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Comparison of Permeability Characteristics of Granular Sub Base Layer in a Model Pavement for Different Grades as per MORT&H 5th Revision

Shivaraj Halyal[1], Prof.G. Kavitha[2], Avinash Balegar[3]

[1] *Department of Civil Engineering, K.L.E. Technological University, Hubli, Karnataka, India*

[2] *Department of Civil Engineering, RASTA-Centre for Road Technology VTU-Extension Centre, Bangalore, Karnataka, India*

[3] *Balegar Associates, Haveri, Karnataka, India*

ABSTRACT

Sub Surface drainage is a key element in the design of pavement system, because it is often lead directly to the pavement failure if laid with lack of preliminary studies need to be conducted for getting good performance of pavement structure throughout its design life . The sub surface drainage problems encountered on each section of highways may be different and will require specific consideration and treatment depending upon site condition. Proper construction and QC/QA testing operations can help to ensure good performance of the sub-base layer. Excessive compaction can alter the gradation and create additional fines that may result in lower permeability than determined in laboratory tests and used in the pavement system design. However, the optimization of structural contributions from high stability, versus the need to provide adequate drainage for pavement materials is still a point of debate. Hence it is very essential to study and compare Drainage characteristics of Granular Subbase in terms of Coefficient of Permeability so that along with stability it's possible to have a clear idea on effect of its material characterization on their effective drainage property as wells before actual execution on site. From this study an attempt has been made to determine and compare drainage characteristics of GSB layer on field using semi model pavement. Such that Permeability characteristics are examined for all six GSB gradations specified in the MoRT&H 5th revision and AASHTO-57 GSB Grade as shown in Table 1 and 2 by varying hydraulic gradient with constant head permeability concept in metal chamber which simulates semi model pavement, so that optimum hydraulic gradient (camber to GSB Layer) is determined for each grades at which maximum hydraulic conductivity is expected. Amongst all six GSB grades specified in MoRT&H (5th revision) Grade III gives maximum permeability of 3675.66 m/day at optimum gradient 2.5% & which is most suitable for all locations where drainage is an at most important consideration. Test conducted on Grade II & Grade I at all gradients, showed no flow through them, because thick particle interlocking. Therefore it is suggested to use in less rainfall areas or areas where there is need of structural support to pavement rather than drainage requirement.

Keywords: Coefficient of Permeability, Hydraulic Gradient, Hydraulic Conductivity, Granular Subbase or GSB

INTRODUCTION

One of the most important factors in building a road is drainage. If every other aspect of highway Design and construction is done perfectly but the drainage does not work well, the road will fail quickly. Highway drainage and sub drainage systems are complex and location specific. Because, sub surface drainage problems encountered on each section of highways may be different and will require specific consideration and treatment. There are many factors to consider when designing drainage systems. Most of the design guides and equations available come from empirical studies applicable only to limited geographic regions. Yet processes derived from empirical studies are often used indiscriminately. It is important to be aware of the situations for which a particular design process is applicable.

Subsurface drainage problem has several adverse effects especially on pavement performance as manifested in premature rutting, cracking. They may also lead to slope failures, particularly when fills are constructed on existing slopes or when roads are constructed through steep cuts. Subsurface drainage that removes excess water from the pavement structure increases the performance and life of a pavement section.

The current practices of pavement construction in India consider the Granular Sub-Base (GSB) as a drainage layer. Good drainage characteristics are generally achieved by providing suitable grade of material having adequate permeability characteristics along with structural adequacy which depending upon site condition with respect to rainfall intensity in that area, also it is important to analyze various factors which affects performance of drainage layer before actually providing it on site, so that designed drainage system will keep pavement structure well drained, well in condition and well performed throughout its design life.

Granular Subbase

According to MoRTH 5th revision, material to be used for the work shall be natural sand, crushed gravel, crushed stone, crushed slag, or combination there of depending upon the grading required. Use of materials like brick metal, kankar and crushed concrete shall be permitted in the lower sub-base. The materials shall be free from organic or other deleterious constituents and shall conform to the gradings and physical requirements given in Table 4. Gradings III and IV shall preferably be used in lower sub-base. Gradings V and VI shall be used as a sub-base cum drainage layer. Where the sub-base is laid in two layers as upper sub-base and lower sub-base the thickness of each layer shall not be less than 150 mm.

