EVALUATION OF STRENGTH PARAMETER OF INDIGENOUS SOIL UNDER VARYING SURCHARGE LOAD

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Abstract- The study examined the result of surcharge load on subgrade soil commonly used in pavement construction in Pakistan. Soil samples of A-6 and A-2-6 types were collected from six locations in KPK and Punjab Division and classified based on AASHTO Soil Classification System. The laboratory tests were performed to define the index properties of soil samples. The ultrasonic pulse velocity technique was used to measure the resilient modulus and swelling, and CBR values were determined using overburdan loads going from 2.27 to 13.8 kg. The study found that increasing surcharge weight led to an increase in ultrasonic pulse velocity and CBR values, and a decrease in soil swelling. The study also developed improved relationships for predicting the resilient modulus values based on CBR measurements, showing strong correlation with equations developed by Green and Hall and Powell et al. from the TRRL. Overall, the study provides insights into the behavior of subgrade soil under different surcharge weights and proposes improved relationships for predicting resilient modulus values, contributing to the design and construction of more reliable and efficient flexible pavements.

Keywords- CBR, Surcharge weight, MR (Resilient modulus), UPV (Ultrasonic pulse velocity), CBR-MR Relationship

1 Overview

A nation's economic progress is significantly influenced by the caliber of its road networks. The quality of the road and the effectiveness of the road pavement are significantly influenced by the strength of the subgrade soil. With rising urbanization, obtaining desired pavement strength while reducing production and construction costs is becoming more and more important. The resistance of the foundation material is assessed using a variety of tests, including the modified Proctor test, unconfined compressive strength, and California bearing ratio. In connection to the subgrade, variables including the MDD "Maximum Dry Density", the modulus of subgrade response, and the FDD "Field Dry Density" are also taken into account. The type of pavement being built determines which strength parameter should be used.

The CBR standards for subgrade soil in pavement construction are established by clients and governmental organizations. However, the industry has not established a clear standard for the usage of additional load (overburden loads) in CBR testing. The overburden pressure caused by the weight of the pavement on the earth is simulated by surcharge weight. The maximum surcharge weight allowed by the standard CBR test protocol is 4.5 kg. For pavement thicknesses of 63.5 mm, Yoder advised a surcharge weight of 2.27 kg, however the mass on soil models shouldn't be least "4.5 kg".

Contractors and construction companies take the depth of the pavement layers above the subgrade into account when calculating the surcharge weight for CBR testing. In this method, heavier surcharge weights than the CBR test's standard weight are frequently used. Increased surcharge weight, however, may cause variances in soil CBR values. Investigating the impact of various surcharge weights on commonly utilized soil types for pavement building is crucial.

Razouki (Razouki, 2014) [1]conducted a study on gypsum-rich roadbed sand with 39% gypsum content, applied a 200 N surcharge loads to CBR models and subjecting them to cyclic soaking and drying processes. The research revealed that CBR values decreased during soaking but increased during drying, indicating significant deformation properties influenced by soaking duration. Jaleel's study examined sub base soil under a 4.5 kg surcharge weight, finding that prolonged soaking periods led to a decrease in the bearing ability of the sub base soil.

The "California Bearing Ratio" (CBR) and resilient modulus of gypsiferous soils were the topic of a study by (Razouki, 1999) [2] that looked at the effects of surcharge weight and soaking duration. Testing clay samples containing 33% gypsum required applying surcharge loads of 45 N, 178 N, and 312 N as well as soaking the samples for various amounts of time, ranging from 0 to 180 days. The results showed a direct correlation between surcharge weight and the predicted robust modulus, with higher surcharge weights for each soaked period demonstrating a rise in modulus. The robust modulus, however, decreased as the soaking duration increased. Additionally, (S.S.Razouki, 2002) [3] investigated how silty subgrade soil behaved when subjected to different additional loads "44.5 N, 89 N, 178 N, and 267 N" and observed that a rising in additional load led to and rise in "CBR" power.

