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INVESTIGATION OF CBR-VALUES OF GRANULAR SUB BASE IN VARIOUS DEGREE OF SATURATION (DOS)

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ABSTRACT: The impact of the Degree of Saturation (DOS) on granular Sub Base material was investigated in this study. Seven numbers of CBR (California Bearing Ratio) samples of granular Sub Base material were fabricated at 95% compaction according to Standard Australian, AS 1289.6.1.1. These samples were prepared against the targeted moisture variation between DOS 50% and 70%. In particular, the CBR samples were prepared in the laboratory through proper gradation with optimum moisture content (OMC) and appropriate mechanical compaction. Afterward, the samples were dried back and further soaked to achieve the target DOS. CBR tests were executed to assess the variations in strength and interpret the effect of DOS. The results demonstrated that the bearing capacity of granular Sub Base escalated gradually with the increase of DOS until it reached DOS of 56%, which was corresponding to OMC. Conversely, the bearing capacity declined substantially with the further increment of DOS. The study elaborated that the bearing capacity of Sub Base material can be decreased with the increase of moisture content beyond the OMC level and could also diminish pavement performance, including durability, and lead to moisture-related damage to the flexible pavement.

Keywords: Granular Sub Base, California Bearing Ratio (CBR), Degree of Saturation (DOS), Bearing Capacity, Moisture Damage.

1. INTRODUCTION

The road sector is generally the most significant part of the transport system that allows a higher percent passenger travel and substantial freight movement within a country. Road exposed to extremes moisture will suffer a significant reduction in strength, resulting in premature failure and disruption of service. These impacts and vulnerability assessments are very noteworthy to the policy and decision-makers that involved significant investment.

Roads pavements are generally divided into two broad categories: rigid and flexible. Generally, flexible pavements comprise an asphalt layer as surfacing and unbound granular materials (UGMs) are used to construct the underneath base and Sub Base layers over the Subgrade. The Sub Base layer mainly comprised selected granular materials with specified gradation and thickness constructed over the Subgrade and thus acted as a support for the Base Course [1].

Pavements become vulnerable when moisture infiltrates inside the pavement's granular layers. It demolishes the bonding between the aggregates system and eventually loses its strength and durability in the presence of water and repeated traffic loading. When all the voids between the aggregate particles of the Base layer are partially or entirely filled with water during non-draining conditions, the pore water pressure counteracts the particle contact stresses that can reduce the effective stress and the materials' strength significantly [2]. Excess moisture content in unbound pavement materials, especially when combined with heavy traffic loads, can result in accelerated pavement deterioration by declining effective stress, bearing capacity, modulus, and, eventually, a significant reduction in service life [3].

When the degree of saturation is low, the pace of permanent deformation is comparatively little, and water acted as a lubricating agent in the granular system. On the other hand, at a high degree of saturation, the permeability becomes low and leads to high pore water pressure, which renders low resistance to deformation [4].

The road engineers need to investigate the changes of materials strength in fluctuating moisture contents to presume the strain behaviors and corresponding distresses, which is significant for pavements management.

Different laboratory tests are to be executed to determine the strength and resilience characteristics of granular materials, including the CBR test, which resembles the field conditions' loading pattern. CBR tests were conducted to investigate the effect of strength variations in various DOS. Data were collected, processed, and examined to obtain a comprehensive understanding of the pavement layers deformation & strength behaviors.

1.1 Sub Base Course

The Sub Base in a flexible pavement placed under the base layer bears loads from the upper layer and transmits to the Subgrade. The Sub Base's principal function is to provide adequate support to the Base and diminish the Subgrade stresses. This layer can also lessen the pumping of Subgrade fines through joints and move up to the pavement surface during the loading action [5]. Moreover, Sub Base enhances the structural support for the base course and surface layers as well. It also facilitates drainage and protects the Base and surfaces from the underlying soil [6]. Unbound Granular Materials (UGMs) are generally used in the comprehensive road system for Base and Sub Base courses.

1.2 Moisture-Damage Mechanisms in Sub Base Layer

Water infiltrates in the pavement through the surface and shoulder during rain, melting of ice, capillary action, and water table changes in different seasons [7]. Climate, Topography, and Materials used in pavement layers are significant since high water table and capillary water rise preliminary creates water intrusion in pavements [8].

