Enhancing the California Bearing Ratio (CBR) Value of Clayey-Sand Type of Soil in Mathura Region

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Abstract. Road transportation is major mode of transportation over all the modes of transportation. Roads provide point to point transportation facility with freedom of movement. For the growth of any country like India roads play important role in transportation of either people or goods. Road surface which is used by vehicles for movement on road is called pavement. The bottom most layer of pavement is subgrade which is compacted layer of soil with required cross slope and gradients. This compacted layer of soil is subgrade is an essential part of road construction and when it requires some standards to meet to be able to receive pavement layers. In some cases when it do not have sufficient properties such as: dry density, California Bearing Ratio (CBR) value; soil needs to be treated so that it fulfills the requirements of subgrade. Lower CBR value will result into lower load carrying capacity of road and life. So it is necessary to treat and improve CBR value. For various type of soil there are different methods to improve the CBR value of subgrade. Here in this study efforts have been done to improve the CBR value of clayey sand type of soil, which is mostly present in the vicinity of the district Mathura. CBR value of clayey sand type of soil could be enhanced using materials like: lime, natural fibers, cement, fly ash, chemical compounds, etc. But in this study it has been tried to use natural occurring materials and waste material- Reclaimed Asphalt Pavement (RAP), so that sustainable, cheap and locally available material could be used. Also the cost of construction does not increase substantially. Laboratory tests were performed and results showed that CBR value of clayey sand type of soil can be increased using materials – lime, jute fiber and RAP in various ratios as mentioned in detail in this study.

Keywords: subgrade; clayey-sand soil; CBR value; lime; jute fiber; RAP

1. Introduction

Good Pavements are vital components for any country or region to grow. Only pavements can provide door to door connectivity in any city and to keep the pavements in good shape a lot of efforts are required from the very beginning, starting from the design phase of pavements to construction and finally
maintenance required for pavements. Pavements are generally layered structures provided on the top of the soil. Before laying the pavements the top layer of soil is generally scrapped and a flat bed of soil is prepared to receive the layers of pavements. This layer of soil is called as subgrade and sometimes subgrade might not be strong enough so that it can carry the load transferred through the layers of pavements. In this case strengthening of subgrade is necessary which is achieved by compaction and compaction itself could not be sufficient for some conditions. In those situations strengthening of subgrade is required as weak subgrade will further require more thickness of pavement layers and it increases the economic feasibility of any road project. To keep the cost of road project we may strengthen the subgrade so that the lesser thickness of pavement layers is required on the top of the subgrade. This strengthening of subgrade could be achieved by heavy compaction of subgrade but compaction is limited to such extent due to limitations of cost, equipment and time. Strengthening of subgrade could also be achieved by adding and mixing some other materials with soil like - cementitious, fibrous materials. It is required to know the proper proportion of these materials to be mixed and compacted with soil.

In a study in Louisiana State University very weak subgrade soil was stabilized with cementitious materials. At high moisture content subgrade loses its strength. Cementitious materials such as lime, class F fly ash could be mixed with soil and it forms a C-S-H (calcium-silicate-hydrates) bond. This C-S-H bond improves the strength of subgrade soil.[1] Another study performed on dispersive soil in Ethiopia (dispersive soil have high strength in dry but it loses strength in the presence of moisture content) shows that mixing of Lime with dispersive soil results in improved CBR values. Lime was added in the ratio of 7% to 9% of dry soil weight and it was cured for 7 days and 14 days. Difference between the result of curing performed for 7 days and 14 days curing was not significant.[2] India has almost 15% to 20% area covered in expansive soil. Expansive soils also show sensitivity to the moisture content and it needs to be taken care while designing for roads in these areas. Conventionally reinforcement was provided as a cure to expansive soil. Lime treated coir geotextiles were used as reinforcement and it resulted in around 52% reduction in swelling when it was used in a single layer and around 81% when used in double layers. CBR values also increased by around 400% and 435% when lime treated coir geotextile was used in single layer and double layer respectively. This reinforced section significantly reduces the thickness of pavement required considerably.[3] Coir waste was also used in another study done in Kerala where it showed around 190% and 335% improvement in CBR value when 2% coir pith and 0.6% of short coir fiber were used respectively. Use of coir waste is an effective measure to uplift rural economy and also beneficial in the perspective of engineering.[4] Another study includes the subgrade soil of coastal area where values of CBR were analyzed when lime was added in the ratio of 2%, 3%, 4%. KENLAYER computer program was used for multilayer interaction of subgrade with pavement layers and M-EPDG analysis was done to check the performance of pavement. It was noticed that lesser thickness of pavement could be used when lime was added in soil without compromising the performance of pavement.[5] Addition of lime in soil makes the soil coarser due to cementation of fine particles with each other. Liquid limit and plastic limit also decreases with addition of lime which is a non-plastic material. Adding lime to soil improves the stability of soil and improves the CBR value. Optimum ratio of adding lime in clayey sand type of soil is 6% [6]. Soil has its importance not just because it acts as a bearing surface for the footings; it also serves as one of the most important ingredient in cement mortar, cement concrete and geopolymer mortar and concrete [7]–[9].