In the field of geotechnical engineering, the UPV method is commonly employed to assess important strength parameters such as "shear modulus, elastic modulus, and Poisson's ratio" (Y.Wang, 2018) [4]. The most reliable approach for this is considered to be direct transmission. During the test, spreader and collector transducers are positioned on opposite sides of the soil models. The test involves timing the passage of waves through the soil model and measuring their amplitude (Y.Wang, 2015) [5]. Poisson's ratio and the resilient modulus can be resolving by means of the wave transmission method by calculating the shearing wave velocity (V_S) and compressive wave velocity (V_C). These velocities are obtained by dividing the length of the model (L) by the time taken (t) for the waves to traverse the soil model (D2845-08, 2000) [6]. The researcher uses the following formulae to calculate the values of the resilient modulus (MR).

$$V_C = L/Tc \ \& \ Vs = L/Ts \tag{1.1}$$

The Poisson's ratio (μ) is determined by employing the equation provided below.

$$\mu = (Vc^2 - 2Vs^2)/\ [2(Vc^2 - Vs^2)] \tag{1.2}$$

MR "Resilient Modulus" is finding using the equation

$$M = [\rho Vs^2\ (3Vc^2 - 4Vs^2)]/\ (Vc^2 - Vs^2) \tag{1.3}$$

Where

- L = the length covered by the pulse within the sample b/w two transducers, also known as the sample length,
- Tc, Ts = the time required for compressive waves and shearing waves to propagate through the sample, respectively,
- Vc = (velocity of compressive wave)
- ρ = (density kg/m3)
- Vs = (velocity of the shearing wave).

Focus is placed on two key goals in this study. First, it examines the effects of increased surcharge weight at various sites on the California Bearing Ratio (CBR), swell percentage, and MR "Resilient modulus" of frail and durable subgrade soils. 2nd, it compares the CBR-MR correlations discovered through laboratory research with those that are frequently used in the field. The objective is to establish if the CBR-MR relationship is constant for all subgrade soil types or if it varies with soil type. The purpose of this study is also to examine how surcharge weight affects soil swelling when it is wet.

2 Experimental Procedures

2.1 Materials

From these Six districts in KPK—Sawabi, Karak, Nowkhar, Lower Dir, Bajaur, and Mardan—were used to gather disturbed soil samples for this study. The samples were collected from a depth of roughly 1 meter below the surface of the ground. These soil samples experienced a number of tests in order to identify their index properties and assign them a classification using the AASHTO soil classification system listed in table 1. In accordance with the standards of the American Association of State Highway and Transportation Officials, the testing included wet sieve analysis and Atterberg's limits tests, such as the liquid limit and plastic limit tests.

Table 1: Geotechnical Properties of A-6 and A-2-6 Soil of Different Location

Properties	**A-6 Karak**	**A-6 Sawabi**	**A-6 Nowkhar**	**A-2-6 Bajaur**	**A-2-6 L Dir**	**A-2-6 Mardan**
Liquid Limit (L.L)	30	32	36	40	39	24
Plastic Limit (P.L)	11	17.5	12	21	22	7.7
Plasticity index (P.I)	19	14.5	24	19	17	16.3
MDD (g/cc)	1.92	1.85	1.804	1.9	1.96	1.87
OMC (%)	8.8	12	10.5	10	9	13.5

2.2 Sample Preparation

In this study, California Bearing Ratio (CBR) models were prepared according to the established test procedure. The samples consisted of A-6 and A-2-6 soils, with three samples compacted for each surcharge weight. Compaction was achieved using (10, 30, 65) blows per layer, correspondingly, with a 4.5 kg hammer and a 45 cm elevation of fall. The models were formed in 15 cm diameter of molds and compressed in five layers. To assess the swelling of the soil, the CBR model were submerged in water for 96 hours, and the percentage of soil swelling was determined using dial gauges with compassion of 0.001 cm.

2.3 UPV (Ultrasonic Pulse Velocity)

To overcome the lack of affordable triaxial equipment in developing countries, researchers used ultrasonic pulse velocity as an alternative method to measure soil's resilient modulus. By soaking soil samples and placing transducers directly on the soil surface, compression and shear velocities were accurately determined, minimizing errors caused by steel molds and surcharge weight plates. Following the ultrasonic pulse velocity assessment, CBR testing was conducted to calculate values based on 95% of the maximum dry density. This cost-effective approach enables the estimation of resilient modulus in regions with limited triaxial equipment availability.

3 Outcome and Discussion

3.1 Modified Proctor Compaction Test (MPCT)

Moisture-Density Proctor Compaction Tests (MPCT) were performed on Two different type soil samples A-6 and A-2-6 following AASHTO T 180 standards, which utilize a 4.45-kg (10-lb.) rammer and a 457-mm (18-in.) drop. The MPCT provided numerical values for OMC (Optimum Moisture Content) and MDD (Maximum Dry Density) for each soil model. The results of the MPCT of A-6 and A-2-6 are summarized in fig 1. The relationship between moisture content and dry density for each soil is depicted graphically in (fig 1a). Based on the MDD and OMC values obtained from the MPCT, soil specimens were prepared for the soaked CBR (California Bearing Ratio) test at 95% relative compaction.