The pores between the particles are comparatively large in coarse-grained aggregate materials Sub Base layer. The material's load-bearing mechanism mostly depends on particle contact stresses and their inter-particle friction under draining conditions. Water ingress to the material can reduce the inter-particle frictional strength, and hence higher resilient and accumulated permanent deformations occurred under traffic loading. When water fills all the voids between the aggregate particles during non-draining conditions, the pore water pressure counteracts the particle contact stresses that substantially reduce the material strength [2].

1.3 Impact of Water in the Pavements Construction and Life Cycle

Water is a vital component in road construction practice as it allows aggregate particles to shift into the most effective packing like a lubricating agent [9]. Unbound granular materials cannot achieve maximum density without it. However, an abnormal water presence may accelerate the deterioration of pavement layers [10].

Granular materials become susceptible to moisture since it allows water to enter the pore structure. A significant reduction of soaking materials' strength was observed when the samples were prepared under drained conditions [11]. Likewise, the pavement's granular layer's deformation was enlarged by increasing moisture conditions [12].

Aggregate's behavior and engineering properties are influenced by the water content. There are many water intrusion sources; for instance, rainfall, seasonal variation of the water table, and corresponding capillary action can magnify water entrance inside the pavement structure [13].

During construction, it is inevitable to eradicate excess moisture from different layers of flexible pavement; otherwise, it will change the soil's mechanical properties and affect pavements design life. Some preventive measures can be taken to counter the moisture entrance, such as setting barriers at the entrance of incoming water and appropriate drainage system [14]. A capillary barrier should be incorporated during the design of Sub Base and base layers as a protective measure. These preventive measures play a vital role in maintaining aggregates moisture content and corresponding mechanical properties and strengths.

1.4 Optimum Moisture Content

The quantity of moisture at which the road Base or Sub Base material can achieve the maximum dry density (MDD) under the application of a standard compaction effort is termed the OMC. During construction of road base or sub-base course, moisture is provided just below the OMC so that tiny adjustments can be made on-site by spraying additional moisture or accommodating rain and finally maintaining the OMC. When moisture content exceeds the OMC, then the road base may turn to wave shape after rolling. The partially compacted wet bed needs to be harrowed and re-opened and allowed to dry back until OMC is achieved and the layer's compaction.

1.5 The Degree of Saturation

The resilient modulus of the unbound material is significantly influenced by the DOS. Theyse [15], under the University of California's pavement research center, reported a tremendous comparative influence on the strength of the unbound materials, and it can be varied up to 30 % to 100% due to the realistic values of DOS [15].

1.6 Conditioning of Pavement Layers for Target Moisture

During the construction of different layers, pavements including Subgrade, Sub Base, and Base layers, each section of allowable thick layer is prepared with OMC. The target moisture content shall be achieved by spraying additional water or dry back in the environmental conditions such as solar heating, air drying, and evaporation.

The pavement material's DOS state requires further drying and then determines the compacted density and in situ moisture content according to Test Method Q146 [16]. Calculation of the degree of saturation can be done by Eq. (1) as follows:

$$S = \frac{w}{\frac{\rho_w}{\rho_d} - \frac{1}{\rho_{st}}} \quad (1)$$

Where,
S= degree of saturation (%)
w = in situ moisture content (%)
ρ_w = water density (t/m³) (taken as 1.00 t/m³)
ρ_d = compacted dry density (t/m³)
ρ_{st}= apparent particle density (t/m³)

1.7 Compaction

The properties of the materials in the field should simulate with the laboratory tests to achieve the required strength and designed pavement. The density of the aggregates in a pavement layer can be achieved by proper compaction. Compaction affects the shear strength as well as the permeability of aggregates. A well-compacted layer is less potential against settlement and volume change. Compaction of the aggregate Base and Sub Base layer with moisture content other than optimum significantly affects its shear strength and permeability [11].

2. IDENTIFICATION OF PROBLEM AND OBJECTIVES

2.1 Problem Statement

The influence of moisture is significant for pavement's longevity, including Asphalt and underneath base and Sub Base layers. Moisture intrusion into the Base and Sub Base layers declines its durability and strength potentials by diminishing granular materials bearing capacity, thus propagating to deformation and leading to moisture damage of pavement. This moisture-induced damage is deeply concerned among different transportation agencies over the years to identify the degree of deterioration concerning the amount of moisture present in the pavement so that mitigating measures can be implemented.