In present study Drainage characteristics are to be determined interms of Permeability characteristics of GSB mix by preparing specimens fulfilling the required gradation of Granular Sub-base layer specified by different agencies such as MORT&H(5th revision), AASHTO-57 as per Job mix formula by using Constant Head Permeability concept with the help of permeability chamber such as Model Pavement of size 2 m x 1.5 m x 1.0 m, pavement of area 1.5 m x 1.5 m with varying the Hydraulic gradient (i) that is slope to permeability chamber of 2.5%, 3.5% and 4% , to simulate the field condition and permeability values are calculated and compared for different gradations.

Coefficient of Permeability

The coefficient of permeability, *k,* also called the hydraulic conductivity. This is a unit of velocity, is a measure of the ease with which fluids can travel through a porous medium.

Darcy's Law

Darcy's law implies a linear relationship between the rate of flow q;or flow velocity, *V;* and the hydraulic gradient, *i.* For valid laminar flow condition, which is the flow of water through void spaces between soil particles, Darcy's law is generally expressed as:

$$v=k \times i$$

$$\text{Or } q=k \times i \times A$$

Where: v=flow discharge velocity in cm/sec, i=hydraulic gradient; q=volume of flow per unit of time in cc/sec; A= cross-sectional area to the direction of flow in cm^2, and k=coefficient of permeability in cm/sec

Optimum Hydraulic Gradient

Excessive gradients lead to turbulent flow, a condition that should be avoided for several reasons. First, Darcy's law no longer applies under turbulent conditions. Second, high seepage Pressures could lead to consolidation of the specimen and, turbulent flow may induce fines movement. Hence it is important to check the hydraulic gradient at which maximum flow or hydraulic conductivity is occured. In current study optimum hydraulic gradients can be detected by plotting hydraulic conductivity *vs.* gradient. Darcy's law says that these two variables are directly proportional. If at some point the slope begins to decrease with increasing gradient, something is inhibiting flow. This could be the onset of the turbulent flow. Alternately, discharge could be plotted against gradient. A drop in hydraulic conductivity would indicate a problem.

LITERATURE REVIEW

To properly protect highway pavement structural sections, subsurface drains must be capable of removing the water as fast as it enters.

Surface water can enter into highway pavement structural sections through cracks or joints in rigid pavements; or through cracks, joints or the pavement surface in flexible pavements. Temperature changes, weathering, pavement deflection under traffic, and other actions can produce openings or highly permeable areas in road surfaces to permit water to enter pavement structural sections. Since all of the specific locations where water can enter structural sections cannot be predicted in advance, so for this purpose subsurface drainage systems are needed for the full width of pavements that may be subjected to significant numbers of heavy wheel impacts while the sections contain excess water.

Chapuis developed a horizontal permeameter to measure the permeability of granular and sandy soils. Dimensions of the permeameter were 0.15 m x 0.15 m x 0.30 m. The design details were compatible with those of the vertical permeameter recommended by ASTM D2434, except a flexible rubber membrane was used on the top of compaction mold, to provide a good seal against leakage. After the sample is saturated using de-aired water, tests are conducted at various hydraulic gradients.

Veeraragavan have reported comparable values of laboratory measured permeability of all six GSB gradations given in the MORT&H (4^{th} revision) speculations. The permeability values obtained in terms of coefficient of permeability of GSB mixes are less than 3.17 m/d indicating that these mixes cannot be used for subsurface drainage purpose. On the contrary, the use of such layer may serve as a structural layer that is a lower sub base but without desired drainage property.

Randolph also developed a horizontal permeameter to measure the permeability of granular materials. A sample is compacted vertically and the measurement of permeability is done horizontally, representing field conditions of vertical compaction and horizontal movement of water in bases. The cross sectional dimensions of the permeameter mould are 0.3 m X 0.3 m. X 0.45 m. Long. This permeameter cell has a perforated plate with 9 mm diameter holes both at the inlet and outlet end of the flow. Flexible closed-cell polypropylene foam sheets are glued to all sides of the sample cell to ensure no leakage in the system. Water chambers are attached with piezometer at the outflow and inflow end to measure the head loss during flow. Using the measured head loss and the quantity of water flowing through sample, horizontal permeability of the material is determined using Darcy's equation.

