Effect of coir fibres on strength, thickness and cost of PMGSY roads

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Abstract. The present study discusses about the effect of adding coir fibres in poor soil in various percentages (i.e. 0.15%, 0.30%, 0.60%, 0.90%, 1.20% and 1.5%) on the strength, thickness and cost of low volume rural roads under PMGSY. Soil sample comes under clay of high compressibility (CH) category and contains substantial amount of finer particles. Laboratory California Bearing Ratio (CBR) and compaction tests are performed for various reinforcement conditions. Upto 0.90% fibre reinforcement, improvement in CBR and dry density is reported and beyond that it decreases. The thickness of pavement is determined as per design catalogues provided in IRC:SP:72-2015. Maximum cost reduction of 21% and 19% in pavement construction corresponding to traffic category T-6 and T-9, respectively, is reported when reinforced with 0.90% coir fibres.

Keywords: Coir, Pavement, Reinforcement, Poor Soil, PMGSY

1. Introduction

The increase of population and industrial activities forces the geotechnical designers to use weak locally available soils which remain unutilized in earlier times [1]. There is no choice left whether to choose or not to choose a land. Significant pavement deterioration is reported on such soils due to two possible mechanisms. Firstly, the fine soil enters into voids of coarse aggregate thereby ruining its drainage capability. Secondly, coarse aggregate of base and sub-base course intrude into subgrade hence deteriorating stone-aggregate strength [2]. The demand of aggregates for one kilometer road length is around 7000 cubic meters with additional 300 cubic meters required for annual maintenance [3]. Moreover due to scarcity of good quality aggregate materials and their mining and transportation causes’ severe environmental degradation, use of some soil reinforcing materials has to be made in order to improve its strength. Tradition materials like lime, fly-ash and cement are now obsolete due to high cost, weather dependency, requirement of curing and poor mixing problems [4]. Recently, fibres and geosynthetics made of natural material are in use. They are eco-friendly, cost effective, have negative carbon emission and a good source of employment generation in rural areas [5], [6] used jute geotextile to study its effect on consolidation properties of soft soil. It was seen that woven jute geotextile can accelerate settlement and act as both drain and filter. [7] discussed the effectiveness of using jute geotextile as a bio-engineering measure. [8] used barley straw on shrinkage, flexural, shear, compressive strength and durability of soil. [9] reviewed properties of natural fibres used as limited life geotextiles (LLG). It was found that greater tensile strength and lower water absorption properties of sisal and roselle makes them suitable for reinforcement purpose. [10] performed tensile and compressive strength tests on soil reinforced with coir and lime fibres. An increase of 4.5 times in
tensile strength and 2.1 times in compressive strength is reported corresponding to 1% fibre content and 90 days curing. [11] studied the mechanical and physiochemical characteristics of kenaf fibres and mechanical properties of Pressed Adobe Blocks (PABs) reinforced with kenaf fibres. It was observed that tensile strength of kenaf fibre was two times that of steel with 0.5 times the stiffness.

In the present work, strength properties of weak subgrade soil are studied by adding varying percentages of randomly distributed coir fibres. The thickness and cost of pavement is also determined for various reinforcement conditions.

2. Materials and Methods

2.1 Study Area and Soil Properties

Darri soil (25.30°N, 78.48°E), Jhansi district, Uttar Pradesh is used in the present work by digging trial pits of 1m depth, followed by sun-baking and broken with wooden mallet. Based on ISCS, it is classified as clay of high compressibility (CH). The various index and engineering properties of soil are shown in Table 1.

| Properties          | Value   |
|---------------------|---------|
| Atterberg’s limits  |         |
| (a) Liquid Limit (%) [17] | 64.41   |
| (b) Plastic Limit (%) | 31.67   |
| (c) Plasticity Index (%) | 32.74   |
| Particle Size Analysis [16] |         |
| (a) Gravel (%)      | 0.00    |
| (b) Sand (%)        | 2.20    |
| (c) Silt (%)        | 5.30    |
| (d) Clay (%)        | 92.50   |
| Specific Gravity [15] | 2.31    |
| OMC (%) [18]        | 18.98   |
| MDD (KN/m^3) [18]   | 17.10   |
| CBR (Soaked) (%) [19] | 2.26    |

2.2 Coir Fibre

Coir fibres are extracted from outer shells of coconut. The fibres are 50-350mm long and diameter varies from 12-25μ. High lignin content (i.e. 45%) makes it stronger and degradation takes place much slower than other natural fibres [12]. They have a service life of 5 to 10 years, retains strength in wet conditions and water absorption is about 150-200% [13]. Figure 1. shows the coconut shells from which fibres were obtained [14]. Table 2 shows the index properties of coir fibres. In the present study, fibres of 10mm length are used.