2.2 Objectives

Notably, this study considered examining the variations in granular Sub Base materials' strength in different DOS. CBR tests were executed on laboratory prepared samples with different moisture content and interpreted the results according to how it varies in different DOS.

3. EXPERIMENTAL PROCEDURE

Suitable granular Sub Base materials were collected from a road construction material stackyard. Sieve analysis was done to ascertain the grading requirements. Afterward, Job mix grading was customized. MDD and corresponding OMC were determined accordingly. The specimens were formulated with different DOS according to practice. Soaking of the specimens was not done prior to testing; instead, follow the curing guidelines as specified. Then, CBR tests were conducted to determine the samples' bearing capacity. The data analysis was done accordingly. The graph obtained from CBR analysis indicated that how the strength was changed in different DOS. Based on the finding's a conclusion was outlined in a modest way for a better understanding of the research work outcome.

3.1 California Bearing Ratio (CBR) Test

In the 1930s, the California State Highway Association developed the California Bearing Ratio (CBR) test. Generally, pavement base layers are constructed with gravel aggregates required to resist deformation generated by vehicular loads [17].

The test CBR implies determining the strength of Subgrade, Sub Base, and Base course material of pavements from the specimen prepared in the laboratory, which is part and parcel of the pavement design procedure. CBR is the ratio of the force needed to penetrate a specific plunger of 1932 mm^2 to a specific distance divided by the standard force required for the same penetration. In this test method, the standard forces are 13.2 and 19.8 kN for the penetration of 2.5 and 5.0 mm, respectively. This method follows the principle of AS 1289.6.1.1[18], and the specimens are prepared from the material passing 19.0 mm sieve in the laboratory. The load-penetration curve is plotted for the collected aggregate samples, and consequently, the CBR values are determined from the graph.

This test can simulate the deformation behavior of the Base or Sub-base under loading conditions in the laboratory. The CBR test considers both the vehicular loads and overlying pavements surcharge loads simultaneously. AASHTO Guide [19] has a similar testing procedure under the designation of T193 for the design of pavement structures [19, 20]. Though CBR tests have been executed broadly on saturated soils, few testing procedures have been done using aggregates base and Sub Base materials with various degrees of saturation [21].

3.2 Sample Preparation

Sub Base materials consisting of crushed rocks were collected from the material stackyard of east-west arterial road Brisbane to accomplish the laboratory experiment. The aggregates' gradations were done through sieve analysis, and took the materials passed through a 19.0 mm sieve. In the next, job mix grading was fixed confronting Austroads grading requirements of class 3, 40 mm Sub Base. The gradation of collected materials is shown in Fig. 1.

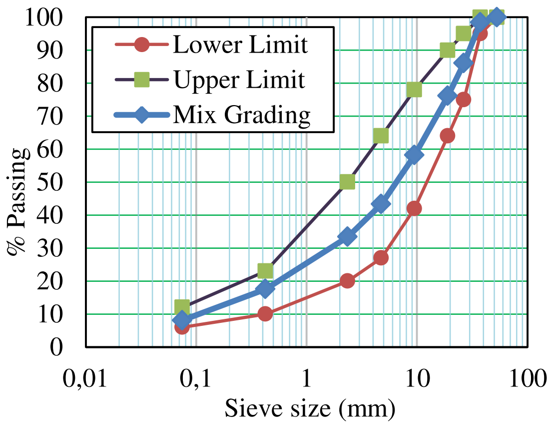

Fig. 1 Particle size distribution of aggregates

MDD and corresponding OMC were determined as per AS 1289.5.1.1 [22] and presented in Table 1. During soil compaction and density tests (standard), the aggregates were compacted by giving 60 blows with a 2.7 kg rammer in 3 equal layer.

Table 1 The moisture content and dry density

Moisture Content (%)	Dry density (t/m^3)
11.50	1.760
12.60	1.780
13.20	1.790
14.20	1.798
15.60	1.770

A smooth curve was developed as depicted in Fig. 2, where the peak indicates the MDD, and its corresponding moisture content represents the OMC of the tested roads Sub Base materials.