Present Study

The metal chamber was fabricated to the dimension of 200*150*100 cm and the porous plates are provided at 25 cm from either side as shown in Figure 1. Subgrade was first laid in the mould and compacted in three layers to get the required compaction i.e. 97% of obtained lab density as per MoRT&H specification. Above the compacted subgrade a plastic sheet was placed as a separation layer in between sub grade and GSB to arrest the water entering into sub grade while studying the permeability of the GSB mix. The drainage characteristics were evaluated for different GSB gradations for material layer thickness of 300 mm. A camber of 2.5%, 3.5% and 4.0% were provided to Permeability chamber itself with the help of Hydraulic Jack arrangement so as to replicate the actual field condition.

Table 1: Grading for Granular Sub-base Materials as per latest MoRT&H 5^{th}

Revision

IS sieve designation	Percent by weight passing the IS sieve					
	Grading I	**Grading II**	**Grading III**	**Grading IV**	**Grading V**	**Grading VI**
75.0mm	100	-	-	-	100	-
53.0mm	80-100	100	100	100	80-100	100
26.5mm	55-90	70-100	55-75	50-80	55-90	75-100
9.50mm	35-65	50-80	-	-	35-65	55-75
4.75mm	25-55	40-65	10-30	15-35	25-50	30-55
2.36mm	20-40	30-50	-	-	10-25	10-25
0.85mm	-	-	-	-	2-10	-
0.425mm	10-15	10-15	-	-	0-5	0-8
0.075mm	<5	<5	<5	<5	-	0-3

Table 2: Grading for Granular Sub-base Materials Proposed by AASHTO- 57

Sieve size in mm	Percent by Weight Passing Sieve
37.5mm	100
25mm	95-100
19mm	-
12.5mm	25-60
9.5mm	-
4.75mm	0-10
2.36mm	0-5
1.18mm	-
0.3mm	-
0.075mm	-

