Subgrade stabilization strategies effect on pavement thickness according to AASHTO pavement design method. (Review)

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Abstract. There are a variety of techniques and materials that have been lately developed and employed for stabilizing weak subgrade soils in pavement construction. Some of these techniques and materials are becoming more common due to their comparative cost-effectiveness, practicality and efficiency. Hence, it is quite agreed that there is a necessity for evaluating and assessing the comparative performance of these pavement subgrade stabilizing methods and treatments. The current research aims to review some relative efficiency of several mechanical and chemical stabilizing mechanisms that have been currently examined by several researchers independently. Ten recent studies that have used different stabilizing mechanisms for stabilizing the strength capacity of different subgrade soils used as pavement foundations. The studied soil types involved Fine grained silt (ML), poorly graded sand (SP), soft sand, Sandy-Clay (CH), Salty sand, clay and soft clay. The laboratory and field California bearing ratio (CBR) test has been chosen as the quantitative basis for comparison. AASHTO (1998) for highway pavement design procedure has been adopted for computing the reduction in pavement thickness due the increase in CBR-value resulting from the adopted stabilizing mechanism for each study. The weakest soil type is silty clay located in India with CBR equal to 1%, while the higher strength soil was clay also located in India with CBR equal to 6.64%. The best reduction achieved by physical additives was from Asphalt emulsion added by 12% that increased CBR from 4.6% to 20.6%. The best reduction achieved by chemical additives was from gypsum added by 25% that increased CBR from 1% to 22%, this result is the best at all. Using geogrids increased CBR from 2.14% to 12.84% whereas no effective reduction was obtained by adding 4% polymers.

Key words  
Subgrade Soil, Pavement Design, Soil Stabilization, CBR, Soil Properties, mechanical and chemical stabilizations.

Introduction
Highway engineers regularly face problems in pavement because of subgrade soil weakness, which may return to low density, high water sensibility, low shear strength and other unaccepted engineering properties. Laboratory and field tests such as CBR and field density values are usually utilized to evaluate subgrade strength. Various methods and technologies should be examined and evaluated to stabilize subgrade layer. Subgrade layer is usually composed of the materials available in the local soil.

Pavement design should rely on economical, adequate, and available subgrade soil materials to ensure sufficient performance. For instance, soft and weak subgrades require careful treatment to guarantee their adequacy and workability for constructing the upper layers of the pavement. Subgrade stabilization is efficient and less costly, that is often because materials available for road paving are
quite cheaper when compared to replacement of subgrade materials by other stronger ones. A difficult problem in construction, maintenance and durability of civil engineering projects were found when the subgrade soil is one or mix of soft clay, silty poor graded, high organic content, or any other undesirable engineering property soil.

Researchers adopted to stabilize subgrade soils into two main categories mechanical stabilization and chemical stabilization. When soil stabilization can be physically accomplished by ensuring particles rearrangement is attained by compaction or induced vibration or also by adopting advanced physical mechanisms including nailing and barriers that means Mechanical Stabilization. Otherwise, when, soil stabilization can be done by chemical reactions between stabilizer (i.e. cementations material) and soil particles like pozollanic materials that means chemical stabilization.

The most recognized and influential geotechnical properties of soil are durability, permeability, compressibility, and strength. Hence, the central target of stabilizing natural soil is to enhance these properties. This is regularly achieved by using additives that bind particles in weak subgrade soils.

Most of stabilization processes occur when the natural soil is soft (clayey peat, silt or organic soils). Several studies mentioned that fine-grained granular soils are most adequate to be stabilized. That is because of their considerable large surface area to particle diameter ratio. Chemical stabilization of soils with swelling hazards incorporates the altering of the physico-synthetic within and around the particles of clay. This can yield less water to accomplish the static imbalance and making it difficult for water that moves out of and into the framework in order to satisfy specific designing highway schemes and administration life of the bitumen[1].

Non-traditional additives that are used for soil stabilization have been developed in increasing rates during the last few decades. These types of stabilizing agents are becoming more common as a result for their comparative cost-effectiveness, short curing time, and comfort at application.

The current research aims to review effect of stabilization subgrade soil strategies denoted by density, optimum water content, California bearing ratio (CBR), and any other subgrade strength parameter on the flexible pavement thickness design. Many experiments will be conducted on subgrade soil samples taken from selected highway pavement design.