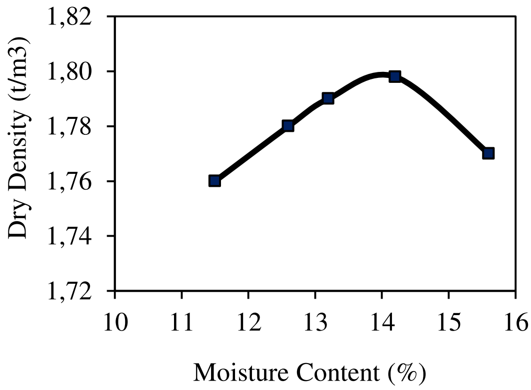

Fig. 2 The optimum moisture content and maximum dry density

In this study, the OMC of the tested materials was found 13.90%, and corresponding MDD was achieved 1.799 t/cum as obtained from Fig. 2.

Table 2 Specification of CBR tests with different DOS

Test Details	The moisture content of specimens at preparation	Targeted Degree of Saturation (DOS) (%)	Number of specimens	Type of conditioning	Actual Degree of Saturation (DOS) (%)
Unsoaked CBR Test	OMC	50% - 70%	1	Dry back in the air	DOS- 50.39 %
			1		DOS- 55.55 %
			1	OMC level	DOS- 56.00 %
			1	Further soaking and dry back	DOS- 57.34 %
			1		DOS- 61.39 %
			1		DOS- 66.45 %
			1		DOS- 70.50 %

Each CBR sample was thoroughly mixed with OMC and put in a cylindrical mold with an internal diameter of 152 mm and a height of 178 mm. Materials were compacted by three layers maintaining the height of each layer. Eighty-eight blows of the rammer provided the compaction effort in eight cycles, wherein each cycle of 11 blows, 8 (eight) blows distributed circumferentially, and the remaining 3 (three) were in the central area.

The same compaction process was followed for the second and third layer accordingly. Samples were dried back in the air, where DOS was required to maintain below OMC. Conversely, additional moisture was sprayed in some samples to achieve the targeted DOS above the OMC according to practice, as shown in Table 2.

3.3 Penetration Test & Determination of Bearing Ratio

The applied load penetrated the unsoaked samples with surcharge weight (4.5 kg) with a constant penetration rate of 1± 0.2 mm/minute. The load reading data for every 0.5mm penetration up to a maximum penetration of 7.5 mm were recorded.

The corresponding load ($f_{2.5}$ & $f_{5.0}$) for penetration of 2.5 mm and 5.0 mm were identified accordingly, and finally, the bearing ratios were determined as follows:

$$CBR_{2.5} = \frac{f_{2.5} X100}{13200}$$

$$CBR_{5.0} = \frac{f_{5.0} X\ 100}{19800}$$

Smooth curves were plotted by applied forces against the corresponding penetration values. Moreover, bearing ratios (CBR at 2.5 and 5.0 mm penetration) versus moisture content were portrayed.

4. CBR TEST RESULTS & DATA ANALYSIS

4.1 CBR and Dry Density Versus Moisture Content

For CBR testing, an MTS Systems machine (model Sintec 10/GL) was engaged in providing a load to the specimens. Finally, data were collected with a PC connected with the testing device along with working software.

Dry density and CBR with respect to moisture content are illustrated in Fig. 3.

At OMC, the specimens were attained both the highest dry density and CBR, respectively. CBR values were increased gradually prior to reaching its maximum level at OMC. Specimens with higher water content above the OMC level were exhibited a dramatic decline of CBR values.

