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Optimizing CBR of Expansive Soil Subgrades Using Woven Geotextiles for Road Construction

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Abstract- This study investigates the effect of geotextile reinforcement on the stabilization of expansive soils used in pavement subgrade applications. Expansive soils, prone to swelling and shrinkage due to moisture fluctuations, present significant challenges for road construction. Laboratory experiments, including California Bearing Ratio (CBR) tests under soaked and unsoaked conditions, were conducted to evaluate the performance of two woven geotextiles (PEC-50 and HP-370) placed at varying depths (4 cm, 7 cm, and 8 cm) within the soil samples. The results demonstrate that geotextile reinforcement significantly improves the load-bearing capacity of expansive soils, with the highest CBR value of 4.32% achieved using PEC-50 at a 4 cm depth. Geotextile placement closer to the upper layers of the soil provided superior performance due to better load distribution and resistance to deformation. PEC-50 consistently outperformed HP-370 across all placement depths, highlighting the importance of geotextile material selection. The study concludes that geotextile reinforcement is an effective solution for stabilizing expansive soils, particularly in moisture-sensitive regions. Practical recommendations include optimal placement depths, geotextile selection criteria, and considerations for multi-layer systems in high-load scenarios. Future work should focus on field validation, dynamic loading effects, and the environmental impact of geotextile applications. This research provides a foundation for cost-effective and sustainable pavement design in expansive soil regions.

Keywords- California Bearing Ratio (CBR), Expansive Soil, Geotextiles, Soil Subgrade Stabilization, Woven Geotextiles, Soil Reinforcement, Pavement Performance.

I. INTRODUCTION

Expansive soils pose significant challenges in geotechnical and pavement engineering due to their tendency to undergo substantial volumetric changes with variations in moisture content. These soils, characterized by high shrink-swell potential, often lead to pavement failures, uneven settlements, and reduced structural integrity. Enhancing the load-bearing capacity and stability of expansive soils is critical, particularly for road construction in regions with moisture-sensitive subgrades.

Geotextile reinforcement has emerged as a promising solution to address these challenges. By improving soil strength, reducing deformation, and distributing applied loads effectively, geotextiles contribute to the stability and durability of pavement structures. This study investigates the impact of geotextile reinforcement on the California Bearing Ratio (CBR) of expansive soils, focusing on the influence of geotextile type, placement depth, and configuration on subgrade performance. The findings aim to provide insights into optimizing geotextile applications for cost-effective and sustainable pavement design.

II. LITERATURE REVIEW

- Babu et al. (2014): In this study, the researchers compared the performance of woven and non-woven geotextiles for reinforcing expansive soils. They found that woven geotextiles provided better tensile strength and more significant CBR improvements compared to non-woven geotextiles. The CBR value of soils reinforced with woven geotextiles showed an improvement of 55%, whereas non-woven geotextiles resulted in only a 30% improvement.