Related Studies:
The quality of the subgrade will greatly influence the pavement design, performance and its service life. Highways built on expansive soil areas are known for bad condition and unpredictable behavior for which the nature of the soil contributes to some extent [2]. In geological time-scales, shrinkage-driven cracks might be in-filled with sediment and hence, imparting inconsistency to the subgrade. When material falls into cracks, the soil does not have the capability of moving back, as a result leading to greater swelling pressures. According to Sajja & Chakravarthi [3], who examined the expected influence of using two types of additives, fly ash and artificial sand, as stabilizer on soft clayey soil as pavement subgrade. The artificial sand (also known as robo sand) is a product that is obtained from crushing stone-it is a well-graded soil that consists primarily of sand size particles. The type of fly ash is class C, which mainly contains particles of silt sized and with plasticity value of zero. "The fly ash is a product that usually exists in thermal power plant (NTPC)" [3]. Mechanical stabilization process is carried out by adding specific percentages of fly ash and artificial sand to the native soil. The analysis results revealed that there is a substantial enhancement after adding the additives on index and geotechnical properties. The findings also implied that the sand plays more pronounced role than fly ash.

Another related research was carried out by Patel, et al. [1]. They examined to what extent the transformation of soil index properties can be enhanced and the volume change of a high plasticity soil
can be reduced by adding certain percentages of (Terrasil + Zycobond) as stabilizers. Where, Terrasil is nano-technology based 100% or nanosilane, water dissolvable, warmth steady and bright, receptive soil modifier to waterproof soil subgrade. Additionally, it lessens free swelling, enhancing dry CBR test value under wet conditions, enhancing road base performance and improves rigidity to deformation by holding frictional values between residue and controls disintegration of subgrade soils. Zycobond, in contrast, is acrylic co-polymer scattering for keeping up soil particles and bestowing to soil disintegration and dust controls resistance, it is mixed with Terrasil arrangement and splashed on treated soils.

A study was made to evaluate the effectiveness of soil stabilization by using chloride (Nacl) compounds and gypsum for silty clay soil, determining the percentage of strength improvement for silty clay soil obtained for different chloride (Nacl) compounds used at different concentration, to increase the shear strength and bearing capacity of the soil, to reduce water content and in-situ conditions and increase in soil properties by indicating CBR test results [4]. While, Mostafa, et al. [5] experimentally treated a particular type of an expansive soil as a subgrade material by adding three different types of chemical additives, which are Addicrete P (of density 1.01 ± 0.01 kilogram/litre), Addibond 65 (of density 1.02 ± 0.02 kilogram/litre), and finally E-Glass Fibers chopped strands type with length of 13 millimeters and filament diameter of (3, 6, 12) micron. A series of laboratory tests such as Atterberge limits, Modified proctor, and California bearing ratio (CBR) were performed for each soil-additive mixed sample. Results showed that there is a tendency from the soil to stabilize by these additives. California bearing ratio was increased from 4.7% to 8.05% and the expansion after the 96 hours soaking time was eliminated from 4.95 millimeters to 0.35 millimeter. This is considered the best effect and was a result from mixing the native soil with a percent of 6% Addicrete P.

Kumar & Rekha, [6], results obtained from a series of CBR load tests are presented. CBR load tests were conducted on geogrid reinforced and unreinforced weak subgrades to understand the general behavior of reinforced subgrades. Geogrids, which is a geosynthetic material commonly made of polymer materials. Geogrids are mainly used as reinforcing material in sub-bases or sub-grades below embankments, pavements, and retaining walls figure-1. Geogrids are frequently fabricated from a variety of polymer materials including polyethylene, polyvinyl alcohol, polyester, or polypropylene [7]. Zumrawi & Mansour, [8] made another study on effect of using geogrid as subgrade reinforcing. They can be made by knitting or weaving yarns, heat-welded from strips of material or produced by punching a fixed pattern of holes in sheet of material and then stretched into a grid. As shown in figure-2, the geogrid is placed at various heights to find the optimum placement of geogrid reinforcement. The loading was applied through a CBR test apparatus using a 50 kN frame and circular plunger of 50 mm diameter. It was concluded that the performance of the subgrade soil can be improved using geogrid reinforcement. The highest CBR achieved for optimum placement and amount of geogrid reinforcement provided for the subgrade soil improved by about 2.4 times the unreinforced. Laboratory tests are carried out on subgrade soil reinforced with one or more layers of geogrids as shown in figure-3. The soil specimens are then compacted in four layers with or without using geogrid sheets. The results state that CBR value depends largely on the number and location of the geogrid sheets used in the soil specimen. In numbers, there was a 26% increase in the CBR value for the case of placing the geogrid sheet at the first layer of soil. Additionally, the CBR value considerably rose by about 62% when all four layer are treated by the geogrid sheets.

