# Laboratory studies on strength and bearing capacity of GSB-soil subgrade composites

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**ABSTRACT: This paper presents a laboratory study of strength of granular sub base (GSB) underlain by a sub grade layer in terms of CBR and bearing capacity. The CBR and shear parameters are determined for different combinations of granular sub base layer and subgrade thickness. Medium scale Direct Shear test was conducted to evaluate shear parameters of the composite layers. The results indicate that with h/T ratio of 0.5, an allowable bearing capacity of 5.2kg/sqcm can be achieved which satisfies minimum required compressive stress of 1.5 kg/cm$^2$ for a subgrade as quoted by different researchers.**

**Keywords – Subgrade, Granular sub base, CBR, Direct shear test**

## I. INTRODUCTION

Flexible pavements are generally adopted for construction of Roads in India. Design of the various pavement layers is very much dependent on the strength of the sub-grade soils over which the pavement is going to be laid. Generally, in highway engineering CBR test is performed to determine the strength of sub-grade soil and these CBR values will be used to design the thickness of flexible pavement. However, the strength of soil is also determined by different bearing capacity equations in geotechnical Engineering. Bearing capacity is associated with shear strength parameters of soil. Hence , an attempt is made to relate CBR and shear parameters of two layered pavement composite.

## II. LITERATURE REVIEW

There are various empirical and semi-empirical methods to design a flexible pavement. Nai C.Yang (1972) explains that for pavement design method in general, ultimate strength methods incorporate the failure characteristics of the slabs. Nominally, this is effected by using an adequate safety factor which insures the pavement system, against failure. The early English method is one such approach. Introduced in 1944 by Glossop and Golder it involves the determination of the thickness of a slab on grade such that when the slab is loaded by static load distributed over a circular or rectangular area, the pressure on the subgrade multiplied by an adequate factor of safety does not affect the bearing capacity of the subgrade soil. Originally, the method was developed for the flexible airfield pavement construction on soft to firm saturated clays, but it was later extended to include rigid pavement construction and other types of subgrade soil. Pell explains that European method is a semi-empirical approach used by German federal Republic The guidance is given about the quality of granular sub bases and considerable attention is given to provide an adequate depth of frost-resistant granular material. This appears to result in a thickness of sub base such that the structures are all constructed on a foundation of satisfactory bearing capacity.

Peter pell (1978), explains that allowable compressive stress of the total pavement is 15kg/sqcm including sub base, base and bituminous surface. Yoder (1975) states that for a two layer system consisting of subgrade and GSB, the allowable compressive stress in the subgrade is limited to 1.5kg/cm$^2$

Bearing capacity is the supporting power of the soil. A bearing type of load is created in CBR testing where load increases gradually over time. Failure due to bearing is defined as sudden decrease in bearing capacity of soil. The failure loading is a function of shear strength of soil.

Glossop, et.al, (1948) explains that for a material of infinite thickness the bearing capacity can be calculated following a theory developed by Prandtl. The "Prandtl bearing capacity can be calculated from the values of initial resistance and angle of internal friction.

The PRANDTL"S bearing capacity $q_U$ is given by the equation

$$\text{Bearing capacity} == \frac{r\,s}{\tan\Phi}\left\{\left[\frac{1+\sin\Phi}{1-\sin\Phi}\right] \times e^{\pi\tan\Phi} - 1\right\} \qquad (1)$$

## III. MATERIALS

In the present study a locally available medium plastic silty sand with clay representing a weak subgrade (CBR < 3%) was reinforced by a GSB grade –III according to MORT&H standards. The subgrade and GSB layer together was tested for CBR and bearing capacity with variations in layer thickness. Table 1 shows the properties of sub grade soil.