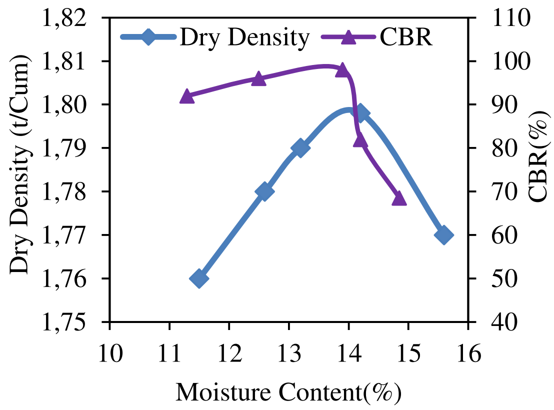

Fig. 3 Dry density and CBR with respect to moisture content

4.2 CBR at 2.5 mm and 5.0mm with respect to DOS

The DOS levels were determined based on the moisture standing under the plunger at the end of the tests. In general, the CBR decreased with the increase of DOS (ranges from 50.39% to 70.50%) for both CBR at 2.5 mm and 5.0 mm of Sub Base materials, as presented in Fig. 4. The maximum CBR value achieved at 5.0 mm was 153%, which was found more significant than the highest CBR value obtained at 2.5 mm that obtained 133%.

4.3 Bilinear Trend of CBR Values at 2.5 and 5.0 mm

The results of the bilinear trend of CBR tests are illustrated in Fig. 5, where the yielding point was identified. The yielding point occurred at the DOS between 55 and 57. There was a moderate increase in CBR values until the yield point, and then it decreased substantially with the increase of DOS.

The findings interpreted the highest CBR strength at DOS of 56.00 %, which was corresponding to the OMC level. However, Strength reduction was observed after DOS of 56.00 %. If the number of samples was increased from DOS below 50.39% or DOS above 70.5%, the yielding point would remain unchanged, but a more reliable linear equation might be obtained.

On top of that, a higher value of the regression coefficient R^2 in the bilinear regression line explained better variability of CBR values (X-axis) in different DOS (Y-axis) than a single linear regression line. Besides, the regression coefficient R^2 values for both the bilinear regression line obtained at CBR at 2.5 mm indicated better fits the data in the regression line than CBR at 5.0 mm.