- Ravindra et al. (2017): This study focused on the use of geotextiles in moisture-sensitive soils and compared the performance of woven polyester and polypropylene non-woven geotextiles. The results showed that woven polyester geotextiles performed better in terms of load distribution and moisture control, leading to higher CBR values and better pavement performance under moisture fluctuations.
- Reddy and Sreedevi (2013) investigated the impact of woven polyester geotextiles on the moisture-induced swelling of expansive clayey soils. The results indicated that the geotextiles significantly reduced the swelling pressure exerted by the soil when exposed to moisture. The swelling potential of the soil was reduced by up to 50% when the geotextile was placed at the optimal depth, demonstrating the geotextile’s effectiveness in moisture control.
- Kumar and Sathya (2015) used non-woven geotextiles to control the moisture content and swelling behavior of expansive soils. The study found that the moisture infiltration was significantly reduced, and the swelling potential was minimized. The geotextile-reinforced soils exhibited more stable behavior under moisture fluctuations, with the CBR values showing up to a 60% increase in load-bearing capacity compared to untreated soils.
- Chowdary et al. (2011) evaluated the performance of woven jute geotextiles for reinforcing expansive soils. The researchers tested the CBR values of soil samples with geotextiles placed at depths of 4 cm, 7 cm, and 8 cm. The results showed that the optimal depth for the jute geotextile was 4 cm, which led to a 45% increase in the CBR value compared to the unreinforced soil. Placement at greater depths did not produce significant improvements, indicating that the placement depth plays a crucial role in maximizing the effectiveness of geotextile reinforcement.
- woven polyester geotextiles were used by Srivastava et al. (2016) to reinforce expansive silty clay subgrades. The study found that the CBR values of the reinforced soil increased by up to 70% when the geotextile was placed at a depth of 0.4 times the total height (H) of the sample. For example, in a sample with a height of 10 cm, the geotextile placed at a depth of 4 cm resulted in the greatest improvement in the CBR value. This study reinforced the idea that shallow placement of geotextiles yields the most effective results in improving the strength of expansive soils.
- Naeini and Mirzakhanlari (2008) focused on the performance of non-woven geotextiles in expansive clay soils. The researchers placed the geotextiles at various depths within the soil samples and conducted CBR tests. They found that placing the geotextile in the middle of the sample yielded the highest CBR improvement compared to placing it at the top or bottom. The CBR value increased by up to 60% when the geotextile was placed at the optimal depth, indicating a significant improvement in the soil’s load-bearing capacity. The study highlighted the importance of placement depth in maximizing the effectiveness of geotextiles for soil reinforcement.
- Sivapragasam and Vanitha (2010) examined the use of woven and non-woven geotextiles for reinforcing expansive soils. They conducted CBR tests on soil samples reinforced with both types of geotextiles placed at different depths. Their results indicated that woven geotextiles performed better than non-woven geotextiles in terms of CBR improvement. The best results were achieved when the geotextile was placed at the center of the soil sample. The CBR value of the soil with the woven geotextile at the optimal depth showed a 40% increase in strength, demonstrating that woven geotextiles are more effective in reinforcing expansive soils.
- Singh and Gill (2012) explored the impact of geogrid reinforcement on expansive soil subgrades. The researchers observed that using a single layer of geogrid increased the California Bearing Ratio (CBR) values by 50–100%, depending on the placement depth and soil type. The study highlighted that the optimal placement depth for the geogrid was typically at 0.3 to 0.4 times the height of the soil sample. Geogrids were found to significantly improve load-bearing capacity and reduce vertical

deformation under loading. This result underscores the potential of geogrids as a cost-effective solution for enhancing subgrade performance in road construction.

- Pokharel et al. (2011) accelerated pavement testing was conducted on geocell-reinforced unpaved roads constructed over weak subgrades. The use of geocells, a three-dimensional honeycomb-like structure, resulted in substantial improvements in load distribution and reduction of rut depths. The study demonstrated that geocells could increase the service life of unpaved roads by distributing traffic loads more effectively. These findings are especially relevant for regions with weak subgrades, where geocells provide a durable solution for preventing pavement failure.
- Kumar et al. (2020) investigated the effectiveness of non-woven geotextiles in improving the strength and stability of expansive soils. When used as a reinforcing layer, non-woven geotextiles enhanced the soil's drainage properties, reduced water infiltration, and minimized swelling behavior. The researchers found that CBR values increased by up to 65% when non-woven geotextiles were placed at an optimal depth. Additionally, the geotextiles improved the load-bearing capacity of the soil under cyclic loading conditions, making them suitable for use in both road construction and foundation improvement.
- Rao and Raju (2019) focused on the performance of woven geotextiles in reinforcing expansive soil subgrades. The researchers placed geotextiles at varying depths within the soil samples and measured CBR values under both dry and wet conditions. The results indicated that woven geotextiles provided excellent reinforcement, with CBR values showing an improvement of up to 70%. The woven geotextiles also reduced swelling pressure and moisture-induced deformation, making them particularly effective for use in areas with high seasonal moisture fluctuations.
- Kumar and Gupta (2012) examined the effect of single-layer geosynthetic reinforcement on the mechanical properties of expansive soils. The researchers found that placing a geosynthetic layer horizontally within the soil significantly enhanced its bearing capacity and reduced settlement under loading. The CBR value of the reinforced soil increased by approximately 80% compared to unreinforced soil. The study emphasized that the position of the geosynthetic layer within the soil matrix plays a crucial role in achieving optimal reinforcement performance.