Table 1 Properties of Subgrade soil

| PROPERTIES | VALUES | PROPERTIES | VALUES |
|---|---|---|---|
| **Natural Moisture content** | **10.68%** | **%Gravel<br>% Sand<br>% Silt &clay** | **2.9%<br>41.4%<br>55.7%** |
| **Liquid limit** | **34%** | **Modified proctor test<br>OMC<br>MDD** | **13.8%<br>1.96g/cc** |
| **Plastic limit** | **16%** | **IS soil classification** | **CL** |
| **Plasticity index** | **18%** | **HRB classification** | **A-6** |
| **Specific gravity** | **2.92** | **Group Index** | **7.34** |
| **Shrinkage limit** | **24.48%** | **CBR(4days soaked)** | **2.5%** |

Hoskote gravel available near Bangalore is vastly used as GSB layer for highway projects but generally it fails to meet the requirements of a GSB as per MORT&H specifications. Hence crushed stone granite aggregates are mixed to GSB along with quarry dust to meet the requirements. The properties of crushed stone aggregates and Hoskote gravel are indicated in Table 2 and Table 3 respectively.

By trial , a mix of Hoskote gravel ,crushed aggregate and crusher dust in proportion of 40% of Hoskote gravel, 40% of 20mm down aggregates and 20% of crusher dust yielded a GSB material satisfying gradation –III as per MORT&H specification as shown in Table 4. The soaked CBR value for the mixture was found to be 55%. The modified proctor test on the mixture gave OMC as 7.5% and maximum dry density as 2.15g/cc.

Table 2 Properties of crushed stone aggregates

| Sl. No. | Tests | Values | Range of Values as per IS/ MORT&H specifications |
|---|---|---|---|
| **1** | **Specific gravity of Aggregates** | **2.62** | **2.5-3.0** |
| **2** | **Aggregate Impact value (%)** | **14%** | **10-30%** |
| **3** | **Aggregate Crushing value (%)** | **20%** | **Max. 45%** |

| | | | |
|---|---|---|---|
| **4** | **Combined Flakiness and Elongation index value (%)** | **22%** | **Max. 30%** |
| **5** | **Aggregate Abrasion value (%)** | **24%** | **Max. 40%** |
| **6** | **Water Absorption (%)** | **0.32** | **Max.2%** |

Table 3 Properties of granular soil (Hoskote gravel)

| **Properties** | **Values** | **Properties** | **Values** |
|---|---|---|---|
| **Moisture content (%)** | **9.29** | **Specific gravity** | **2.79** |
| **Liquid limit (%)** | **31** | **Shrinkage limit (%)** | **22.3** |
| **Plastic limit (%)**<br><br>**Plasticity index** | **25**<br><br>**06** | **%Gravel**<br><br>**% Sand**<br><br>**% Silt and clay** | **77.5**<br><br>**9.0**<br><br>**13.5** |

Table 4 Gradation analysis of proportioned GSB materials.

| **IS sieve size, mm** | **Specification as per MORTH, Table 400.2 for close graded GSB (% Passing)** | **Obtained gradation** |
|---|---|---|
| **75** | **-** | **-** |
| **53** | **-** | **-** |
| **26.5** | **100** | **100** |
| **9.5** | **65-95** | **67.3** |
| **4.75** | **50-80** | **53.4** |
| **2.36** | **40-65** | **44.6** |
| **0.425** | **20-35** | **24.1** |
| **0.075** | **3-10** | **4.3** |

## IV. EXPERIMENTAL STUDIES

The experimental studies include conventional soaked CBR test as per (IS 2720-Part 16) and Medium scale Direct Shear test. Initially, these tests were conducted on sub-grade soil and GSB materials separately. Later the, tests were performed on different thickness combinations of GSB and subgrade layers together. The total thickness of two layers together is denoted as “T”. The total thickness T in CBR test is 127.5mm, and in Direct Shear test is 150mm. The different combinations of height of GSB and sub-grade layers are as shown in Table 5 and is designated as type I to type V henceforth.

Table 5 Combinations of soil and GSB materials

| **Thickness of Soil layer** | **Thickness of GSB layer “h”** | **h/T ratio** | **Type** |
|---|---|---|---|
| **100%** | **0** | **0** | **I** |
| **75%** | **25%** | **0.25** | **II** |

| | | | |
|---|---|---|---|
| **50%** | **50%** | **0.50** | **III** |
| **25%** | **75%** | **0.75** | **IV** |
| **0** | **100%** | **1** | **V** |

Where, h= thickness of GSB layer, T= total thickness of both soil sub-grade and GSB layers.

