is marked as the grain size representing the selected sieve size.

Now on this chart, the grain size distribution curves of the selected materials to be mixed are plotted. For example, three materials, A, B, and C available locally are to be mixed. The grain size distribution curves of these three materials are plotted as shown in Fig. 1. The balancing straight lines of A, B, and C are obtained, allowing only minimum of the areas equally on either side of the balancing lines. The opposite ends of the balancing straight lines of A and B are joined. Similarly those of B and C are also joined.

The points where these two lines meet the sloping line (desired gradation line) indicate the proportions in which the materials A, B, and C are to be mixed. These values may be read from the Y-axis by projecting the points of intersection of the sloping line as shown in Fig. 1.

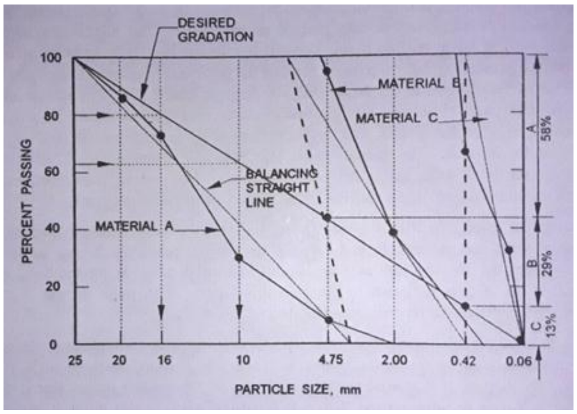

Fig. 1: Proportioning of materials by Rothfutch's Method

Index Properties: The desirable values of Liquid Limit (LL) and Plasticity Index (PI) values based on performance studies on soil stabilized roads are given below to be carried out on the fraction of selected design mixes, passing 0.425 mm sieve.

Table 1: Desirable properties of LL and PI

Pavement Layer	*Base Course*	*Surface Course*
Liquid Limit	25%, max.	35%, max.
Plasticity Index	6%, max.	5 to 10%

Stability: The commonly accepted stability test on soil mixes in India in California Bearing Ratio (CBR) test. The soaked CBR value should be adopted for pavement design in regions with high rainfall and at locations where the pavement layer is likely to be subjected to soaking conditions. However, in arid regions and at locations with good drainage, un-soaked CBR value will be more appropriate for design.

Construction Steps:

a. The subgrade is prepared as per standard procedures
b. The materials are mixed to the desired proportions as per design. Generally the proportions are converted from weight to volume basis
c. The existing moisture content is checked by a rapid method and additional water required is spread and the material is re-mixed. The wet mix is spread to the desired grade and compacted by rollers. Rolling is started from the edges and with adequate longitudinal overlap, it is continued upto the centre. Rolling is continued till adequate compaction is achieved
d. When to layers such as base course and surface course are to be constructed, the process is repeated with appropriate proportion of mixes

Soil Stabilization using Soft Aggregates/ Mehra's Method of Stabilization/ IRC Method:

a. Soil is collected from approved borrow pits and stacked on roadside
b. Water is added upto the OMC and soil is mixed and spread to a desired camber and grade
c. 11.5 cm thick loose base course material (sandy soil) is spread and rolled by 8 tonnes power roller to a compacted thickness of about 7.5 cm
d. Surface course material (brick aggregate + soil in the ratio 1:2) mixed with adequate water is spread to 11.5 cm loose thickness and the layer is rolled by 8 tonnes power roller to a compacted thickness of about 7.5 cm
e. After rolling, the surface is watered and left overnight. The surface is again rolled and finished.
f. The road is closed to traffic for four to five days and kept sprinkled with water. For next few days, only rubber-tyred traffic is allowed and after about two weeks the road is opened to all traffic.

B. SOIL-CEMENT STABILIZATION

Principles and Applications: 'Soil-Cement' is an intimate mix of soil, cement and water which is well compacted and cured to form a string base course, so as to fulfill the specified stability and durability

In granular soil, the mechanism of stabilization is due to the development of bond between the hydrated cement and the compacted soil particles at the point of contact. In fine grained soil, the stabilization is due to reduction in plasticity and formation of matrix enclosing small clay lumps.

