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Abstract Strength Characteristics of Expansive Soil Blended with Vitrified Polish Waste and Coir Fibre

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Abstract - *Expansive soils present a major challenge in geotechnical engineering due to their pronounced swelling and shrinking behaviour, resulting from water absorption during monsoon seasons and evaporation in summer. This volume change in soil can produce a large amount of stress, sometimes as high as 720 Kpa on the structures constructed on it, often leading to several structural problems like uplift of foundation, differential settlements, heaving, rutting, and cracking in superstructures. The presence of montmorillonite minerals with an expanding lattice structure in expansive soils causes pavement problems like longitudinal and transverse cracking. Among the different geotechnical techniques, soil stabilisation is the most popular technique. There is an increasing trend of research on the use of industrial waste materials for effective soil stabilisation in construction engineering. Vitrified Polish Waste (VPW), a by-product of the manufacturing and construction industry, can be effectively used to improve pavement subgrade conditions at low cost. Similarly, large quantities of waste are generated by the coir industry, creating disposal challenges. The use of coir fibre not only enhances soil engineering properties but also offers an eco-friendly waste management solution. The present study examines the combined use of VPW and coir fibre in varying proportions to evaluate their effect on expansive soil behaviour. The results show that increasing VPW content decreases the Optimum Moisture Content (OMC), while adding coir fibre increases OMC. It is observed that from load tests, maximum strength is obtained with the addition of 15% VPW and 1% of Coir fibre.*

Key Words: **Vitrified polish waste VPW, Coir fiber, Expansive soil, Stabilisation**

1. INTRODUCTION

Expansive soils, commonly referred to as black cotton soils due to their suitability for cotton cultivation, occupy nearly 20% of India's geographical area. These soils undergo significant volume changes resulting from physical and chemical variations induced by seasonal fluctuations in moisture content. [1]. The use of chemical additives and reinforcement techniques to improve the suitability of VPW-stabilised marine clay for pavement construction [2]. The Optimum Moisture Content (OMC) increases with the increase in the percentage of coir fibre, and the CBR and UCS values also show an improvement. The maximum increase in the strength properties was found at 1% coir fibre content, which is the optimum percentage [3]. The incorporation of 10% Vitrified Polish Waste (VPW) with expansive soil leads to a substantial enhancement in the engineering characteristics of expansive soil. VPW has vast potential as a soil stabilising admixture, although further refinement is required to conform to IRC standards [4]. The optimum result was obtained at 0.5% coconut fibre content, where UCS values increased from 186.45 kN/m^2 to 240.2 kN/m^2 (3 days) and from 274.12 kN/m^2 to 581.7 kN/m^2 (14 days), and soaked CBR values improved by 20.62%. In general, the literature confirms that 30% fly ash and 0.5% coconut fibre content is the best stabilising combination [5].

The effectiveness of using coir waste as a stabiliser was examined in the study to enhance the subgrade properties of expansive soil. Although the engineering properties were improved significantly, further research is recommended for implementation. Processing and using coir waste also helps in rural employment [6]. The experiment was conducted successfully to assess the geotechnical characteristics of expansive soils modified with Rice Husk Ash (RHA), coconut fibre (CF), and eggshell powder (EG). The addition of RHA, CF, and EG affected the texture of the clay soil by reducing the fine material content. The swelling potential of the expansive soil was reduced with the addition of these admixtures. In addition, the compressibility of the soil was reduced when a combination of lime and RHA was added [7]. The results of various tests conducted on VPW and Fiber addition clearly showed improvement in the compaction and strength properties of expansive soils. In general, the literature review confirms that VPW is an economical and effective ground improvement material [8]. The addition of VPW, lime, and waste plastic resulted in a substantial improvement in the compaction, strength, and penetration properties of expansive soil, along with an effective utilisation of waste materials [9].The results showed that the addition of 1.2% CCF (Coconut Coir Fiber) gave the highest increase in strength, with the UCC strength increasing to 132.59 kPa and the soaked CBR value rising to 18.98%, which is almost four times higher than that of the unreinforced soil. [10]. The study concludes that coir fibre is a biodegradable, low-cost, and available material that can be used for economical soil stabilisation. Most importantly, the addition of coir fibre increases the California Bearing Ratio (CBR) value because of its reinforcing action, which helps the soil resist higher loads. This helps in reducing the pavement thickness, making the construction of roads more economical [11]. This study examined the potential use of coir geotextiles, which are natural and eco-friendly materials, in the construction of rural roads. The results show that coir geotextiles have the potential to improve the poor subgrade soils and also support the coir industry [12]. The research work investigated the influence of lime and coir fibre on the stabilisation of expansive soil. The optimal mixture of 1% coir fibre and 5% hydrated lime was determined [13]. Laboratory tests revealed that the addition of 2%, 2.5%, and 3% coir pith increased the strength properties of black cotton soil. The increase in the CBR values shows an improvement in the surface hardness and strength of the soil [14]. Experimental work on clayey soil (CL) stabilised with coir fibre (0.25%–1%), which revealed marked improvement in strength and compaction characteristics, with 0.5% fibre concentration found to be optimum. In general, the use of 0.5% coir fibre is found to be effective and economical for stabilising clayey soils [15]. The study indicates that the addition of 0.75% xanthan gum and 0.5% coconut fibre is the most effective mixture for the stabilisation of soil. This is because it provides the highest compressive strength and bearing capacity, making it the optimal mixture for the improvement of soil [16].