Experimental setup for Horizontal Permeability

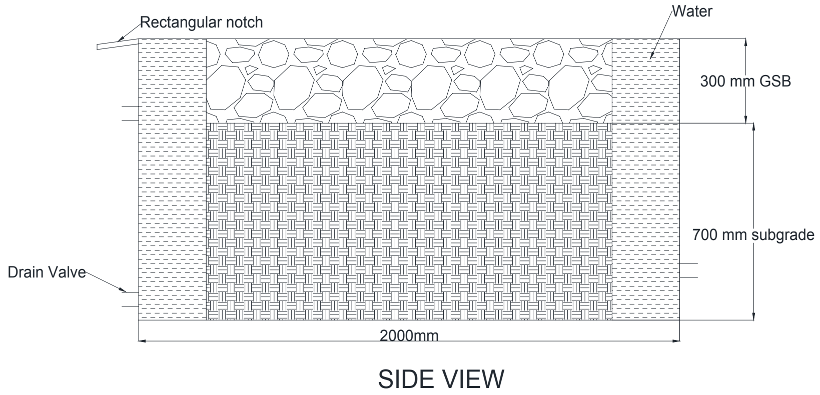

Figure 1: Side view of permeability chamber

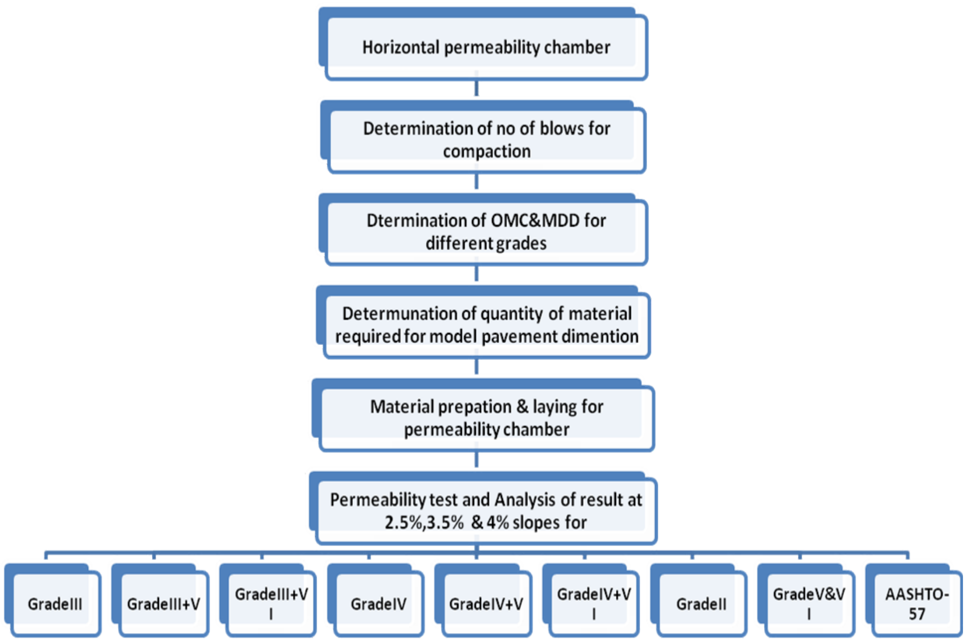

Figure 2: Flow chart of Experimental Work conducted

The materials used in the present study are Crushed stones from Tippagondanahalli quarry area near Magadi in Ramanagar district. Different sizes of aggregates used for present study are 40 mm down, 20 mm down, 12 mm down, 6 mm down, 4.75 mm down and quarry dust as shown in Figure 2. The physical properties of the these aggregate materials were determined in the VOLVO RASTA laboratory and values got were under the limit and satisfying requirements of study as per MoRT&H 5th revision 2013. Weight of the total quantity of dry aggregate required to fit volume of semi model pavement area is calculated as per volume of an area for each grade material separately and then according to Rothfutch's method, proportioning of GSB gradation is carried out to determine percentage of different sizes aggregate required to prepare sample according to each grade specified in MoRT&H 5th revision as shown in Table 1 and 2.

Table 3: Optimum Moisture Content and Maximum Dry Density for GSB Grades obtained from laboratory compaction test

Mix	Grades	Max Dry Density (gm/cc)	Optimum Moisture Content (%)
As per Job Mix Formula	GRADE-III	2.14	3.18
	GRADE-IV	2.16	3.50
	GRADE-V	2.20	3.53
	GRADE-VI	2.29	3.87
	GRADE-I	2.42	4.15
	GRADE-II	2.39	4.00
	AASHTO-57	2.03	1.73

Hydraulic Jack Arrangement is provided as shown in the Figure 4 & 6 at one side of Permeability Chamber to provide hydraulic gradient or camber to simulate field condition by lifting chamber itself and analyze permeability characteristics of GSB gradations at different Hydraulic gradients. In present study it has been considered 2.5%, 3.5% and 4.0% camber to check variability of permeability value of GSB grades.

Water is taken from an Over Head tank which is at top of the building; a separate connection is made from the tank to the field area which is the gravity flow. Capacity of over head tank is 10000 liters.

A geo filter textile was placed between the sub base specimen and the porous plate and for preventing the fines from clogging the porous Plates and affecting actual permeability values. In this study Geotextile of 200 GSM is provided, as higher the GSM (Grams per square meter) was restricting the flow.

Material were staked as per the sizes nearby experimental setup according to size of aggregates and calculated quantity of different size aggregate material for each grade are taken and mixed thoroughly in mechanical mixer by adding OMC (Optimum Moisture Content) which is previously determined by Modified Compaction test in laboratory for all six grades values are shown in Table 3, during process of mixing and laying of GSB material it was confirmed that there is no segregation occurred. The prepared sample is laid in two layers and compaction is carried till it achieves required density by aid of metal plate hammer. In case of combination grades like Grade-III + Grade-V, sample is prepared as per the required quantity and laid in two layers each of 150 mm respectively as per MoRT&H specification.

After laying and compaction of GSB layer, water supply was provided from the overhead tank, 2 inlet and outlet valves of 2 inch and 1.5 inch respectively were provided for the entry of water into the specimen and also Rectangular notch of 15 cm width, 26 cm length & 2.5 cm depth is provide for collection of discharge.. Initially the sample was kept for saturation for about 24 hours so as make sure that all the air voids were removed, saturation hours may extend depending upon the gradations because dense gradations may require saturation up to 8 days. After attaining the saturated condition the water was discharged through the Rectangular notch with clear discharge of water and expulsion of air from the sample.