*4.1. CBR TEST*

For the CBR test, Compaction was done in 5 layers with 56 blows for each layer as per the requirements. In case of combined layer composition (for type II, type III and type IV), GSB layer is compacted first for a corresponding volume before sub-grade soil. After compaction, the mould is reversed. The prepared specimen is soaked for a period of four days and later tested. The following table gives the CBR value for different h/T ratios.

Table 5 CBR Value for various h/T ratio

| **h/T ratio** | **0** | **0.25** | **0.5** | **0.75** | **1.0** |
|---|---|---|---|---|---|
| **CBR %** | **2.5** | **18** | **32** | **44** | **55** |

*4.2.DIRECT SHEAR TEST*

In this test a medium Direct Shear apparatus was used for testing samples of size 150mmX150mmX150mm. The strain rate for shear load ranges from 1mm/min to 99mm/min. The loading unit has different normal stresses up to a maximum of 3kg/cm$^{2.}$ It consists of an electronic data acquisition system comprising of micro controlled based signal conditional unit with processing unit. The apparatus consist of one shear box assembly (as outlined in IS 11593). The subgrade and GSB were tested for shear parameters separately first and then for different combinations. Load versus displacement is shown for soil layer and GSB layer in Figure1 and Figure 2 respectively.

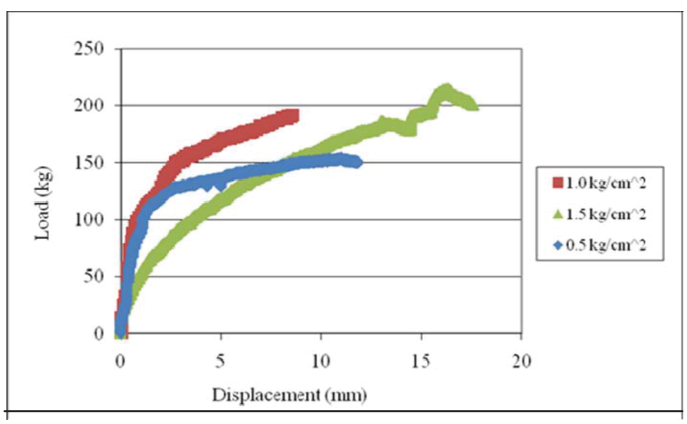


Figure 1 . load v/s displacement for soil subgrade

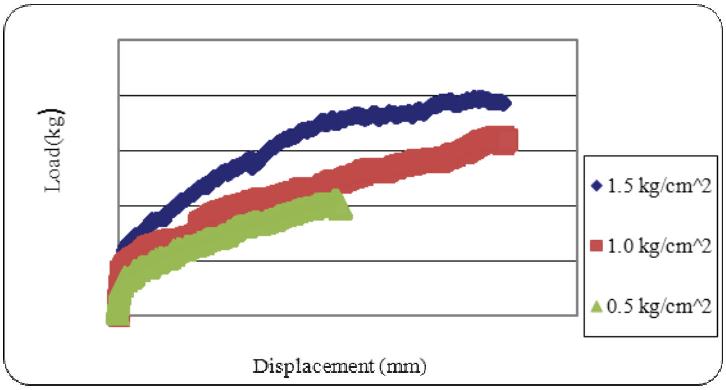


Figure 2 load v/s displacement for only GSB layer

The Table 6 gives shear parameters for different combinations of soil sub grade and GSB layers.