The present investigation aimed to enhance the strength characteristics of expansive soil and to determine the optimum combination of Vitrified Polish Waste (VPW) and Coconut fibres. Coconut fibres were incorporated at dosages of 0.25%, 0.50%, 0.75%, 1.0% and 1.25%, while Vitrified Polish waste was added in proportions of 5%, 10%, 15%, and 20% by dry weight of soil. A series of compaction, soaked California Bearing Ratio (CBR), and load tests were performed to evaluate the engineering behaviour of the treated soil.

2. HIGHLIGHTS

- The influence of Vitrified polish waste and Coir waste on expansive soil was investigated.
- The use of industrial wastes offers an alternative approach to reduce the construction cost of road particularly in rural areas.

3. MATERIALS

3.1 Black Cotton Soil (ES):

The soil sample used in this investigation was collected from Odalarevu, near Amalapuram, Andhra Pradesh, India. The geotechnical characteristics of the expansive soil were determined following the respective Indian Standard (IS) codes. The determined properties are summarised in the table below.

Table -1: Properties of Black cotton soil

Property	Symbol / Unit	Value	Test Method (IS Code)
Liquid Limit	WL (%)	87.00	IS: 2720 (Part 5) – 1985
Plastic Limit	WP (%)	36.75	IS: 2720 (Part 5) – 1985
Plasticity Index	IP (%)	49.50	—
Soil Classification	—	CH (Highly Plastic Clay)	IS: 1498 – 1970
Specific Gravity	G	2.65	IS: 2720 (Part 3) – 1980
Differential Free Swell	DFS (%)	130	IS: 2720 (Part 40) – 1977
Maximum Dry Density	MDD (g/cc)	1.446	IS: 2720 (Part 8) – 1983
Optimum Moisture Content	OMC (%)	27.99	IS: 2720 (Part 8) – 1983
Soaked California Bearing Ratio	CBR (%)	1.23	IS: 2720 (Part 16) – 1987

Fig -1: Black cotton soil

The results indicate that the collected soil can be classified as highly plastic clay (CH), exhibiting a high degree of swell potential and low bearing capacity, which necessitates stabilisation for engineering applications.

3.2 Vitrified Polish Waste (VPW)

Vitrified Polish Waste sampled for the study was collected from RAK Ceramics, Samalkota, East Godavari, and Andhra Pradesh.

Fig -2: Vitrified Polish Waste

3.3 Coconut Fibre

The coir fibre used in this study was extracted from coconut husk, a hard structural fibre. The fibrous husks were soaked in pits or slow-moving water bodies to facilitate swelling and softening of the fibres. Subsequently, the long bristle fibres were separated from the shorter mattress fibres through a process known as wet milling. Coir fibre is elastic, capable of being twisted without breaking, and retains a natural curl, making it suitable for various commercial applications, particularly in mattress manufacturing. The fibres used in this study had an average diameter of 0.5 mm and were cut into lengths of 3–5 cm, with proportions of 0.25%, 0.50%, 0.75%, 1.0% and 1.25% by dry weight of soil.