Hamza Gullu showed in his study that adding 4% lime, 0.75% of jute fiber and 0.25% of steel fiber in soil as stabilizer helped in improving UCS value of soil for both the non-freeze-thaw cycle and the freeze-thaw cycle. Waste rubber fibers could also be used to improve the geotechnical properties of clay stabilizes soil.[10] For construction of rigid pavements marble dust, silica fumes, GGBS could also be used as cement replacement and it results in approximately similar strength of concrete with lesser shrinkage, cracks in concrete.[11], [12] Natural fiber as well as synthetic fibers could also be used for
reinforcing soil. Fiber characteristics such as skin friction, weight, aspect ratio and modulus of elasticity as well as soil characteristics such as particle size and gradation are important factors while choosing the reinforcing material for any type of soil [13]. It has been found in studies that coir fiber have better resilient response against synthetic fiber and higher coefficient of friction[14]. Natural pozzolans such as fly ash, ground granulated blast furnace slag, rice husk ash and bagasse ash not only find their place as a construction material [15], [16]but also helps in improving the properties of the soil. Zhang et al. found that adding fly ash up to 15 % with soil resulted in better CBR value and low frost-heave, thaw-weakening susceptibility. Also the use of fiber in sub base showed slight improvement in CBR value [17]. Polyethylene Terephthalate (PET) is also being used in the form of fiber to improve the geotechnical properties of soil in addition to the fly ash. In a study it was shown that PET fiber could be used along with fly ash in the ratio of 1.2% and 15% respectively to improve strength of the subgrade.[18] Due to urbanization huge amount of construction and demolition waste is produced. Dumping of these waste materials is also a big issue. Recycling this waste will be very beneficial from the environmental as well as economical point of view. Junhui Zhang similarly showed that there are several more waste materials such as waste foundry sand.[19]

Recycled Asphalt Pavement (RAP) in a ratio of 15% to 50 % could be used as a replacement in hot-mix asphalt and also it could be replaced as a base course in pavement construction. Although some kind of geocell reinforcement will be necessary when using the RAP.[20] Jie han also suggested that RAP could be used in base course sustainably but it requires the use of geosynthetics. Use of geocell improves the performance of base course in flexible pavements while reducing the creep and permanent deformations.[20] It could be concluded here that it has been suggested to use reclaimed bituminous pavement and recycled concrete aggregate in base and subbase layers of pavement but to make the pavement sustainable and durable it is required to provide some reinforcement.

In a case study by Clara Celauro it was found that adding lime to soil reduced the overall cost of pavement including the cost of maintenance by 6%. In another set of sample in which lime and RCA both were used simultaneously also reduced overall cost by up to 6% in their life. Moreover this type of replacement also proves to be more environmentally suitable.[21] Md Mehedi Hasan studied the use of RAP in subgrade soil and found that it increases the resilient capacity of soil and also soil becomes less sensitive to confining pressure. If the RAP is not available in sufficient quantity to use it in base course it could be added with subgrade also. It will ensure the use of RAP in pavement also uniformity and homogeneous pavement could be constructed. In this report the use of RAP in subgrade is later studied and discussed.[22] It has been verified that the use of sustainable construction techniques (lime stabilization, natural fibers and RAP) in subgrade can lead to the reduction of total cost and also these are environmentally suitable.

In this paper a study is done on the use of Lime, Natural Fibers and RAP in subgrade is analyzed and discussed. Tests for subgrade were performed and the suitable ratio of these materials to be used with soil without compromising the strength of subgrade is found. All the materials that are used in this study are generally waste material or these could be procured at a very cheap price. At the time of preparation of subgrade these materials could be mixed with soil and compacted to required densities as discussed later in this paper to achieve the gain in CBR value of subgrade.

2. Methodology
Subgrade of pavements are most important key in the construction of roads. Subgrades are equivalent to the foundation in case of building construction. Soil available at site of road construction is not always ready to accept pavement layers on to it, insufficient CBR value, moisture content, dry density are not always sufficient for road construction. In this case soil needs to be treated so that required standards of subgrade could only be satisfied. Based upon the literature review some materials (lime, jute fiber and
RAP) that are locally available were chosen and their effectiveness to improve the key factor for any pavement construction i.e. CBR value was tested and compared.

3. Preparation of Samples

Design of pavements in India is done on the basis of CBR value of subgrade. This CBR value is the ratio of load sustained by sample at standard penetration and standard load. Second step of pavement design is to find the amount of traffic for which the pavement is to be used in terms of million standard axles (msa). Here our prime focus is on improving the CBR value for the pavement. Preparation of CBR sample is done at the optimum moisture content (OMC) of the soil so that the soil sample is at its maximum dry density. To find the OMC standard proctor test is specified by the Bureau of Indian Standards. (IS : 2720, Part 8 - 1983) the water content of sample is determined as specified in IS: 2720 (Part 2) – 1973  CBR Test is a soil index which is somehow related to its strength. Sample is prepared and tested according to the IS 2720 (Part 16) – 1987. Load penetration curve is drawn using the value obtained from CBR test and sometimes a correction is required to eliminate the initial convex downward curve. All the CBR test data later shown in this paper is already corrected if required.