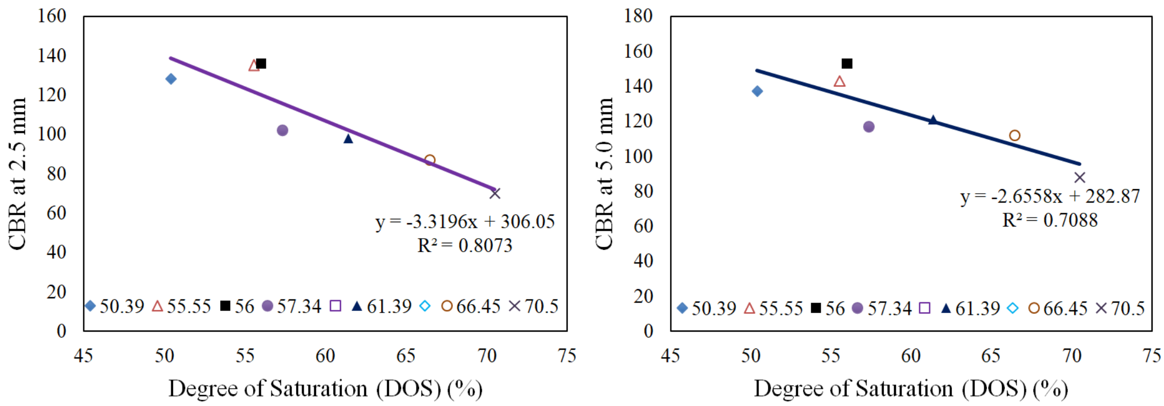

Fig. 4 The correlation of CBR at 2.5 mm (left) and 5.0 mm (right) versus DOS

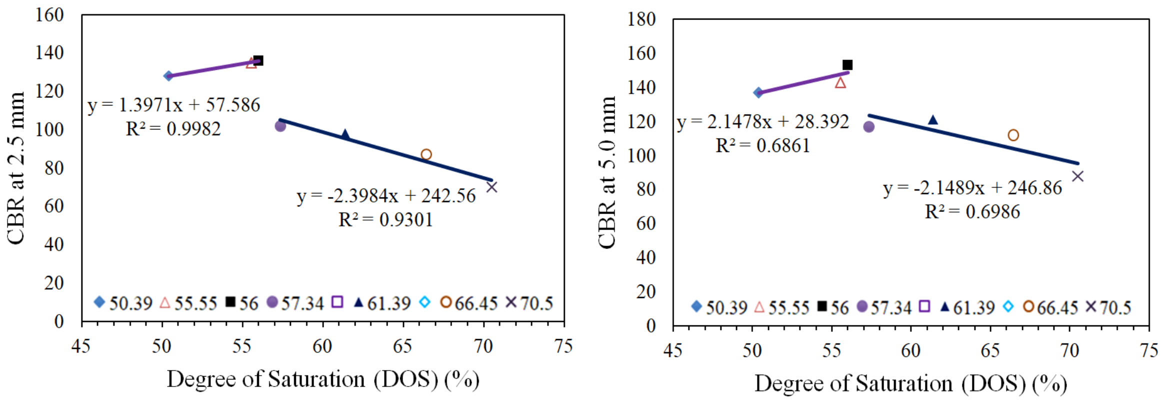

Fig. 5 The bilinear relation of CBR at 2.5 mm (left) and 5.0 mm (right) versus DOS

4.4 Loads Versus Displacement

The relationship between the load and displacement in various DOS ranges from 50.39 % to 70.50 %, as depicted in Fig. 6. The maximum vertical load was investigated approximately 38.10 kN against the maximum displacement of 7.4 mm for DOS of 56.00 %, which was the resultant DOS of OMC. This was followed by the DOS 55.55 % that attained above 35 kN. On the contrary, the maximum vertical loads correspond to the maximum displacement of different DOS below 55%, and above 56% were all acquired less than 35 kN.

4.5 Stiffness (Load/Displacement) Versus Vertical Displacement

The relationships of aggregates stiffness versus displacement are presented in Fig. 7, where the aggregates stiffness values after the displacement of nearly 5 (five) millimeters, at various DOS between 50.39 % and 56.00 %, were all above 50 kN/cm and decreased slightly. In contrast, at different DOS from 57.34% to 70.50 %, the aggregates stiffness values after the displacement of approximately 5(five) millimeters were interpreted almost all between 40-50 kN/cm expect the one at DOS of 70.50 %. However, The DOS of 56% showed higher stiffness than others.

4.6 Pliability (Displacement/Load) Versus Vertical Displacement

The pliability of aggregates was evaluated from DOS ranges between 50.39 % and 70.50 %, and shown in Fig. 8.

The aggregates' pliability values were declined with the increment of displacement until approximately two millimeters, and then it remained plateau at different DOS.

After the displacement of one millimeter, the aggregates pliability values at various DOS between 50.39 % and 70.50 % were inspected approximately between 2.0 to 3.0 cm/kN. Nonetheless, the aggregates pliability revealed lowest at the DOS level at 56 %.