1)

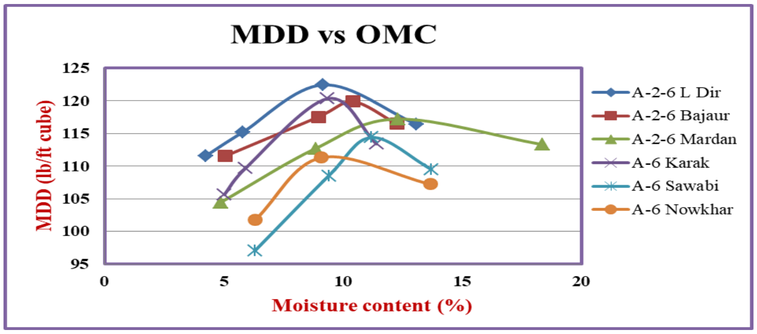


Figure 1: Dry densities vs Moisture content of A-6 and A-2-6 Soil

3.2 California Bearing Ratio (CBR)

This study focuses on the impact of rising additional weight (surcharge loads) since (2.27 to 13.8 kg) on the CBR data of two soil types. The results show a significant increase in CBR data for the "A-6, A-2-6" soil as the surcharge weight increases. The CBR values for different locations 1, 2, 3 of A-6 and A-2-6 soil rise from (2.2% to 11.7%, 2.3% to 10.1%, and 1.95% to 8%) and (1, 6.9% to 19%, 5.5% to 22% and 6% to 15.5%) with rising surcharge load result presented in fig 2(a), 2(b). This rise in CBR value can be attributed to the stiffening of the soil within the California Bearing Ratio molds owing to the additional burden from the extra mass (T.Hergul, 2012) [7]. Factors such as clay mineralogy, index properties, and compactive energy also contribute to the rise in CBR values reported by (H.B.Nagaraj, 2018) [8]. The reduction in voids ratio caused by the greater additional load further enhances the strength of the soil. Overall, this study sheds light on the influence of surcharge weight on CBR values and the underlying factors affecting soil behavior (MAJEED, 2014) [9].

To compare the behavior of infirm and durable soils under the equal surcharge load, strength ratios of the "CBR" models were finded. For this purpose strength ratio indicates the comparative rise in CBR data for every increment in surcharge load compared to the CBR data found at the standard weight of 4.5 kg. The results showed in table 2 and 3.

2a)

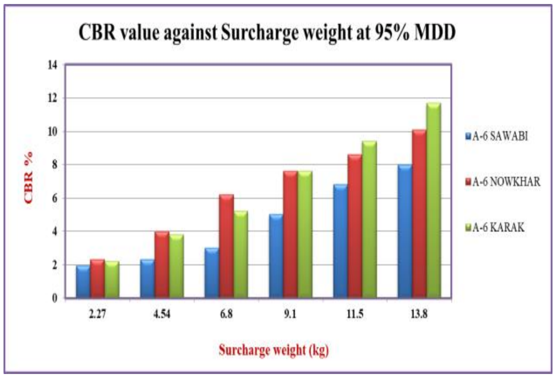


Fig 2a: CBR % A-6 Soil of different location

2b)

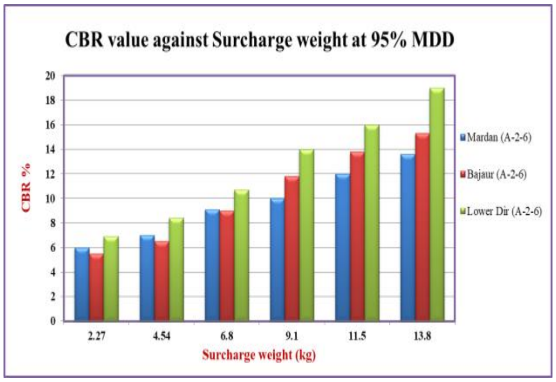


Fig 2b: CBR % A-2-6 Soil of different location

Table 2: Strength Ratio CBR(S)/CBR (4.5)

Sample ID	**Surcharge wt (kg)**	**4.5**	**6.8**	**9.1**	**11.5**	**13.8**
A-6 Karak	$CBR_s/CBR_{4.5}$	1	1.36	2	2.47	3.07
A-6 Sawabi	$CBR_s/CBR_{4.5}$	1	1.30	2.17	2.95	3.47
A-6 Nowkhar	$CBR_s/CBR_{4.5}$	1	1.55	1.9	2.15	2.52