Figure 1. Coconut Shells
Table 2. Index properties of coir fibre

| Properties                  | Value       |
|-----------------------------|-------------|
| Length (mm)                 | 15-280      |
| Unit Weight (KN/m$^3$)      | 11.50       |
| Breaking elongation (%)     | 29.04       |
| Diameter (mm)               | 1-1.5       |
| Specific Gravity            | 1.15        |
| Swelling in water (%)       | 5           |
| Young’s Modulus (GN/m$^2$)  | 4.5         |
| Tenacity (g/tex)            | 10.0        |

3. Experimental Procedure

Firstly, index properties (consistency limits, specific gravity,… etc.) of clayey soil are determined. Then modified proctor tests as per IS: 2720 (Part 8) – 1983 and CBR tests as per IS: 2720 (Part 16) – 1987 are performed. Different quantities of coir fibre in soils will cause different effects. A quantity less than optimum will lead to little or no improvement, whereas excess amount may result in strength reduction. Hence, on the basis of experimental work, optimum quantity of coir fibre is decided. Table 3 shows the various percentages of coir fibre mixed with soil.

Table 3. Dose of Coir Fibre

| Fibre Percent by Weight of Soil (%) | Weight per 1 kg of Soil (g) |
|-------------------------------------|-----------------------------|
| 0.15                                | 1.5                         |
| 0.30                                | 3                           |
| 0.60                                | 6                           |
| 0.90                                | 9                           |
| 1.20                                | 12                          |
| 1.50                                | 15                          |

3.1 Compaction Test

Heavy compaction tests are performed on soil samples strengthened with and without fibres. 2.8kg mass of soil and corresponding amount of fibre based on the percentage of fibre content (by weight of soil) are mixed and then water is added to the mixture, followed by 20min continuous hand mixing. In order to avoid loss of water, mixing is carried out in a metal tray. Initially, 12% water is added to soil-fibre mixture (5 samples) and sealed in plastic a bag for 24 hours to achieve constant water content and after that in increment of 2% water is added before testing.

3.2 California Bearing Ratio Test

CBR specimens are prepared as per the OMC and MDD values of corresponding reinforcement conditions. The specimens are tested in most critical condition i.e. after a soaking period of 96 hours. The penetration rate of plunger is kept constant at 1.25mm/min and the load values corresponding to penetration levels of 2.5mm and 5mm are reported. The percentage of fibre is kept similar to that used in compaction tests.

4. Results and Discussion

4.1 Effect on MDD

Table 4 shows the results of MDD and OMC of soil reinforced with various percentages of coir fibres. The MDD for unreinforced soil sample is 17.10KN/m$^3$ which increases to 17.52KN/m$^3$, 18.06KN/m$^3$, 18.50KN/m$^3$, 18.99KN/m$^3$, 19.48KN/m$^3$. The OMC values are 20.52%, 21.06%, 21.61%, 22.16%, 22.71% respectively.
18.37kN/m$^3$, 18.80kN/m$^3$, 18.22kN/m$^3$ and 17.73kN/m$^3$, respectively, when reinforced with 0.15%, 0.30%, 0.60%, 0.90%, 1.2% and 1.5% coir fibres of 10mm length. At lower fibre content, MDD increases, but as the fibre content increases, reduction in MDD is reported. This is due to greater compactness achieved at lower fibre content. However, with increase in fibre percent this effect is overcome by lower unit weight of coir fibres as compared to soil particles in the soil fibre mixture.

4.2 Effect on OMC

The OMC initially decreases and then increases with increase in fibre content. This is due to hydrophilic nature of natural coir fibres. The maximum OMC recorded is 19.44% corresponding to 1.50% fibre content reinforcement.

### Table 4. OMC and MDD of soil reinforced with and without coir fibres

| Coir Fibre (%) | OMC (%) | MDD (KN/m$^3$) |
|----------------|---------|----------------|
| Unreinforced soil | 18.98 | 17.10 |
| 0.15 | 18.33 | 17.52 |
| 0.30 | 17.94 | 18.06 |
| 0.60 | 17.65 | 18.37 |
| 0.90 | 17.87 | 18.80 |
| 1.20 | 18.73 | 18.22 |
| 1.50 | 19.44 | 17.73 |

4.3 Effect on CBR

For unreinforced soil, CBR value is 2.26% which increases to 2.79%, 3.48%, 4.18%, 5.05%, 4.71% and 4.01%, respectively, when reinforced with 0.15%, 0.30%, 0.60%, 0.90%, 1.20% and 1.50% coir fibres of 10mm length as shown in Table 5. This increase in CBR is due to three dimensional bonding between soil particles and fibre surface thus providing greater resistance to penetration of plunger. The subgrade class has changed from very poor to fair category.