Once completing the all prerequisites, Gradient is provided to Permeability chamber itself at one end of the chamber by lifting chamber itself by hydraulic jack arrangement (rear end), by varying hydraulic gradient discharge is collected through Notch till constant set of readings are obtained. The discharge time recorded to collect 10000 ml water; usually readings are collected every hour by noting temperature, water viscosity changes primarily with temperature because unit weight and other properties remain constant. Since permeability is inversely proportional to viscosity, permeability increases when the temperature is higher. During whole process of permeability test for each grade of GSB, Constant Head of water is maintained at entry of metal chamber itself even though head is maintained at Overhead tank. Finally Coefficient of Permeability is calculated for each grade using Darcy's constant Head Permeability formula in m/day or cm/sec as shown in Table 4.

Multiple linear regression equation is developed by correlating statically, observed coefficient of permeability of different grades with those properties which known to exert influence on Permeability. The result shows that most significant properties were effective grain size D_{10}, Porosity n, Voids ration e, achieved compacted density, material passing 75 micron sieve as shown in Table 5.

Figure 3 : Field Setup of Horizontal Permeability Chamber

Figure 4: Rear Elevation of Fabricated Chamber showing Hydraulic Jack arrangement

Figure 5: Front Elevation of Fabricated Chamber

Figure 6: Gradient provision by Hydraulic Jack Arrangement to semi model pavement

Data collection and analysis

Horizontal permeability characteristics determined for granular sub-base Grade III, Grade III+V, Grade III+VI, Grade IV, Grade V, Grade VI, Grade IV+V, Grade IV+VI, Grade II (MORT&H 5th revision) and AASHTO-57 gradations by varying Hydraulic gradient 2.5%, 3.5% and 4.0%. Combination Grades such as Grade III+V, Grade III+VI, Grade IV+V, Grade IV+VI are laid in two layers of 150 mm+150 mm,(viz bottom layer will be Grade III and top layer will be Grade V as per MORT&H 5th revision).

ABSTRACT OF PERMEABILITY READINGS

(HORIZONTAL PERMEABILITY CHAMBER)

Table 4: Abstract of k values at different gradient

GRADE OF GSB	PERMEABILITY at 2.5% slope, m/day	PERMEABILITY at 3.5% slope, m/day	PERMEABILITY at 4% slope, m/day
GRADE III	3675.66	3056.23	2831.52
GRADE III+V	3049.40	2493.53	2263.51
GRADE III+VI	2432.37	2212.83	1913.35
GRADE IV	2418.28	1698.74	1601.42
GRADE IV+V	2366.20	2040.49	1943.52
GRADE IV+VI	1605.64	1489.04	1489.12
AASHTO57	3186.70	2319.21	2132.59
GRADE V	2423.14	1930.83	1695.51
GRADE VI	1293.62	1297.34	1476.96
GRADE I & II	**NO FLOW WAS OBSERVED FOR ALL HEADS**		

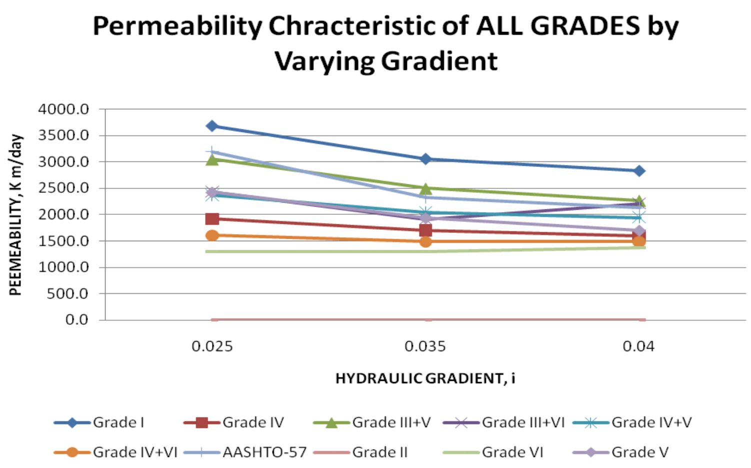

Figure 7: Comparison of Coefficient Permeability for all Grades of GSB

Multiple Linear Regression equation

Table 5: Parameters for developing Multiple Linear Regression equation

Grade	Observed Permeability highest, K m/day	Voids ratio, e	75micron passing,%	Effective grain size D_{10}	Predicted permeability, K m/day
GRADE I&II	0	0.16	2.050	0.15	28.32
GRADE III	3675.66	0.36	0.660	0.86	2907.75
GRADE IV	2418.28	0.28	0.780	0.5	2343.65
GRADE V	2423.14	0.24	0.000	1.3	2140.57
GRADE VI	1476.96	0.19	0.780	0.55	1443.55
AASHTO-57	3186.70	0.43	0.000	1.63	3633.52