Table 3: Strength Ratio CBR(S)/CBR (4.5)

Sample ID	**Surcharge wt (kg)**	**4.5**	**6.8**	**9.1**	**11.5**	**13.8**
A-2-6 Dir	$CBR_s/CBR_{4.5}$	1	1.38	1.81	2.12	2.35
A-2-6 Bajaur	$CBR_s/CBR_{4.5}$	1	1.27	1.66	1.90	2.26
A-2-6 Mardan	$CBR_s/CBR_{4.5}$	1	1.3	1.42	1.64	1.94

Strength Ratio is explained as CBR S/CBR 4.5 Where;
CBR (S) = "CBR" data of confirmed soil model at any functional surcharge load "S."
CBR (4.5) = "CBR" data of established surcharge load "4.5 kg" functional on tested soil models

3.3 Swelling Potential

One of the main aims of this research was to investigate the impact of various surcharge weights on the swelling potential of A-6 and A-2-6 soils. A comparison of the two soil types revealed that A-2-6 soil exhibited lower swelling compared to A-6 soil. The swelling data after 96 hours of soaking showed a major reduction in swell percentage as the surcharge load increased. The highest compaction effort of 65 blows per layer resulted in the least amount of swelling. For A-6 soil, the swelling potential decreased of Location 1, 2, 3 from 1.53-1.47-1.58% to 0.84-0.81-0.95% when the surcharge load increased from "2.27 to 13.8" kg as listed in fig 3(a). Similarly, for A-2-6 soil, the swelling potential decreased of Location 1, 2, 3 from 1.66-1.7-1.79% to 0.75-1.03-0.87% with the rising in overburden load since 2.27 kg to 13.8 kg as listed in fig 3(b). The higher compressive energy increased the dry density of the soil, foremost to a decrease in swell percentage. These findings align with previous research by (A.K.Mishra, 2008) [10] who observed a decrease in clayey soil swelling with rising dry density. The decrease in swell percentage can be credited to the reduction in void spaces between soil particles caused by increased compactive effort, ultimately reducing the overall voids in the clayey soil. When we utilized weak soil and increased the surcharge weight, the swelling decreased. To enhance the CBR value and minimize the potential for swelling, the surcharge weight was increased. However, in the field, the standard surcharge weight was used, resulting in greater soil swelling and deformation in the road structure. In the field, we lacked control over this aspect, whereas in the laboratory, we were able to increase the surcharge weight and effectively manage the swelling."

3(a)

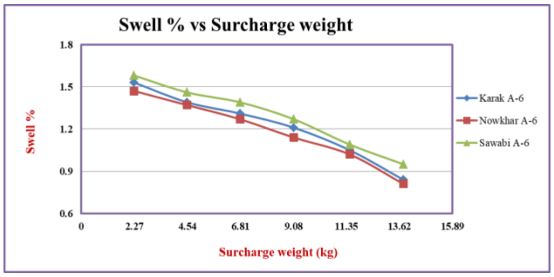


Fig 3a: Swell % of A-6 Soil

(3b)

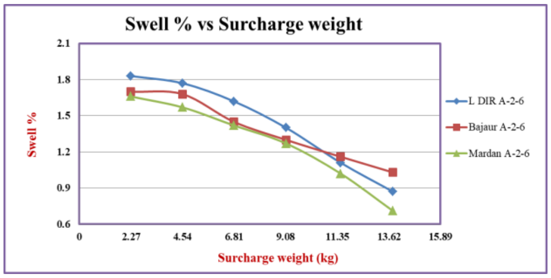
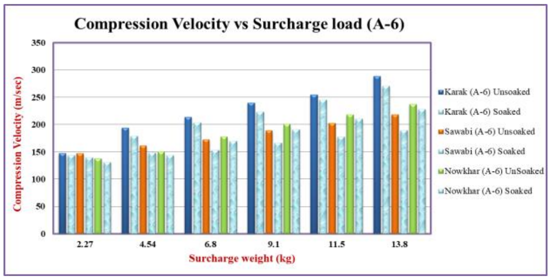