Fig -3: Coconut Fibre

4 EXPERIMENTAL INVESTIGATIONS

In this study, black cotton soil was blended with varying proportions of vitrified polish waste (VPW) by dry weight to evaluate its influence on the soil's geotechnical properties and to determine the optimum percentage of VPW. Subsequently, the expansive soil containing the optimum VPW content was further reinforced with different percentages of coir fibre, and its compaction characteristics, soaked California Bearing Ratio (CBR), and cyclic plate load performance were evaluated. All laboratory tests were carried out in accordance with the respective Indian Standard (IS) codes to establish the optimal mix proportions and to assess the effect of VPW and coir fibre on the strength improvement of black cotton soil.

4.1 Compaction Characteristics

The compaction characteristics of black cotton soil, both untreated and treated with varying proportions of vitrified polish waste (VPW) and coir fibre, were determined in the laboratory in accordance with the Modified Proctor Compaction Test as specified in IS: 2720 (Part VIII) – 1983.

4.2 California Bearing Ratio (CBR)

CBR test has been conducted on treated and untreated expansive soil as per IS: 2720 part XVI-1987 as shown in Fig.4, with various proportions of Vitrified Polish Waste and Coconut Fibre under soaked condition.

4.3 Cyclic Plate Load Test

The laboratory cyclic plate load test was performed to evaluate the ultimate load-carrying capacity and maximum settlement of the soil under applied loading conditions. The model flexible pavement system comprised a 25 cm layer of untreated or treated expansive soil serving as the subgrade, overlaid by a 5 cm gravel cushion as the sub-base, and a 5 cm WBM-III layer forming the base course. The load was applied using a circular steel plate of 10 cm diameter, positioned on the surface of the model pavement. The steel test tank was mounted on the base of a compression testing machine, and two dial gauges with a least count of 0.01 mm were used to record settlements. A hydraulic jack with a capacity of 500 kN was utilised to apply the loading in controlled increments.

The cyclic load tests were conducted on specimens prepared at their respective optimum moisture content (OMC) conditions, under successive simulated tyre pressures of 500, 560, 630, 700, 1000, and 1200 kPa. For each pressure level, six loading–unloading cycles were applied until the deformation readings stabilized, indicating negligible variation between consecutive cycles. All model flexible pavement specimens were tested under Saturated conditions to assess the subgrade performance realistically.

Fig - 4: Experimental Cyclic Plate Load Set for Finding Load – Settlement

5. TEST RESULTS

In the laboratory, a series of tests was carried out on black cotton soil stabilised with varying proportions of vitrified polish waste and coir fibre to determine the optimum mix ratios and to evaluate their influence on the strength characteristics of the soil. The results obtained from these tests are presented below.

5.1 Compaction Properties Test

The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values were observed to vary with different proportions of vitrified polish waste (VPW). The OMC and MDD were recorded as 26.12% and 1.488 g/cc, 25.37% and 1.501 g/cc, 24.48% and 1.518 g/cc, and 23.02% and 1.511 g/cc for 5%, 10%, 15%, and 20% VPW, respectively, as shown in Chart 1. The maximum dry density was achieved at 15% VPW content, indicating this as the optimum proportion for stabilisation. Further, when coir fibre was added to the soil containing 15% VPW at proportions of 0.5%, 0.75%, 1.0%, and 1.25%, the corresponding OMC and MDD values were 25.74% and 1.502 g/cc, 26.25% and 1.493 g/cc, 26.93% and 1.520 g/cc, and 27.37% and 1.480 g/cc, respectively, as presented in Chart 2. The maximum dry density was obtained at 1.0% coir fibre content, which demonstrated superior performance compared to other combinations. Based on the test results, the optimum proportions of vitrified polish waste and coir fibre were determined to be 15% and 1.0%, respectively.