Soil stabilized roads using low % of cement forms a strong and excellent subgrade of all types of pavements. Soil-Cement can be used as the sub-base course of both flexible and rigid pavements even for roads carrying heavy traffic. However as the Soil-Cement sub-base course is likely to develop cracks, suitable measures should be taken to prevent the development of reflection cracks in the bituminous layers of flexible pavements.

Design of Soil-Cement Mix: There are various mix design methods, the most commonly known being the British Standard Method, PCA and ASTM Standard methods. BIS has also standardized Soil-Cement Mix method, which is based on both British and ASTM standards of mix design.

British Standard Method for Soil-Cement Mix Design: The British Standard Method of mix design is based on the compressive strength of specimens cured for 7 days. Soil-Cement specimens are prepared with different cement contents in constant volume moulds of size 5 cm diameter and 10 cm height by compacting at OMC and Proctor density. The compressive strength of these specimens are tested after 7 days of curing and a graph is plotted with cement content vs. compressive strength as shown in Fig. 2. The cement content corresponding to strength of 17.5 kg/ cm2 is taken as the design cement content and this is considered quite adequate when the Soil-Cement is to be used for base course of highway pavements with light to medium traffic. However for heavy traffic, a higher strength factor of 28 to 35 kg/ cm2 has been suggested for mix design.

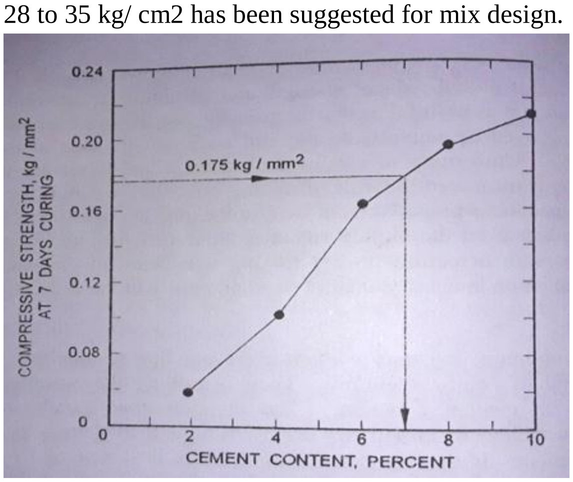

Fig. 2: Compressive Strength for varying cement contents

PCA and ASTM Standard Methods for Soil-Cement Mix Design: In the PCA/ ASTM method, the design criteria are based on durability or the ability of the Soil-Cement specimens to withstand the specified wet-dry cycles and freeze-thaw cycles. Durability is decided based on resistance to loss in weight due to brushing the surface, volume change and moisture content during the specified durability cycles.

According to the PCA mix design criteria, the maximum Soil-Cement loss after 12 cycles of wet-dry of freeze-thaw tests should not exceed the following limits:

Table 2: Maximum Permissible limits for PCA Method

Soil Type (HRB Classification)	*Max. Brushing Loss, % by weight*
A-1, A-3, A-2-4, A-2-5	14
A-2-6, A-2-7, A-4, A-5	10
A-6, A-7	7

Indian Standard Method: Method of tests for Soil-Cement mixes has been standardized by the Bureau of Indian Standards (BIS). Determination of unconfined compressive strength of Soil-Cement standardized by the BIS is similar to the British Standard Test method. The wetting-drying and freezing-thawing tests of compacted Soil-Cement mixtures standardized by the BIS are similar to PCA method and the ASTM Standard methods of testing Soil-Cement. The BIS has also standardized the flexural strength test on Soil-Cement samples using simple beam with third point loading.