III. MATERIALS USED IN THE STUDY

This study utilized expansive soil and geotextiles to investigate the effectiveness of geotextile reinforcement in stabilizing pavement subgrades. Expansive soils were chosen for their significant volume changes with moisture fluctuations, while geotextiles were selected for their ability to enhance soil strength and stability.

1. Expansive Soil

Expansive soils, also called shrink-swell soils, exhibit swelling when wet and shrinkage when dry, causing structural issues like cracking and deformation. For this study, locally sourced expansive silty clay with high plasticity and swelling potential was selected. Tests were conducted to determine its physical and mechanical properties, essential for understanding its behavior under geotextile reinforcement.

2. Geotextiles

Two woven geotextiles, HP-370 and PEC-50, were selected for their reinforcement potential. These geotextiles, made from durable synthetic materials, were chosen based on their tensile strength, elongation at break, and puncture resistance, ensuring compatibility with expansive soils and traffic stresses.

HP-370 provides flexibility, while PEC-50 offers higher strength and durability, making them ideal for pavement subgrade stabilization.

Geotextile	Tensile Strength	Elongation at Break	Puncture Resistance
HP-370	35 kN/m	15%	1.2 kN
PEC-50	50 kN/m	12%	1.5 kN

IV. METHODOLOGY

The methodology outlines the steps undertaken to investigate the impact of geotextile reinforcement on the stabilization of expansive soils. The study involves soil sample preparation, geotextile placement, CBR testing, and statistical analysis. Below is the detailed process:

1. Soil Sample Collection and Preparation

- Soil samples were excavated from a road construction site in Damoh.
- Samples were air-dried, pulverized, and sieved following IS 2720-Part 4 (1985).
- The physical and engineering properties, including specific gravity and Atterberg limits, were determined.
- Proctor compaction tests were conducted to identify the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
- Soil samples were prepared at the OMC for consistent testing.

2. Geotextile Selection and Placement

- Two woven geotextiles, HP-370 and PEC-50, were selected based on their tensile strength, elongation, and puncture resistance.
- Geotextiles were placed at varying depths (4 cm, 7 cm, and 8 cm) within compacted soil layers in CBR molds.
- Control samples were prepared without geotextile reinforcement for baseline comparison.

3. CBR Testing

- Soaked Test: Samples were submerged in water for 96 hours to simulate moisture conditions.
- Unsoaked Test: Samples were tested in their natural, dry state.
- CBR tests were conducted following ASTM D1883, recording the penetration resistance at depths of 2.5 mm and 5 mm.

V. RESULT ANALYSIS

This chapter presents the results of the experimental investigation carried out to evaluate the performance of geotextile reinforcement in expansive soils for pavement subgrade applications. The data obtained from various tests, including soil characterization, CBR tests, and geotextile reinforcement experiments, are analyzed and discussed in this chapter. Key factors such as geotextile type, placement depth, and their effect on the CBR values of expansive soils are examined in detail.

1. Soil Characterization Results

The soil characterization tests were conducted to determine the physical properties of the expansive soil used in the study. These properties are critical for understanding how the soil behaves under different conditions, including the effect of geotextile reinforcement.

Specific Gravity

The specific gravity of the gravel soil was determined to assess its suitability as a subgrade material. The results of the three trials, along with the mean values, are presented in Table 4.1.

1: Specific Gravity Teast Result

Description	Value (gms)
Mass of empty bottle	0.602
Mass of bottle + dry soil	1.215
Mass of bottle + dry soil + water	1.842
Mass of bottle + water	1.46
Mass of dry soil	0.613
Mass of water filling the bottle	0.858
Mass of water displaced by soil	0.231
Specific Gravity	2.653

The mean specific gravity of the soil was found to be 2.726, which is typical for coarse-grained soils and suitable for use as subgrade material.