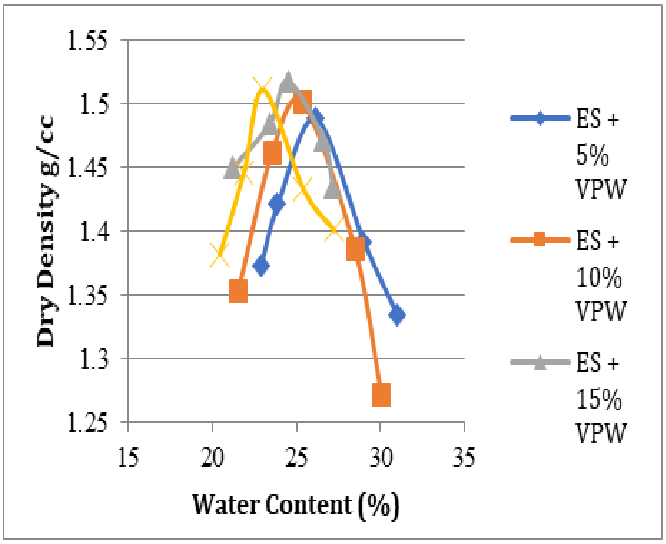

Chart -1: Compaction Values of black cotton soil Treated of different % of Vitrified polish waste

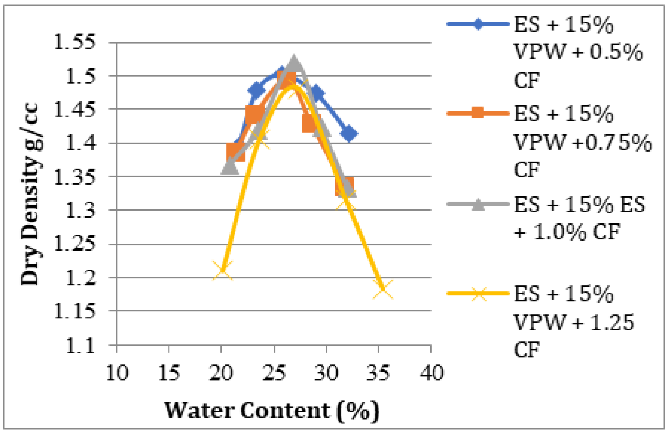

Chart -2: Compaction values of 85% black cotton soil blended with 15% VPW and % of CF.

5.2 California Bearing Ratio Test (CBR)

Soaked CBR tests were performed on black cotton soil blended with varying proportions of vitrified polish waste (VPW) and coir fibre, and the results are presented in Chart 3. The soaked CBR values for black cotton soil mixed with 10%, 15%, and 20% VPW were 3.62%, 4.36%, and 3.84%, respectively, indicating that the maximum CBR value was achieved at 15% VPW content.

Further, when coir fibre was incorporated into the VPW-treated expansive soil at proportions of 0.5%, 0.75%, 1.0%, and 1.25%, the corresponding soaked CBR values were 4.62%, 5.82%, 8.06%, and 6.31%, as shown in Chart 4. Based on these results, the optimum proportions of vitrified polish waste and coir fibre were determined to be 15% and 1.0%, respectively. The improvement in compaction characteristics contributed to the increase in CBR values, indicating a significant enhancement in the overall strength of the soil.

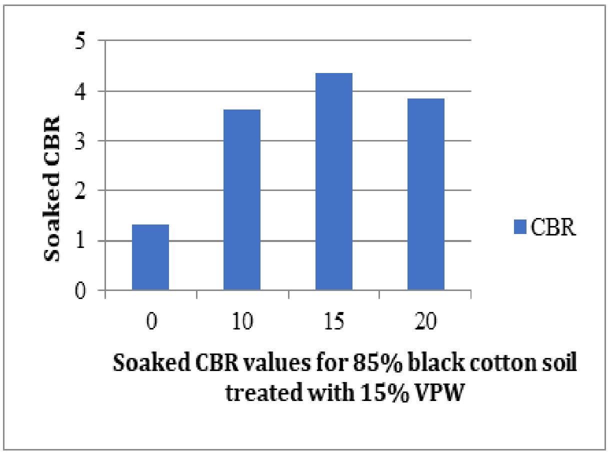

Chart -3: Soaked CBR values for 85% black cotton soil treated with 15% VPW

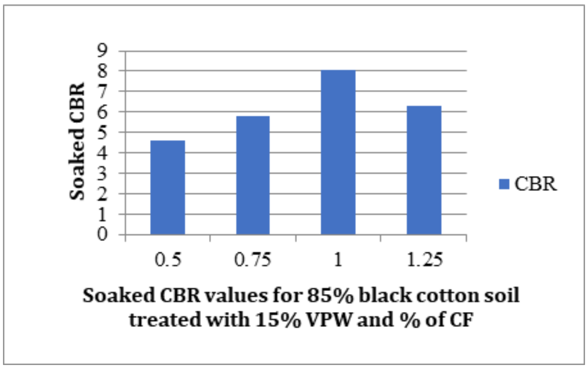

Chart -4: Soaked CBR values for 85% black cotton soil treated with 15% VPW and % of Coconut Fibre