Construction Steps for Mix-In-Place Method:

a. Preparation of subgrade or sub-base
b. Pulverization of soil
c. Application of cement and dry mixing
d. Spraying required proportion of water and remixing
e. Spreading the mix and grading
f. Compaction to be done with minimum possible delay after wet mixing
g. The Soil-Cement layer to be cure for the specified period by moist curing either by preventing the moisture to escape or by covering with moist materials
h. Joint with old work or construction joint is to be made carefully as the old soil cement is brittle

and the edges may get severely damaged if specific care is not taken during scarifying, pulverizing, mixing, and compaction of the new section of base course

i)Field control tests consists of checking: (i) moisture content of soil, (ii) moisture content of Soil-Cement mix, (iii) cement content of the mix, (iv) degree of pulverization by sieving through 4,75 mm sieve, (v) mixing efficiency, (vi) density of compaction, and (vii) thickness of compacted layer

Construction Steps for Plant-Mix Method:

a. Preparation of subgrade or sub-base
b. Pulverization of soil, application of cement and dry mixing in the plant
c. Adding required proportion of water and remixing in the plant
d. Spreading and grading using machinery
e. Compaction to be done by specified rollers with minimum possible delay after spreading
f. Curing the Soil-Cement layer to be done for the specified period by suitable method
g. Joint with old work or construction joint to be made carefully during compaction of the new work
h. Field density tests on density of compaction

C. SOIL-LIME STABILIZATION

Principles and Applications: When soils are treated with lime, either modification in soil properties or binding or both actions may take place. In the case of clayey soils with high plasticity the predominant action is generally modification resulting benefits such as reduction in plasticity and volume changes due to changes in moisture content. Other benefits are, Soil-Lime mixes become friable and easy to be pulverized having less affinity with water; also there could be 'pozzolanic action' resulting in slow rate of increase in strength with curing period. All these modifications are considered desirable in construction of soil stabilized roads. Lime also imparts a little binding action in soils.

The maximum dry density of Soil-Lime mix is decreased to 2 to 3% in terms of untreated soils; however this decrease in dry density with the addition of small proportion of lime does not cause reduction in strength.

Soil-Lime is quite suitable as sub-base course for all types of pavements and base course for pavements with very low traffic. As in the case of Soil-Cement, Soil-Lime also cannot be used as a surface course even for light traffic in view of its very poor resistance to abrasion and impact. Soil-Lime is quite suitable in warm regions; but it is not very suitable under freezing temperatures.

Mix Design: There is no standard method of mix design. If lime is used mainly as a modifier for highly plastic clay, then the optimal lime content may be decided based on lime fixation limit or at a higher value so as to reduce the plasticity index and swelling values upto the desired limits. Some strength test also may be considered as a criterion for the design of mix. However the compressive strength of Soil-Lime specimens without additives at seven days curing may be quite low.

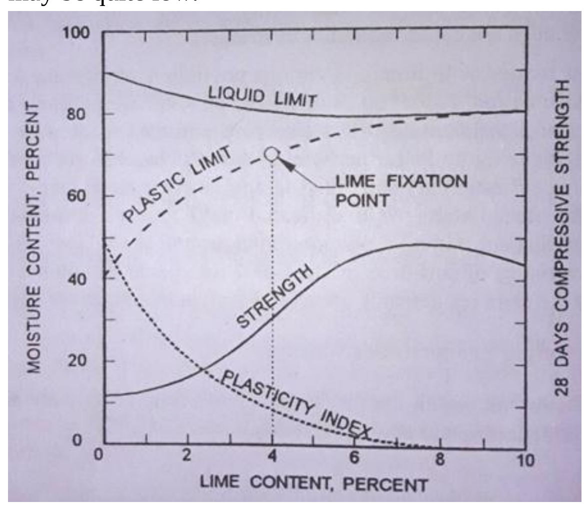

Fig. 3: Effect of lime content on properties of Clay-Lime mixes

Construction Steps:

a. Preparation of subgrade or sub-base
b. Pulverization of soil to be stabilized
c. Addition of part of lime as dry powder, mixing, spraying water, and remixing. Lime may also be added to the soil in slurry form, by mixing with water
d. Allowing the mixture for about a day for pre-conditioning the soil, and remixing when pulverization becomes easy
e. Addition of rest of the lime and water if necessary and remixing
f. Spreading the lime treated mix to desired grade and compaction

g. Soil-Lime layer is protected from drying out and is allowed for moist curing
h. Field control tests include checking moisture content at the time of compaction and checking dry density soon after compaction