Table 6 Shear parameters for different combinations of sub grade soil and GSB layers.

| Layer thickness, Soil: GSB | | 100: 0 | 75: 25 | 50: 50 | 25: 75 | 0: 100 |
|---|---|---|---|---|---|---|
| **h/T ratio** | | **0** | **0.25** | **0.50** | **0.75** | **1.0** |
| **Shear parameters** | **C (Kg/cm$^2$)** | **0.6** | **0.5** | **0.375** | **0.20** | **0.19** |
| | **ϕ (Degrees)** | **12** | **18.4** | **25** | **36.5** | **40** |
| **CBR (%)** | | **2.45** | **18** | **32** | **44** | **55** |

## V. RESULTS

The experimental results obtained the, soaked CBR, cohesion 'C', and angle of internal friction 'Ø' for different thickness combination of subgrade and GSB layers are plotted as graphs of h/T v/s CBR, h/T v/s C and h/T v/s Ø as given in figure 3, figure 4 and figure 5 respectively.

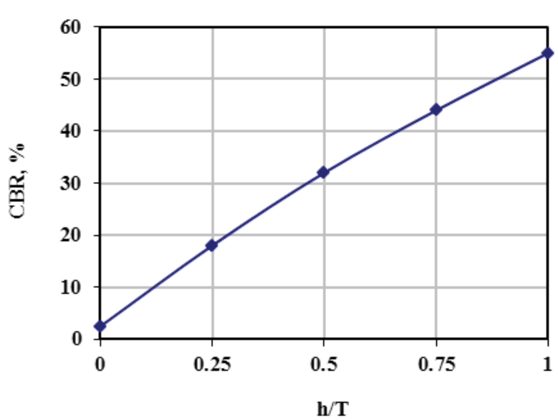

Figure 3 Effect of h/T ratio on CBR

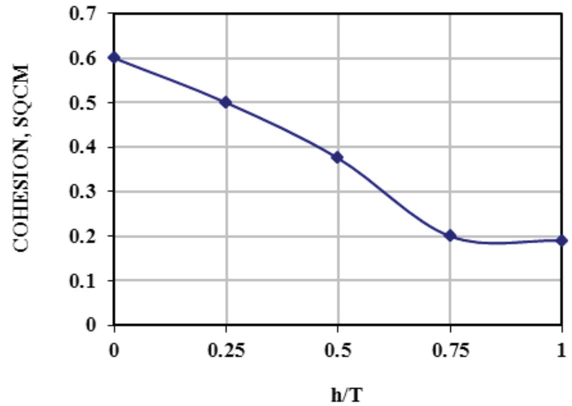


Figure. 4 Cohesion v/s h/T

From Figure 4, it is observed that as thickness of GSB layer increases, cohesion value decreases. From Figure 5, it is observed that as thickness of GSB layer increases, angle of internal friction Ø increases.

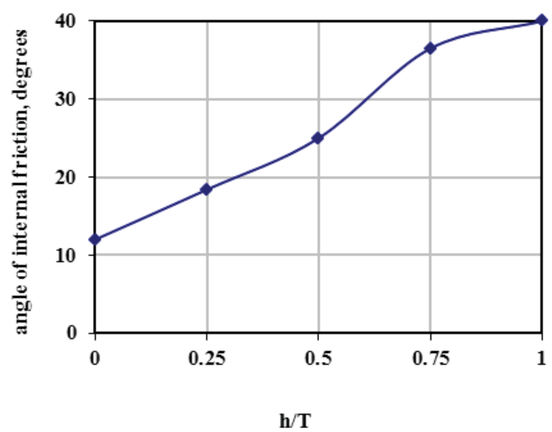


Figure 5 Variation of angle of internal friction Ø of two layer pavement composite with thickness of GSB material

*A Undrained shear strength*

The undrained shear strength $\mathbf{S_u}$ was found using,

$$S_u = C + \sigma \tan(\Phi) \text{ kg/cm}^2 \qquad (2)$$

where $\sigma$ = normal pressure at 1.5kg/cm$^2$ c = cohesion, $\Phi$ = angle of shearing resistance

The figure. 6 gives the plot between undrained shear strength '$S_u$' and h/T ratio. It is seen from Fig 6, that $S_u$ increases progressively with very slow progress from 0 to 0.5 (h/T ratio), and increases rapidly from 0.5 to 1.0