Fig 3b: Swell % of A-2-6 Soil

3.4 UPV (Ultrasonic Pulse Velocity)

The results of the "Ultrasonic Pulse Velocity Test" for A-6 and A-2-6 soils are presented in fig 4(a), 4(b). The study reveals that the velocity is higher in the dry condition compared to the soaked condition. Additionally, increasing the compaction effort to 65 blows/layer significantly increases the velocities compared to 30 and 10 blows/layer. This increase in velocity corresponds to higher CBR values, which can be attributed to greater compressed and shear wave velocities resulting from increased surcharge load. Both velocities and CBR values show an upward trend as the surcharge load increases from "2.27 to 13.8" kg. At the maximum compaction effort, A-6 soil exhibits increasing velocities and CBR values from Location 1 to 3. Similarly, A-2-6 soil demonstrates higher velocities and CBR values compared to A-6 soil. The enhanced soil stiffness under greater surcharge load contributes to the elevated compressed and shears wave velocities. The observed velocity increase in A-2-6 soil surpasses that of A-6 soil, and the reasons behind this difference align with previous discussion on CBR value.

4(a)



4(b)

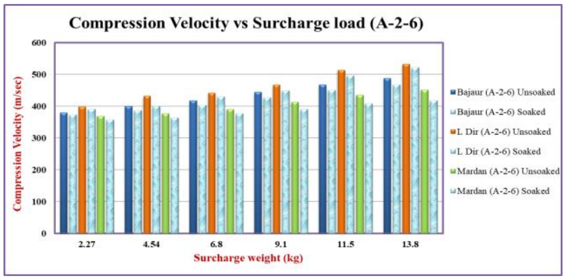


Fig 4a: Compression Velocity of A-6 soil

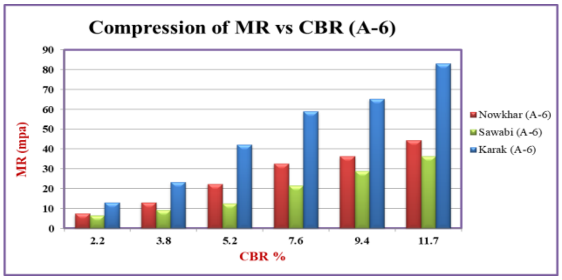
Fig 4b: Compression Velocity of A-2-6 soil

3.5 Resilient Modulus (MR)

In recent research, I analyzed the CBR test value and resilient modulus of A-6 and A-2-6 soil from various locations. The CBR value assesses soil strength and bearing capacity, while the resilient modulus measures resistance to repeated loading without permanent deformation. The study found a positive correlation between CBR value and resilient modulus, indicating stronger and more resilient soils fig 5(a), 5(b). Resilient modulus is crucial for understanding soil performance under traffic loads, affecting stress and deformation distribution. By varying surcharge load, the research demonstrated that increased load elevated the resilient modulus for both soil types. These findings advance geotechnical engineering by providing insights into soil behavior under different loading conditions.

Overall, research highlights the strong correlation between the CBR value and resilient modulus, emphasizing the importance of soil strength and resilience in engineering applications. These findings can contribute to the development of more accurate design methodologies for geotechnical projects, leading to safer and more efficient infrastructures.

5(a)



5(b)

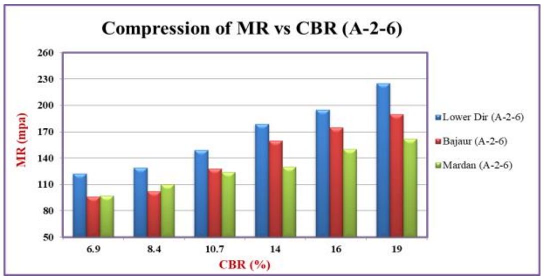


Fig 5a: Resilient modulus of A-6 Soil

Fig 5b: Resilient modulus of A-2-6 Soil

4 Conclusions

Based on the conducted study, the following conclusions can be inferred:

1. Overall, the correlation between compaction effort, compression velocity, and CBR value, indicating that increasing the compaction effort leads to higher compression rates and improved strength properties of the soil.
2. The velocity exhibited a decrease during soaking compared to the unsoaked condition. This means that when the CBR mold was soaked, its velocity decreased compared to its velocity in the unsoaked state. So the higher velocity showed higher CBR value and there is a correlation between increased velocity and improved strength properties.
3. Increasing the surcharge weight significantly improves the CBR strength ratio of "A-6 and A-2-6" soil, indicating that lower CBR silty clay can be utilized as subgrade soil with minimum pavement thickness. Additionally, both soils experience reduced swelling with higher surcharge weight. A correlation between the MR value, CBR value, and compression velocity, indicating that increasing the CBR and compression velocity leads to increased stiffness or rigidity of the material.

4. The variation in soil mineralogy at different locations results in differences in MR (Resilient Modulus), CBR and pulse velocity values for the same soil type

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