5.3 Cyclic Plate Load Test

From the laboratory cyclic plate load test results, the untreated black cotton soil subgrade model of the flexible pavement showed an ultimate bearing pressure of 630 kPa at a deformation of 2.61 mm. In contrast, the subgrade model stabilised with 15% vitrified polish waste and 1% coir fibre exhibited a substantially higher ultimate bearing pressure of 1200 kPa with a reduced deformation of 2.39 mm, as illustrated in Charts 5 and 6. These results clearly demonstrate a notable improvement in the load-bearing capacity and stiffness of black cotton soil when stabilised with 15% vitrified polish waste and 1% coir fibre compared to the untreated soil.

Chart -5: Laboratory Cyclic plate load test results of untreated Expansive soil at Saturation

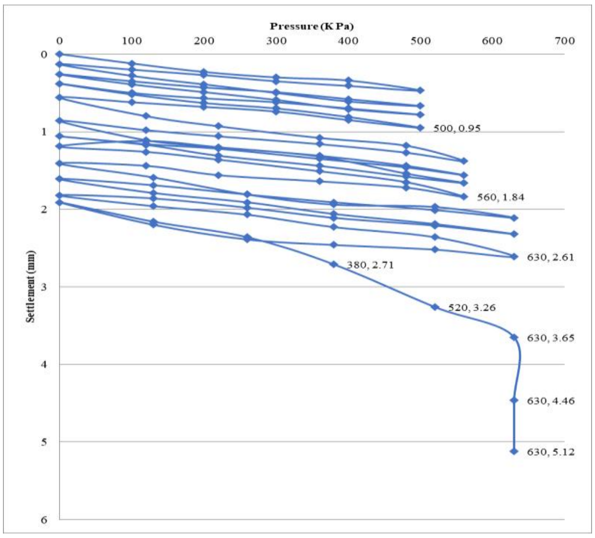

Chart -6: Laboratory cyclic plate load test result of treated Expansive clay with an optimum 15% VPW and 1% CF at Saturation

6. CONCLUSIONS

Based on the findings of the laboratory investigations, the following conclusions can be drawn:

1. The liquid limit of expansive soil decreased by 22.4% with the addition of 15% vitrified polish waste (VPW) and further decreased by 19.99% with the inclusion of 1% coir fibre, indicating improved workability and reduced plasticity.
2. The plastic limit of the expansive soil decreased by 11.9% upon the addition of 15% VPW, and an additional 9% reduction was observed when 1% coir fibre was incorporated.
3. The plasticity index showed a substantial reduction of 28.8% with 15% VPW, and further decreased by 50.2% upon the inclusion of 1% coir fibre, demonstrating a significant improvement in soil stability.
4. The optimum moisture content (OMC) decreased by 13.32% with 15% VPW, whereas a 9% increase was noted when 1% coir fibre was added in combination with 15% VPW, compared to untreated soil.
5. The maximum dry density (MDD) increased by 3.12% with 15% VPW, but decreased by 2.31% with the combined addition of 1% coir fibre and 15% VPW, relative to the untreated expansive soil.
6. The soaked California Bearing Ratio (CBR) value increased significantly by 227.64% with 15% VPW, and further improved by 118.11% upon the inclusion of 1% coir fibre, reflecting enhanced load-bearing capacity.
7. Cyclic plate load test results revealed that the ultimate cyclic pressure of the treated expansive clay subgrade increased markedly from 630 kPa (untreated) to 1200 kPa, confirming improved subgrade strength.
8. Settlement values reduced from 2.61 mm to 2.41 mm with the addition of 1% coir fibre and 15% VPW, indicating enhanced deformation resistance of the treated soil.
9. The incorporation of industrial waste materials such as vitrified polish waste (VPW) provides a sustainable and economical approach for improving subgrade performance, particularly beneficial for rural road construction in developing regions.

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