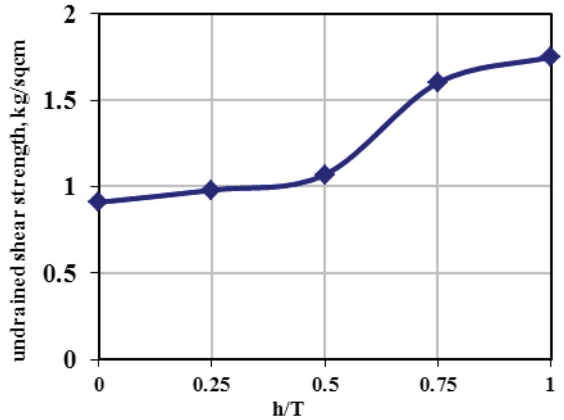


Figure 6 Effect of GSB layer thickness on undrained shear strength $S_u$

Further, CBR versus Ø and CBR versus $S_u$ were plotted separately as shown in Figure 7 and Figure 8 respectively. From Figure 7, it is seen that CBR value increases with increase in Ø value.

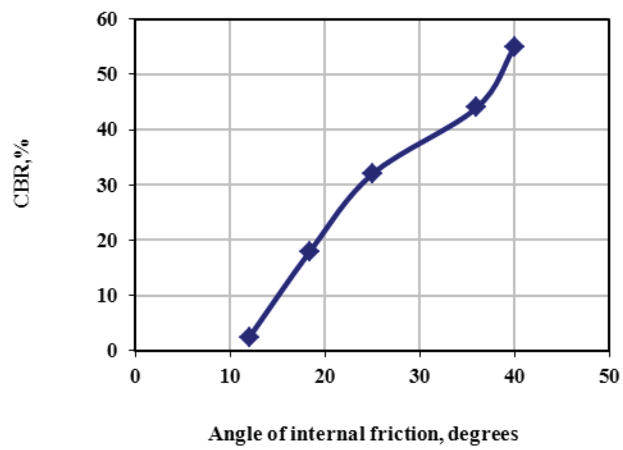


Figure. 7 Variation of CBR of two layer composite with angle of internal friction

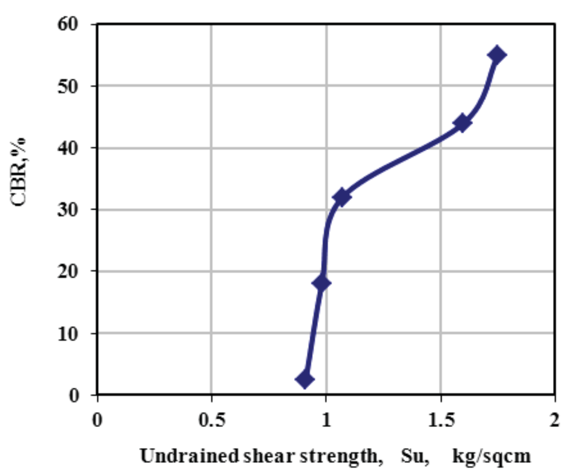


Figure. 8 Variation of CBR of composite layer with undrained shear strength

*B. Estimation of bearing capacity*

The bearing capacity was calculated using prandtl equation for two layer pavement

$$q_u = \frac{\tau_e}{\tan\Phi}\left\{\left[\frac{1+\sin\Phi}{1-\sin\Phi}\right] \times e^{\pi\tan\Phi} - 1\right\} \qquad (3)$$

Where $q_u$ = bearing capacity in kg/cm$^2$ , $\Phi$ = angle of internal friction

$\tau_e$ = initial resistance at 1kg/cm$^2$ obtained from shear strength graph

The allowable bearing capacity is calculated from ultimate bearing capacity with factor of safety 3. The variation of bearing capacity with the depth of sub base layer 'h' is shown in Figure 9. The allowable bearing capacity varies from a minimum value for h=0 to a maximum corresponding to the bearing capacity of top sub base layer only.