### Table 5. CBR of soil reinforced with and without coir fibres

| Coir Fibre (%) | CBR (%) |
|----------------|---------|
| Unreinforced soil | 2.26 |
| 0.15 | 2.79 |
| 0.30 | 3.48 |
| 0.60 | 4.18 |
| 0.90 | 5.05 |
| 1.20 | 4.71 |
| 1.50 | 4.01 |

4.4 Cost Analysis

The cost analysis of single lane pavement of 3.75m width and 1km length, constructed on soil reinforced with and without coir fibres are conducted as per IRC:SP:72-2015 design catalogues. T-6 (0.3msa - 0.6msa) and T-9 (1.5msa – 2msa) traffic categories are considered for analysis. Materials required for 1km length, 3.75m width and variable thickness depending on different pavement layers are considered. The rates of various pavement layer materials are obtained from the detailed project report of road construction under PMGSY-II for Jhansi region of Uttar Pradesh. Table 6 shows the various works and rates of materials. Table 7 and Table 8 shows the cost and thickness of pavement for traffic category T-6 and T-9, respectively, for various reinforcement conditions. Maximum reduction of 21% and 19% in pavement cost is reported for traffic category T-6 and T-9, respectively, corresponding to 0.90% coir fibre reinforcement.
### Table 6. Works and Rates of Pavement Layer Materials

| Works | Rates (Jhansi Region) |
|-------|-----------------------|
| Drainage layer of 100mm thickness | `1,868.80 /cu.m |
| 9.5-4.75mm = 35% | |
| 4.75-2.36mm = 12.5% | |
| ≤ 2.36mm = 52.5% | |
| Granular sub-base grading 1 | `2,094.10 /cu.m |
| 53-9.5mm = 50% | |
| 9.5-2.36mm = 20% | |
| ≤ 2.36mm = 30% | |
| Water bound macadam grading 2 | `2,591.40 /cu.m |
| a) Aggregate (63-45mm) | |
| b) Stone Screening (11.2mm) | |
| c) Binding material | |
| Water bound macadam grading 3 | `2,685.90 /cu.m |
| a) Aggregate (53-22.4mm) | |
| b) Stone Screening (11.2mm) | |
| Bituminous macadam of 50mm thickness | `7,400 /cu.m |
| 25-10mm = 40% | |
| 10-5mm = 40% | |
| ≤ 5mm = 20% | |
| OGPC of 20mm thickness | `141.30 /sq.m |
| Coir fibre of 10mm length | Obtained from local market |

Source: DPR reports of Jhansi region

### Table 7. Cost of Pavement for Traffic Category T-6

| Coir Fibre (%) | Thickness of Pavement (mm) | Reduction in Thickness (%) | Cost of Pavement (C) | Change in Cost (%) |
|----------------|-----------------------------|----------------------------|----------------------|--------------------|
| Unreinforced soil | 670 | --- | 4,677,674 | --- |
| 0.15 | 670 | 0 | 4,677,674 | 0 |
| 0.30 | 595 | 11.20 | 4,228,519 | 9.60 |
| 0.60 | 595 | 11.20 | 4,228,519 | 9.60 |
| 0.90 | 495 | 26.11 | 3,696,113 | 20.98 |
| 1.20 | 595 | 11.20 | 4,228,519 | 9.60 |
| 1.50 | 595 | 11.20 | 4,228,519 | 9.60 |

### Table 8. Cost of Pavement for Traffic Category T-9

| Coir Fibre (%) | Thickness of Pavement (mm) | Reduction in Thickness (%) | Cost of Pavement (C) | Change in Cost (%) |
|----------------|-----------------------------|----------------------------|----------------------|--------------------|
| Unreinforced soil | 845 | --- | 6,767,456 | --- |
| 0.15 | 845 | 0 | 6,767,456 | 0 |
| 0.30 | 695 | 17.75 | 6,374,832 | 5.80 |
| 0.60 | 695 | 17.75 | 6,374,832 | 5.80 |
| 0.90 | 570 | 32.54 | 5,496,394 | 18.78 |
| 1.20 | 695 | 17.75 | 6,374,832 | 5.80 |
| 1.50 | 695 | 17.75 | 6,374,832 | 5.80 |
5. Conclusions
Based on the present investigation, following conclusions are drawn.
1. The MDD of clayey soil increases up to 0.90% coir fibre reinforcement, beyond that it decreases due to lower specific gravity of coir fibres.
2. As the fibre content increases, with initial decrease an increase in OMC is reported, indicating hydrophilic nature of natural coir fibres.
3. Upto 0.90% fibre content, increase in CBR is observed (max. 2.23 times). However, at higher fibre content due to lack of bonding with soil CBR value decreases.
4. Maximum reduction of 26% and 32% in pavement thickness corresponding to traffic categories T-6 and T-9, respectively, are reported. It will save good quality aggregate materials which were depleting day by day.
5. Fibre content of 0.90% in clayey soil is found to be most optimum when analysed on the basis of strength improvement, thickness and cost reduction. However, it is recommended to provide some chemical treatment to coir fibre to reduce its hydrophilic nature before being used in soil.

In construction of flexible pavements and embankments on soft soils having lower bearing capacity, these conclusions can be effectively used. Moreover, use of coir fibres in soil stabilization will reduce the waste disposal problems and lead to better environmental conditions. However, to fully understand the working mechanism of coir fibres more research is required.

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