Liquid Limit

Table 2 Liquid Limit Test Results

Test No.	1	2	3	4
Mass of Can (w1) [g]	26.4	25.41	26.7	26
Mass of Can + Wet Soil [g]	35.3	40.85	40.7	38
Mass of Can + Dry Soil [g]	32.3	35.48	35.8	34
Mass of Water (w2 - w3) [g]	3.08	5.37	4.87	4
Mass of Dry Soil (w3 - w1) [g]	5.85	10.08	9.07	8
Water Content (%)	51.4	53.32	53.8	53

$$\text{Liquid Limit} = \frac{51.36+53032+53.75+52.81}{4}$$

$$= 52.81\%$$

Plastic Limit

Test No.	1	2	3	4
Mass of Can (w1) [g]	28.5	28.11	28.3	28.1
Mass of Can + Wet Soil [g]	36.2	34.93	35	34.8
Mass of Can + Dry Soil [g]	34.6	33.61	33.9	33.7
Mass of Water (w2 - w3) [g]	1.59	1.32	1.1	1.1
Mass of Dry Soil (w3 - w1) [g]	6.13	5.57	5.6	5.6
Water Content (%)	25.9	24.05	24.943	24.943

$$\text{Plastic Limit} = \frac{24.93+24.045+24.9425+24.9425}{4}$$

$$= 24.965\%$$

Particle size distribution (Wet Sieve Analysis)

By taking soil sample of 500g following results are found for particle size distribution

Table 3 Result of Practical size distribution

Sieve Size (mm)	4.75	2.36	1.18	0.6	0.425	0.3	0.15	0.075
Soil Type	Gravel	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Mass of Sieve (g)	418	432	402	372	359	366	357	313
Mass of Sieve + Soil (g)	422	438	410	382	370			
Soil Retained (g)	4	6	8	10	11			
Percent Retained (%)	0.8	1.2	1.6	2	2.2			
Cumulative Percent Retained (%)	0.8	2	3.6	5.6	7.8			
Percent Finer (%)	99.2	98	96.4	94.4	92.2			

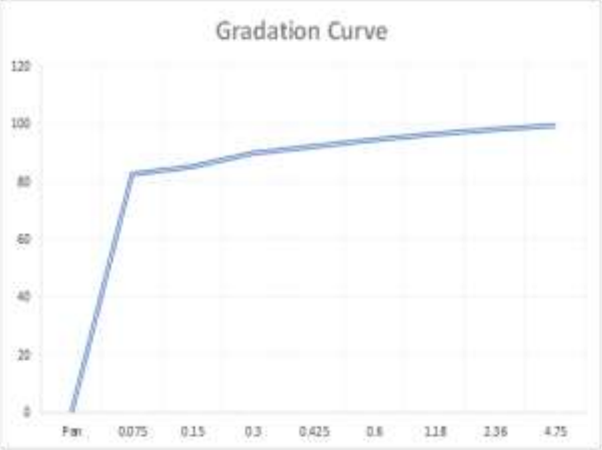


Figure 5.1 Gradation curve of Particles size analysis

Plasticity Index (PI)

The Plasticity Index is a measure of the plasticity of the soil, which reflects its ability to undergo deformation without cracking. It is calculated as the difference between the Liquid Limit (LL) and Plastic Limit (PL):

$$PI = LL - PL = 52.810 - 24.965 = 27.845$$

$$\text{A- Line} = 0.73\,(L.L-20) = 0.73(52.810-20) = 23.9513$$

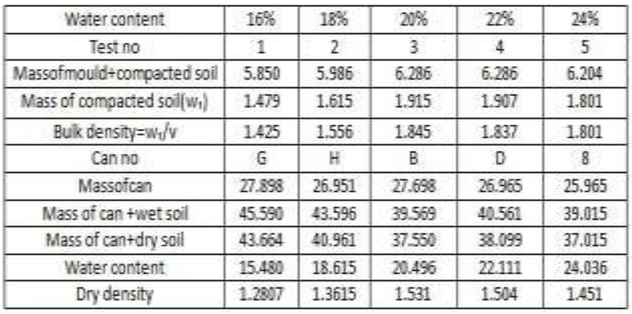
Classification of Soil

Since the plasticity index (PI) is greater than the A-Line value (PI > A-Line), the soil is classified as clayey or cohesive soil. Moreover, as the PI is greater than 7 and the Liquid Limit (LL) is above 50, the soil is classified as CH (Highly Plastic Clay) according to the Unified Soil Classification System (USCS).