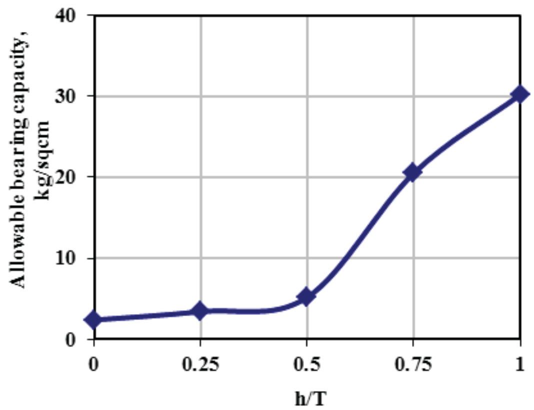


Figure. 9 Variation of pavement allowable bearing capacity with thickness of GSB

Figure 10 shows the variation of CBR with allowable bearing capacity for different h/T ratios.

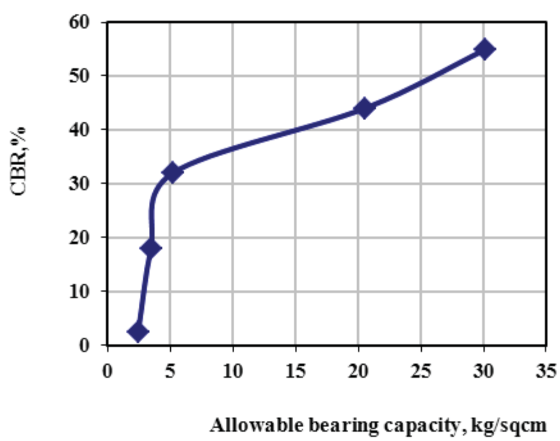


Figure. 10 variation of CBR of composite layer with allowable bearing capacity

The analysed experimental results are consolidated in Table 7.

Table. 7 Allowable bearing capacity

| **h/T** | **0** | **0.25** | **0.5** | **0.75** | **1.0** |
|---|---|---|---|---|---|
| **CBR, %** | **2.45** | **18** | **32** | **44** | **55** |

| | | | | | |
|---|---|---|---|---|---|
| **Undrained shear strength, kg/sq cm** | **0.91** | **0.98** | **1.07** | **1.60** | **1.75** |
| **Allowable bearing capacity, kg/cm$^2$** | **2.40** | **3.43** | **5.19** | **20.5** | **30.2** |
| **Φ, degrees** | **12** | **18** | **25** | **36** | **40** |

## VI. DISCUSSIONS

The present experimental investigation was aimed at determining the effect of GSB layer thickness on the overall strength of pavement considering only sub base and subgrade layers. Hence the parameters involved are h/T ratio, basic properties of layer materials (CBR, cohesion, angle of internal friction), undrained shear strength ‘Su’ and allowable bearing capacity ‘qa’. The discussion follows on the above lines.

### *A.Effect of h/T ratio on CBR*

Figure. 3 shows the variation of CBR with h/T ratio. The CBR value increases gradually, with gradual progress of h/T ratio from 0 to 1.0. As the thickness of the GSB increases, the CBR also increases proportionately**.** This is due **to** the presumed pressure bulb (which has a depth of D=2B, where B is the diameter of the CBR plunger=5cms ) lying within the soil layer in Type-I test with low CBR of 2.5% and then CBR increases to 55% where the pressure bulb is fully in GSB layer with h/T = 1.0.

### *B. Effect of angle of shearing resistance ‘Φ’ on CBR*

Figure. 7 shows the variation of CBR with angle of friction Φ. It is seen from the figure 5 that between $10^0$ to $30^0$ of angle of internal friction, the CBR increases slowly. This range of ‘Φ’ is within local shear failure of $\Phi < 28^0$ and further increase in Φ value, the CBR increases rapidly to reach a value of $40^0$ and stabilizes at that level which lies within the general shear failure value ( $\Phi > 36^0$ )

### *C..Effect of undrained shear strength Su on CBR*

The effect of ‘Su’ on CBR is plotted in figure 8. It is seen that when Su increases from 0.91 to 1.07 kg/cm$^2$ CBR value increases rapidly from 2% to 32%. On the other hand beyond, Su of 1.07kg/cm$^2$, when h/T ratio is 0.5 and above, the CBR value increases from 32% and is 55% when $S_u$ is 1.75kg/cm$^2$.This is because of variation in the pressure bulb location for different h/T ratios.