Where, an attempt is taken to analyze the properties of soil using gypsum and Nacl. Numerous quantities of salts (15%, 20%, and 25%) are added to the soil. The main conclusions of this experimental research were that as the percentage of each of the chemical components goes up the optimum moisture content goes down and the maximum dry density goes up. Increasing the amount of additives leads to a fall into the values of liquid limit, plastic limit and plasticity index. The unconfined compressive strength increases as the chemical content increases and also bearing capacity of soil increases [4].
Figure 1. Geogrid Material used in the study [6]

Figure 2. Geogrid components [8]

Al-Jumaili & Al-Jameel, [9] studied the effect of geogrid reinforcement on CBR of subgrade soft sand soil from Al-Najaf city on total pavement thickness. The results indicated that the value of CBR was about 2.14% without using geogrid, whereas this value was 12.84% in case of putting geogrid at 0.2H from the top of the specimen. Also, the reinforcement of subgrade with geogrid at 0.2 from the subgrade layer thickness will reduce the total pavement thickness by (30-40) %. While an attempt of experimental study on the effect of adding asphalt emulsion and Portland cement on the engineering properties of sand poorly graded river soil used as sub-grade soil (brought from sides of Al-Kufa River in Najaf state middle west of Iraq) in pavement construction, were adding in (0, 3, 6, 9, 12 and 15) % by weight. compaction, optimum water content, CBR and direct shear tests were performed. Results showed an increase in dry density in different rates. While the optimum water content decreases with increasing asphalt emulsion and increases with increasing cement added. Direct shear of soil stabilized with cement is higher than both natural soil and that stabilized with asphalt emulsion. CBR values showed the same trend of direct shear test results [10].
Polymers including polyacrylamides, polyvinyl acetate, and polybutadienes have been adopted globally for stabilization of weak and problematic soil. The efficiency of these additives relies primarily on the type of the natural soil and the percentage of the additive itself [11]. The natural sub-grade soil is composed of silt and clay (84%) and sand (16%). The results are as follows: 1910 Kg/m³ MDD, 13% OMC and 4.09 % CBR. The optimum amount of additive (4%) yielded a soil with 1994 Kg/m³ MDD, 10.1% OMC and 21.9 % CBR. It can be noted that there is a significant enhancement in CBR value up to 435 % at optimum additive amount of 4%.

In 2018 waste asphalt concrete (WAC) as one of main current sustainable problems facing accumulation in high quantities as a result of the highway failures, maintenance and reconstructions. On the other hand, presence of large amounts of poorly graded sand soil (PGS) (classified according to unified soil classification system) that is found near rivers, which are not suitable in case of using it as sub-grade soil. Modified Procter test, CBR, Direct Shear test were depend on evaluating the stabilized soil properties. PSG river soil used as subgrade soil in this research brought from sides of Sadit AL-Handayi in Babylon Governorate located in middle west of Iraq, about 60 km south west of Baghdad, capital of Iraq. Results showed that the adding of WAC increases the dry density in different rate. While the optimum water content decreases with increasing WAC added. Direct shear of stabilized soil increase while angle of internal friction decreases with increasing of added WAC. CBR values increase with increasing WAC added [12].

**Pavement Design boundary Conditions:**

To determine the best choice regarding the best sub-grade soil stabilization technique for each of the soil types used in previous review, constant pavement design parameters employed in design procedure according to AASHTO 1998 pavement design method. Table-1 shows these parameter in detail. Table-2 illustrates the quality and thickness of pavement layer according to well-known AASHTO pavement design procedure. The selected flexible pavement as usual consists of three layers of surface course, base course and sub-base course stetted on subgrade soil. These layers are considered to be constant and the effect of subgrade stabilization techniques on whole pavement thickness will be tested. Table-3 reveals the pavement thickness designs in detail.
Table 1. Pavement Design Parameters adopted in Study

| No. | Parameter | Value |
|-----|-----------|-------|
| 1-  | Analysis Period | 15 years |
| 2-  | Traffic | $7 \times 10^6$ ESAL |
| 3-  | Reliability (R) | 95% |
| 4-  | Standard deviations (So) | 0.45 |
| 5-  | Serviceability Index (Pt) | 1.6 |
| 6-  | Initial Serviceability (Pi) | 4.6 |
| 7-  | Terminal Serviceability (Pt) | 3 |
| 8-  | Water Drainage | Good |