4. Results and Analysis

According to IRC-37-2001 code for a higher value of CBR lesser thickness of pavement is required. To improve the CBR value study is done here on the basis of mixing soil with Lime, Jute fiber and RAP. These materials are mixed with soil in various proportions based upon some previous knowledge of literature review. Here the values of Standard Proctor test and California Bearing Ratio are explained in tabular form for various compositions.

4.1 Plain Soil

Soil samples as extracted from Mathura region were tested for Standard Proctor Test. Once we got the OMC (Optimum Moisture content) from the graph, further the samples were prepared for the California Bearing Ratio Test accordingly and results are shown below in table 1. The OMC was found out to be 18.25 % and CBR at 2.5 mm penetration was found out to be 5.83%.
Figure 1. OMC and Dry Density of Plain Soil sample.

Table 1. OMC and Dry Density values of Plain Soil sample.

|                          |        |
|--------------------------|--------|
| Optimum Moisture Content (OMC) | 18.25 % |
| California Bearing Ratio (CBR)     | 5.83 % |

4.2 Soil mixed with Lime

Soil samples extracted from the same location were further mixed with varying ratios of Lime, such as 3%, 5%, 10% by weight of soil and samples for Standard Proctor test were prepared. OMC was found out for all three compositions and samples for California Bearing Ratio Test were prepared and tested. It was found that CBR value at 2.5 mm penetration was 10.83%, 12.49% and 13.79% for each sample having 3%, 5% and 10% of Lime content respectively.

Figure 2. Improvement in CBR value for various lime content in soil by w/w.

Table 2. CBR values for composition of soil tested with addition of lime by w/w ratio.

| Type of Soil             | CBR value                                      |
|--------------------------|-----------------------------------------------|
| Soil + 3% Lime           | 10.83 % at 2.5 mm penetration                  |
| Soil + 5% Lime           | 12.49 % at 2.5 mm penetration                  |
| Soil + 10% Lime          | 13.79 % at 2.5 mm penetration                  |

4.3 Soil mixed with Jute Fiber

Locally available Jute fiber was acquired and it was cut into a length of 50 mm. Further, these jute fibers were mixed with plain soil in proportions of 0.5%, 1% and 1.5% by weight of soil for testing. CBR value at 2.5mm penetration was found out to be 6.56%, 8.02% and 8.48% respectively.
Figure 3. Improvement in CBR value for various jute fiber content in soil by w/w.

Table 3. CBR values for composition of soil tested with addition of jute fiber by w/w ratio.

| Type of Soil                  | CBR Value                  |
|-------------------------------|----------------------------|
| Soil + 0.5% Jute fiber        | 6.56% at 2.5 mm penetration|
| Soil + 1% Jute fiber          | 8.02% at 2.5 mm penetration|
| Soil + 1.5% Jute fiber        | 8.48% at 2.5 mm penetration|

4.4 Soil mixed with RAP

Pavements are seldom resurfaced with a new layer after scraping the top surface layer of bituminous concrete. This scrapped material was collected and used as RAP with plain soil for testing. This RAP was mixed with plain soil in proportions of 5%, 10% and 15% by weight of plain soil. Tests for OMC were conducted and it was found out to be % and further, CBR test samples were prepared and tested at % OMC and CBR value at 2.5 mm penetration was found out to be 7.01%, 7.87% and 8.27% respectively for 5%, 10% and 15% of the RAP.
Table 4. CBR values for composition of soil tested with addition of RAP by w/w ratio.

| Type of Soil          | CBR Value          |
|-----------------------|--------------------|
| Soil + 5% RAP         | 7.01% at 2.5 mm penetration |
| Soil + 10% RAP        | 7.87% at 2.5 mm penetration |
| Soil + 15% RAP        | 8.27% at 2.5 mm penetration |

5. Summary and Conclusions

It is a general practice to get at least 8% of CBR value at subgrade for construction of road and if it is not available after compaction, some treatment should be used. Values of CBR for various compositions were observed and minimum required values of CBR for each type of composition are identified below in the table 5. In this study the plain soil sample that was collected had a low CBR value (5.83%). After using lime, jute fiber and RAP it is observed that CBR value has significantly improved and it attains a value of at least 8% when lime was added in %, jute fiber was added in % and RAP was used in % by weight of plain soil. Results shows that CBR value of soil could be improved using sustainable materials and these are also easily available. The result of this study could be further used by highway engineers at locations having similar characteristics of the same kind of soil to economically improve the CBR value using cheap materials like Lime, Jute Fibers and RAP, which are also easily available in local market.

Table 5. Selected value of materials used to attain at least 8% of subgrade CBR value.

| Type of Soil composition | CBR Value |
|--------------------------|-----------|
| Plain Soil               | 5.83%     |
| Soil + 2.5% Lime         | 8.71%     |
| Soil + 1% Jute fiber     | 8.02%     |
| Soil + 15% RAP           | 8.27%     |
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