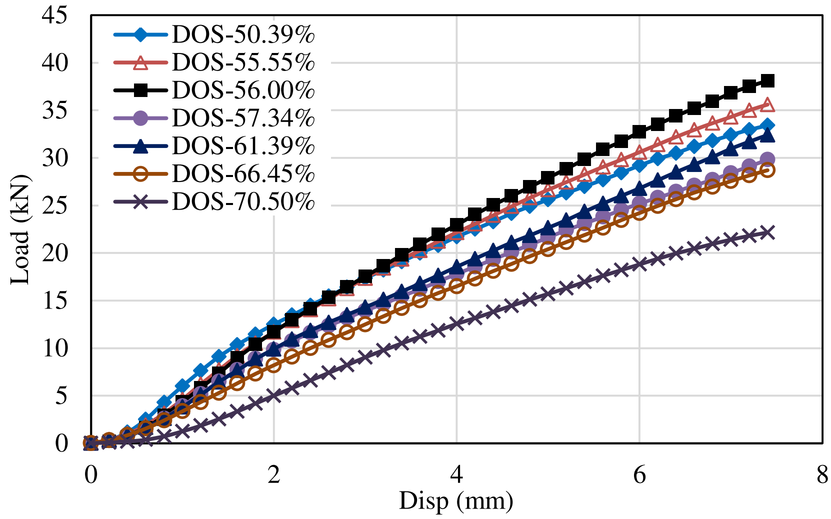

Fig. 6 The relationship of load versus vertical displacement at various DOS

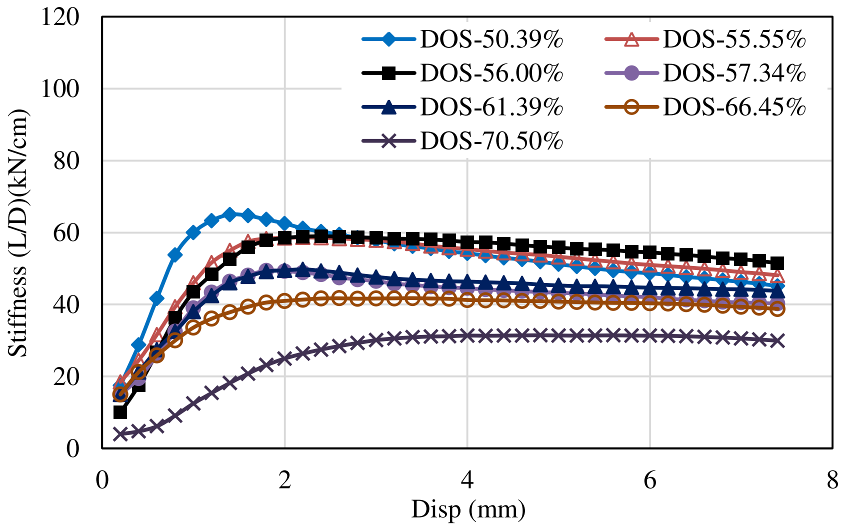

Fig. 7 The relationship of stiffness (L/D) versus vertical displacement at various DOS

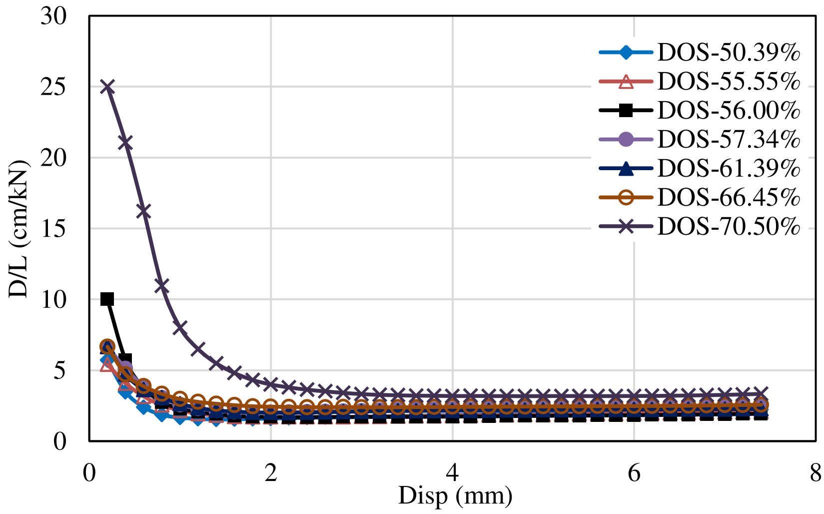

Fig. 8 The relationship of pliability (D/L) versus vertical displacement

5. FINDINGS & CONCLUSIONS

CBR tests were investigated on the samples with various DOS. According to CBR tests, it was identified that between 50 and 56 % DOS, the samples demonstrated higher strength, whereas the samples expressed softening behavior above 56% of DOS. Findings interpreted from the laboratory experiment test are summarized as follows:

(i) The CBR values of the aggregates Sub Base declined as the degree of saturation increased above OMC at both 2.5 and 5.0 mm.

(ii) The stiffness of specimens at higher DOS was comparatively fewer than the stiffness of specimens at lower DOS. The specimen at DOS corresponding to OMC exhibited relatively higher stiffness against significant displacement.

(iii) The pliability of aggregate Sub Base materials at various degrees of saturation remained constant after a level of specific vertical displacement, and the trend of the pliability of specimens at different DOS was relatively similar. However, the DOS corresponding to OMC demonstrated lower pliability.

In conclusion, from the results, it is established that the CBR threshold happens somewhat at a higher DOS level. Consequently, the obtained results gave preliminary indications of the potential of aggregate Sub Base materials' inherent moisture sensitivity, which is revealed from the unsoaked CBR test and interpreted in terms of stiffness.

In different flood-prone and high rainfall areas, it experiences high water tables and frequent capillary action. This study facilitates understanding the moisture susceptibility of granular layers to the road construction agencies and illustrates how the strength of the Sub Base layer changes according to the variations of moisture contents.

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