D. SOIL-BITUMEN STABILIZATION

Principles and Applications: The basic principle of bituminous stabilization is considered as water-proofing with some binding action. By water-proofing the inherent strength and other properties of the soil could be retained. In case of cohesionless soils the binding action is also important. Generally both water-proofing and binding actions are provided to soil.

In granular soil the coarser grains may be individually coated and stuck together by a thin film of bituminous materials. But in fine grained soils bituminous material plugs up the voids between small soil clods, thus water proofing the compacted Soil-Bitumen.

Most commonly used bituminous materials are cutback and emulsion. As heating of large quantities of soil and bitumen is not possible, a suitable grade of cutback is chosen depending upon the climatic conditions and mixing problems, in order to enable mixing at day temperature of the locality. Emulsions may also be used, especially in places where there is scarcity of water for construction purposes. After the Soil-Bitumen (cutback or emulsion) is compacted, the layer is cured and during the curing period the water and volatiles evaporate and the mix hardens.

Bituminous stabilized layer may be used as a sub-base or base course of low volume roads and even as surface course for roads with light vehicles in low rainfall regions.

Mix Design: There is no standard method of mix design. However Soil-Water bitumen mixes are generally compacted at the optimum moisture content corresponding to maximum dry density. These specimens are prepared with various bitumen contents and are tested for stability and water absorption. CBR test and modified Hubbard Field test are considered suitable for evaluating the stability and water-proofing effects. Other laboratory tests that may be used in the Soil-Bitumen mixes free from coarse particles are ‘Iowa Bearing Value’ test and cone penetration test. A graph may be plotted with bitumen content versus stability value and the optimum bitumen content corresponding to the maximum stability value may be found. Either this value or a lower value of bitumen content may be adopted if the desired stability value and water-proofing action are achieved for that mix.

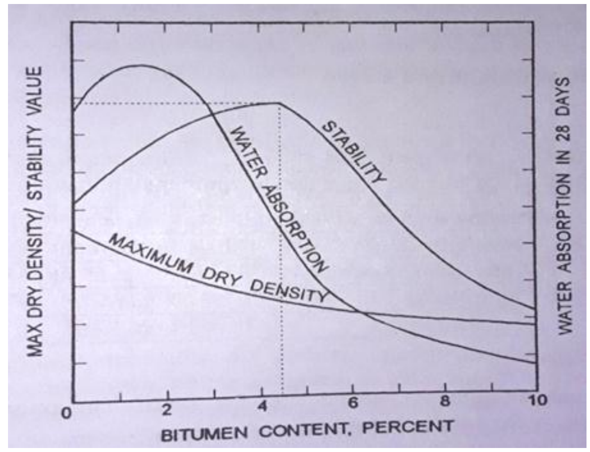

Fig. 4: Effect of bitumen content on properties of Soil-bitumen

Construction Steps:

a. Pulverization of soil
b. Spraying of water and mixing; the quantity of water to be added will be lesser if bituminous emulsion is used for stabilization
c. Spraying of cutback or emulsion on the moist soil and remixing until the bituminous binder is well distributed
d. The mix is spread, graded and compacted
e. The compacted layer is allowed to cue, allowing the moisture and volatiles of solvent to evaporate
f. Field control tests include: (i) checking of pulverization of wet mixed soil, (ii) checking of moisture content and bitumen content before compaction, and (iii) checking of dry density after compaction

III. CONCLUSION

So from the above discussions, it is worth mentioning that constructions of roads using Soil Stabilization Techniques will probably be one of the most sought after technologies in the near future due to its cost economy and easier construction procedure in comparison to the conventional methods which are costly and complex in nature. Therein lies the prospect of this comprehensive study.

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