### *D. Effect of h/T ratio on allowable bearing capacity ‘qa’*

The Figure..9 shows that Bearing capacity ‘$q_a$’ increases progressively, with very slow progress for h/T ratio from 0 to 0.5, and increases at a faster rate from h/T ratio of 0.5 to 1.0.

The low bearing capacity ‘$q_a$’ value (for h/T ratio ranging from 0 to 0.5) of 2.4 kg/cm$^2$ to 5.19kg/cm$^2$ is primarily due to the local shear failure condition which is clearly shown by the increase of Φ values from $12^0$ to $25^0$ . Also in this region the shear plane completely lies in the sub-grade soil only. The overburden of GSB layer has very little effect on the CBR. Further for the h/T ratio from 0.75 to 1.0, the angle of internal friction increases from $25^0$ to $40^0$ which is due to the general failure criteria and also the shear plane is in the GSB layer, the allowable bearing capacity increases from 5.2 kg/cm$^2$ to 30 kg/cm$^2$.

In actual pavement Engineering practice, the sub-grade depth of 500mm is considered to be optimum and correspondingly the GSB layer thickness is chosen less than this value. As per IRC -37, for a CBR of 3% and traffic of 10-150 msa, the maximum GSB layer thickness is 380mm which corresponds to GSB/total thickness ratio of 0.43, yields a bearing capacity of 5.16kg/cm$^2$ from this study. This value is greater than 1.5kg/cm$^2$ which is allowable compressive stress for sub-grade of any pavement as quoted by Pell (1978), Yoder (1975) and other researchers.

## VII. CONCLUSIONS

- The sub-grade selected with low CBR less than 3% and angle of internal friction of $12^0$ qualifies as poor sub-grade which needs either stabilization or reinforcing layers in between base and sub-grade

- The GSB selected is a combination of Hoskote gravel, crushed aggregates and crusher dust which has yielded CBR of 55% and qualifies for GSB-III as per MORTH.

- The combination of GSB and sub-grade simulated for the study shows that as GSB/Total thickness ratio increases, CBR increases from 2.5% to 55% for soil to GSB. The angle of internal friction from $12^0$ to $40^0$ and the corresponding shear strength from 0.91 kg/cm$^2$ to 1.75kg/cm$^2$.

- As the GSB layer thickness increases, the angle of internal friction increases from $12^o$ to an ultimate value of $40^o$ and the same is reflected in CBR values. This indicates that the effective interlocking effect is more if the GSB thickness increases.

- The cohesion for sub grade only is 0.6kg/cm$^2$ and for GSB it is 0.2kg/cm$^2$, whereas the GSB/total thickness ratio of 0.5 has yielded very low value of cohesion of 0.375 kg/cm$^2$. In this case the shear plane passes through the soil layer and the overlying GSB has a tendency to dilate during the shear process and hence the reduction. Whereas for the GSB/total thickness ratio of 0.75, the cohesion reduces to 0.2kg/cm$^2$. The shear plane in this case passes through the GSB layer. As the CBR value increases with h/T ratio, the cohesion decreases considerably.

- The concept of bearing capacity applied to the pavement layer has shown that the allowable bearing capacity of 5.16 kg/cm$^2$ can be achieved with h/T ratio of 0.43 considering maximum thickness of GSB as 380mm and sub grade 500mm thickness for 3% CBR. Whereas, allowable compressive stress for sub grade is limited to 1.5kg/cm$^2$ . This indicates that based on bearing capacity the thickness of GSB layer can be reduced to a value lower than 380mm suitably.

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