Table 2. Pavement Layers Parameters depended in Study

| No. | Layer | Its materials | Parameter | Value |
|-----|-------|---------------|-----------|-------|
| 1-  | Subgrade | Natural soil | $a_4$ | |
| 2-  | Subbase | Granular | $a_3, m$ | 0.14, 1.1 |
| 3-  | Base | Crushed stone | $a_2, m$ | 0.17, 1.1 |
| 4-  | Surface | Asphalt concrete | $a_1$ | 0.44 |

* where $a_1, a_2, a_3, a_4$: layer equivalent structural coefficients, & $m$: layer drainage coefficient.

Table 3. Pavement Layers Thickness Design Parameters Values

| NO. | Layer | Materials | Parameter | Value |
|-----|-------|-----------|-----------|-------|
| 1-  | subgrade | Natural soil | $M_r^*$ | 7 ksi |
|     |     |            | $S_N^*$ | 5.2   |
| 2-  | Subbase | Granular | $M_r^*$ | 20 ksi |
|     |     |            | $S_N^*$ | 3.5 |
|     |     |            | $a_3$  | 0.14 |
|     |     |            | $D^*$  | 8 inch |
|     |     |            | $m$    | 1.1 |
| 3-  | Base | Crushed stone | $M_r^*$ | 40 ksi |
|     |     |            | $S_N^*$ | 2.7 |
|     |     |            | $a_2$  | 0.17 |
The sub-grade quality and stabilization technique:

Table-4 below shows the depending coding of available references from different locations around the globe and different soil types. While table-5 shows the details of these studies in terms of locations, soil type, engineering property studied, types of additives or stabilization techniques depended, effect of studied technique on engineering property studied by listing its value before and after treatment and percent added.

Depending on design data that are presented in table-1 and thickness layers calculated in table-2 except sub-grade soil strength before and after treatment change the sub-grade supporting values according to data presented in table-5, new pavement thickness calculated in order to study the effect of many stabilization technique results shown in table-6 and figure-4 in terms of pavement thickness before and after treatment in addition to percent of reduction for each treatment.

As seen in table-6 and figure 4-1 maximum reduction in pavement thickness is in case 3-A that is for silty clay treated by 25% of gypsum, as shown in table-6, were the CBR for subgrade soil increase from 1% to 22%, which causes a reduction for pavement thickness from 50 inches to 19 inches. Although here the CBR value of 1% is unacceptable in pavement design according to all worldwide specifications, but it is used in thickness calculation in order to show the effect of stabilization treatment techniques. On the other hand there is a treatment that has minimum effect in case 9-A (see table-6, -1 and figure-4) where the CBR value slightly increases from 4.09 to 4.35 by adding polymers for fine grained ML soil by 4%.

Table 4. Numbering of References that are used as comparative studies

| No. | Reference Name                      | Year of Issue |
|-----|-------------------------------------|---------------|
| 1-  | (Sajja&Chakravarthi, 2014)[3]       | 2014          |
| 2-  | (Patel, et al. 2015)[1]             | 2015          |
| 3-  | (GVLN et al. 2016)[4]              | 2016          |
| 4-  | (Mostafa, et al. 2016)[5]          | 2016          |
| 5-  | (Kumar&Rekha, 2016)[6]             | 2016          |
| 6-  | (Zumrawi&Mansour, 2016)[8]         | 2016          |
| 7-  | (Al-Jumaili&Al-Jameel, 2016)[9]    | 2016          |
Conclusions:
The main conclusions for each type of stabilization technique adopted in above review, are as follows:

1- Soil types taken in this review are: Fine grained ML, poorly graded sand (SGP), soft sand, sandy-clay (CH), salty sand, clay and soft clay.

2- The lower strength soil type reviewed was silty clay located in India with CBR equal to 1%, while the higher strength soil is clay which is also located in India with CBR equal to 6.64%.

3- Stabilization techniques reviewed are chemical and physical stabilizations in addition to use of geogrid and polymers.

4- The major property reviewed was CBR since almost worldwide requirements depend it in assessing acceptance engineering properties.