The particle size distribution of the soil has 0.8% gravel, 17.6% sand and 28.2% silt and clay. This classification indicates that the soil is predominantly fine-grained, with a high percentage of silt and clay, contributing to its cohesive and plastic nature.

Compaction Test

Table 4 Modified Procter Test Result



Water content	16%	18%	20%	22%	24%
Test no	1	2	3	4	5
Massofmould+compacted soil	5.850	5.986	6.286	6.286	6.204
Mass of compacted soil(w_1)	1.479	1.615	1.915	1.907	1.801
Bulk density=w_1/v	1.425	1.556	1.845	1.837	1.801
Can no	G	H	B	D	8
Massofcan	27.898	26.951	27.698	26.965	25.965
Mass of can +wet soil	45.590	43.596	39.569	40.561	39.015
Mass of can+dry soil	43.664	40.961	37.550	38.099	37.015
Water content	15.480	18.615	20.496	22.111	24.036
Dry density	1.2807	1.3615	1.531	1.504	1.451

Hence maximum dry density (MDD) is 1.531 at Optimum water content (OMC) 20.496%.

2. CBR Test Results

CBR test without geotextile

Table 5 CBR test result without geotextile

Test Stage	Penetration Depth (mm)	Proving Ring Reading (Division)	Applied Load (P) (N)
1	0	0	0
2	0.5	2	118.272
3	1	3	177.408
4	1.5	4	236.544
5	2	5	295.68
6	2.5	5	295.68
7	4	6	354.816
8	5	7	413.952
9	7.5	7	413.952
10	10	8	473.088
11	12.5	10	591.36

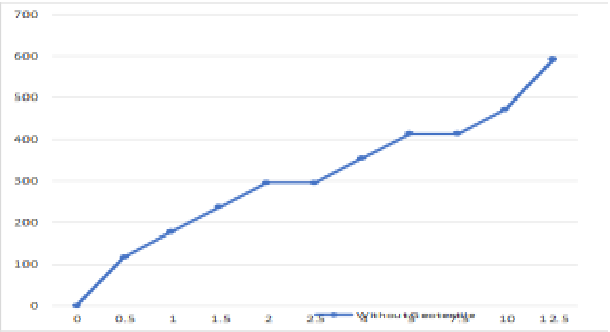


Figure 5.2 variation of test load vs penetration without geotextile

CBR value = test load × 100 / standard load

For 2.5 mm penetration = 295.68 × 100 / 13700

= 2.16

For 5 mm penetration = 413.952× 100 / 20550

= 2.01

Maximum CBR between these two is taken i.e. 2.16

CBR test with HP-370 geotextile in distances at 4cm

Table ***Error! No text of specified style in document.****6 CBR test result with HP-370 geotextile in distances at 4cm*

Test Stage	Penetration Depth (mm)	Proving Ring Reading (Division)	Applied Load (P) (N)
1	0	0	0
2	0.5	4	236.544
3	1	6	354.816
4	1.5	8	473.088
5	2	9	532.224
6	2.5	9	532.224
7	4	10	591.36
8	5	11	650.495
9	7.5	12	709.632
10	10	14	827.904
11	12.5	15	887.04

For 2.5 mm penetration = 532.224× 100 / 13700

= 3.89

For 5 mm penetration = 650.495× 100 / 20550

= 3.17

Maximum CBR between these two is taken i.e. 3.885

CBR test with HP-370 geotextile in distances at 7cm

Table 7 CBR test with HP-370 geotextile in distances at 7cm

Test Stage	Penetration Depth (mm)	Proving Ring Reading (Division)	Applied Load (P) (N)
1	0	0	0
2	0.5	2	118.272
3	1	4	236.544
4	1.5	5	295.68
5	2	6	354.816
6	2.5	7	413.952
7	4	8	473.033
8	5	9	532.224
9	7.5	11	650.495
10	10	12	709.632
11	12.5	13	768.768