5- The higher percent of pavement thickness reduction achieved by physical additives was adopted by adding asphalt emulsion by 12% that increase CBR from 4.6% to 20.6%

6- Gypsum added by 25% as soil chemical additives attained highest reduction in pavement thickness when CBR increase from 1% to 22%.

7- Geogrid when butted at 0.2% from height increase CBR from 2.14% to 12.84% represented best pavement thickness reduction.

8- No effective reduction achieved by adding polymers; when added by 4%, CBR increases slightly from 4.09% to 4.35%.
Table 5. Details of Studies Depend in Comparison

| No. | location | Soil type | Property Studied | Additives type | Min value (before treatment) | Max. value (after treatment) | Added percent |
|-----|----------|-----------|------------------|----------------|-----------------------------|-------------------------------|---------------|
| 1-  | India    | Soft clay | Dynamic cone pen. Test - CBR | Artificial sand(RS) - fly ash (FS) | 1.87 | 4.38 | 40% RS+10%FS |
| 2-  | India    | Clay      | CBR              | Terrasil(T) - Zycobond (Z) | 6.64 | 12.15 | - 0.041 % (T) - 0.020 % (Z) |
| 3- A| India    | Silty clay| liquid limit -plastic limit - CBR | gypsum | 0.4 | 0.33 | 0.020 % |
| 3- B| India    | Silty clay| liquid limit -plastic limit - CBR | NACL   | 0.4 | 0.33 | 0.200 % |
| 4- A| Egypt    | Clay      | CBR shrinkage-expansion | Addicrete P | 4.7 | 8.05 | 6% |
| 4- B| Egypt    | Clay      | CBR shrinkage-expansion | Addibond 65 | 4.7 | 70 | 6% |
| 5-  | India    | Salty sand| CBR              | Geogrid | 2.9 | 5.96 | (b/D) =3 (u/D) =0.1 |
| 6-  | Khartoum | Sandy-Clay (CH) | CBR          | Geogrid | 3.4 | 5.5 | Several layers |
| 7-  | Iraq     | Soft sand | CBR              | Geogrid | 2.14 | 12.84 | 0.2 H |
| 8- A| Iraq     | Poorly graded sand (SP) | CBR          | Asphalt Emulsion | 4.6 | 20.6 | 12% |
| 8- B| Iraq     | Poorly graded sand (SP) | CBR          | Portland Cement | 4.6 | 15.2 | 9% |
| 9- A| India    | Fine grained ML | CBR          | polymers | 4.09 | 4.35 | 4% |
| 9- B| India    | Fine grained ML | CBR          | Portland Cement | 4.09 | 9.35 | 15% |
| 10  | Iraq     | poorly sand graded (PSG) | CBR          | (WAC)Waste asphalt concrete | 3.2 | 8.3 | 48% |
Table 6. Effect of sub-grade stabilization on pavement layers thickness

| No. | Thickness of asphalt pavement (D) in inches | Reduction (%) |
|-----|---------------------------------------------|---------------|
|     | before treated subgrade | after treated subgrade |               |
| 1-  | 41.5 | 32.5 | 21.69 |
| 2-  | 28.0 | 23.0 | 17.85 |
| 3-  | 50.0 | 19.0 | 62.00 |
| 4-  | 53.0 | 29.5 | 44.34 |
| 5-  | 31.5 | 26.5 | 15.87 |
| 6-  | 31.5 | 26.5 | 15.87 |
| 7-  | 36.5 | 29.0 | 20.55 |
| 8-  | 35.0 | 29.5 | 15.71 |
| 9-  | 42.5 | 23.0 | 45.88 |
| 10- | 31.5 | 20.0 | 36.51 |
| 11- | 31.5 | 21.5 | 31.75 |
| 12- | 32.0 | 31.5 | 1.59 |
| 13- | 31.5 | 25.0 | 20.63 |
| 14  | 35.5 | 26.5 | 25.35 |

Figure 4. Reduction in total pavement thickness according to stabilization techniques

Recommendations
For further research work in this field, it is recommended that
1- More stabilization techniques should be experimented and research basis must be widened.
2- Optimization in selecting the efficient stabilization technique for each type of soil should be utilized in this regard.
3- An applicative study must be conducted.
4- An economic research work should be followed in order to calculate the cost of each stabilization technique.
5- There is a need for comparison of more tests such as resilient modulus and unconfined tests using modern AASHTO version.
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