For 2.5 mm penetration = 413.952× 100 / 13700

= 3.02

For 5 mm penetration = 532.224× 100 / 20550

= 2.59

Maximum CBR between these two is taken i.e. 3.02

CBR test with HP-370 geotextile in distances at 8cm

Table 8 CBR test with HP-370 geotextile in distances at 8cm

Test Stage	Penetration Depth (mm)	Proving Ring Reading (Division)	Applied Load (P) (N)
1	0	0	0
2	0.5	2	118.272
3	1	3	177.408
4	1.5	4	236.544
5	2	5	295.68
6	2.5	6	354.816
7	4	7	413.952
8	5	8	473.088
9	7.5	9	532.224
10	10	10	591.36
11	12.5	11	650.496

CBR value = test load × 100 / standard load

For 2.5 mm penetration = 354.816× 100 / 13700

= 2.59

For 5 mm penetration = 473.088× 100 / 20550

= 2.30

Maximum CBR between these two is taken i.e. 2.59

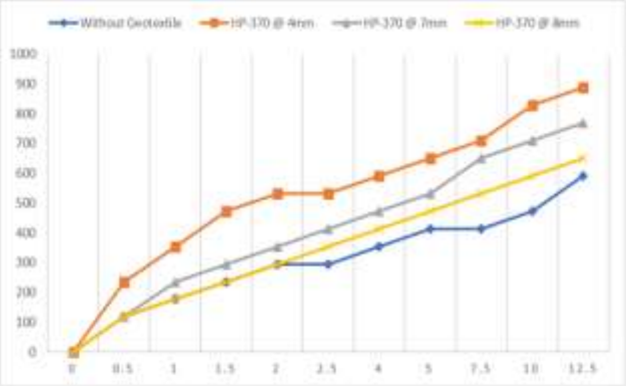


Figure5..3 Variation of test load with penetration with HP-360 at 4cm,7cm,8 cm for top and without geotextile

CBR test with pec-50 geotextile in 4cm distances

Table 9 CBR test with pec-50 geotextile in 4cm distances

Test Stage	**Penetration Depth (mm)**	**Proving Ring Reading (Division)**	**Applied Load (P) (N)**
1	0	0	0
2	0.5	3	177.408
3	1	5	295.68
4	1.5	7	413.952
5	2	8	473.952
6	2.5	10	591.36
7	4	11	650.49
8	5	12	709.632
9	7.5	13	768.768
10	10	14	873.904
11	12.5	15	887.04

CBR value = test load × 100 / standard load

For 2.5 mm penetration = 591.36× 100 / 13700

= 4.32

For 5 mm penetration = 709.632× 100 / 20550

= 3.45

Maximum CBR between these two is taken i.e. 4.32

CBR test with pec-50 geotextile in distances at 7cm

Table 10 CBR test with pec-50 geotextile in distances at 7cm

Test Stage	Penetration Depth (mm)	Proving Ring Reading (Division)	Applied Load (P) (N)
1	0	0	0
2	0.5	2	118.272
3	1	4	236.544
4	1.5	5	295.68
5	2	7	413.952
6	2.5	8	473.088
7	4	10	591.36
8	5	11	650.496
9	7.5	12	709.632
10	10	13	768.768
11	12.5	15	887.04

CBR value = test load × 100 / standard load

For 2.5 mm penetration = 473.088× 100 / 13700

= 3.45

For 5 mm penetration = 650.496× 100 / 20550

= 3.17

Maximum CBR between these two is taken i.e. 3.45

CBR test with pec-50 geotextile in distances at 8cm

Table 11 CBR test with pec-50 geotextile in distances at 8cm

Test Stage	Penetration Depth (mm)	Proving Ring Reading (Division)	Applied Load (P) (N)
1	0	0	0
2	0.5	2	118.272
3	1	3	177.408
4	1.5	5	295.68
5	2	6	354.816
6	2.5	7	413.952
7	4	9	532.224
8	5	10	591.36
9	7.5	12	709.632
10	10	13	768.768
11	12.5	14	873.04

CBR value = test load × 100 / standard load

For 2.5 mm penetration = 413.952× 100 / 13700

= 3.02

For 5 mm penetration = 591.36× 100 / 20550

= 2.88

Maximum CBR between these two is taken i.e. 3.02

Table 12 Variation of CBR with different test condition

Test Condition	CBR Value		
	2.5 mm penetration	5 mm Penetration	Maximum Value
without Geotextile	2.16	2.01	2.16
HP-370 geotextile in distances at 4 cm	3.89	3.17	3.89
HP-370 geotextile in distances at 7 cm	3.02	2.59	3.02
HP-370 geotextile in distances at 8 cm	2.59	2.3	2.59
pec-50 geotextile in distances at 4 cm	4.32	3.45	4.32
pec-50 geotextile in distances at 7 cm	3.45	3.14	3.45
pec-50 geotextile in distances at 8 cm	3.02	2.88	3.02

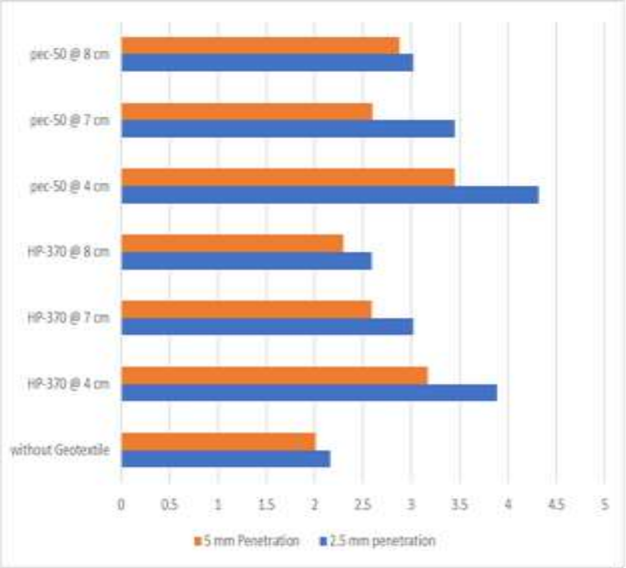


Figure ***Error! No text of specified style in document.****.4 Variation of CBR with different test condition*

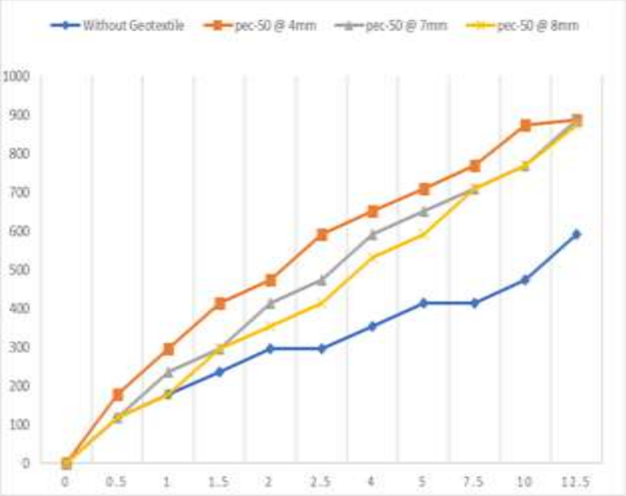


Figure ***Error! No text of specified style in document.****.5Variation of test load with penetration with pec-50 at 4cm,7cm,8 cm for top and without geotextile*

VI. CONCLUSION

Following conclusions are made from this study

- **CBR Improvement with Geotextile Reinforcement**: The inclusion of geotextiles (PEC-50 and HP-370) significantly enhanced the CBR values of expansive soils, increasing their load-bearing capacity.
- **Optimal Depth Performance**: PEC-50 achieved the highest CBR improvement (4.32%) at a depth of 4 cm. Performance decreased as the placement depth increased beyond 7 cm.
- **Effect of Placement Depth**: Geotextiles placed closer to the surface layers provided superior reinforcement due to better load distribution and resistance to deformation.
- **Comparison of Geotextile Types**: PEC-50 consistently outperformed HP-370 and HP-360 in improving the CBR values across various depths.
- **Practical Implications**: Reinforced subgrades are suitable for low-volume roads, flexible pavements, and areas with moisture-sensitive soils. Placement depth of 7–8 cm is recommended for standard subgrade reinforcement.
- **Economic and Long-Term Benefits**: Geotextile reinforcement, despite higher initial costs, reduces maintenance needs and prolongs pavement lifespan, making it a cost-effective solution.
- **Scope for Future Research**: Field validations, multi-layer reinforcement studies, dynamic loading effects, and environmental assessments are essential to enhance the practical utility of geotextile-reinforced pavements.

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