Equation generated by statistical correlation is as follows,

$$Y = 1.250598 + 10.97405X_1 - 1.37138X_2 - 1.08219X_3$$

Where,

Y= Permeability of different grades in m/day X_1= Voids ratio, n

X_2= 75micron passing material, % X_3= Effective grain size, D10

RESULTS AND DISCUSSION

Permeability results for different gradations as specified in the MoRT&H 5th revision and AASHTHO-57 are tabulated in the Table 1 and discussion about all grades are quoted as follows.

In present study multiple regression equation was developed by comparing maximum hydraulic conductivity with parameter affecting K values such as Voids ratio e, 75micron passing material and effective grain size material D_{10}. By regression equation predicted permeability values are obtained for all grades**.** Out of six GSB grades Grade III, Grade IV, Grade V and Grade VI obtained permeability values are more than predicted values. AASHTO-57 Grade obtained permeability is around 17%less than predicted value, for Grade I & Grade II no flow of water is observed so values are less than predicted value. So it requires ascertaining these parameters before conducting test to know trend of 'k' values with these parameters as shown in Figure 3.

Grade III

According to Indian standards i.e. MoRT&H 5th revision Grade III is open grade to be provided for GSB. As per compaction test conducted and obtained MDD of 2.14gm/cc & OMC of 3.18 % to be achieved in the field. Permeability test conducted in the field for Grade III at 2.5%, 3.5% & 4.0% hydraulic gradients. At 2.5% hydraulic gradient maximum hydraulic conductivity of 3675.66 m/day is observed and which is more than predicted values obtained by multiple linear regression analysis by comparing various factors.

Grade IV

Grade IV is also having open gradation but having approximately 5% more finer material compare to Grade III. MDD & OMC obtained from compaction test conducted at lab level are 2.16 gm/cc and 3.5%. Same as Grade III permeability test conducted on Grade IV also at all three hydraulic gradients and obtained maximum hydraulic conductivity of 2418.28 m/day at optimum gradient of 2.5% which is less than predicted value from multiple linear regressions model developed.

Grade V

Grade V is having approximately 50% finer material i.e.4.75 mm sieve passing, so this grade is considered as close graded. MDD & OMC obtained are 2.2 gm/cc & 3.53% respectively. Test results for this grade shows that optimum hydraulic gradient is 2.5% for maximum hydraulic conductivity of 2423.14 m/day.

Grade VI

Grade VI is having 5% more 4.75 mm passing material, 3% more 425 micron passing material and also 3% 75micron material than Grade V so it is little denser than compared to Grade V. MDD and OMC are 2.19 gm/cc & 3.87% respectively. Permeability result shows that 4.0% is optimum gradient at maximum hydraulic conductivity of 1476.96 m/day.

Combination grades of GSB

In present study it has been worked on combination grade to know their drainage performance on site, Permeability test result for combination grade of Grade III+V is gave maximum hydraulic conductivity of 3049.4 m/day at optimum gradient of 2.5%.

For Combination Grade III+VI, maximum hydraulic conductivity is 2432.37 m/day at optimum gradient of 2.5%.

Like Grade III combination, it has been worked on Grade VI combinations also. Permeability test conducted on Grade IV+V and got maximum hydraulic conductivity of 2366.20 m/day at optimum hydraulic gradient 2.5%. For combination of Grade IV+VI maximum hydraulic conductivity of 1605.6 m/day at optimum hydraulic gradient of 2.5% is observed.

Grade I & II

Grade II is the densest grade next to the Grade I amongst all Indian grades specified in the MoRT&H 5th revision. This grade is having around 65% of 4.75 mm passing material and around 30-50% of 2.36 mm passing material so it is Grade II is the close graded. MDD & OMC from lab compaction test on this grade gives result of 2.29 gm/cc & 4.15% respectively. Permeability test also for this grade is conducted at 2.5%, 3.5% & 4.0% gradients but no flow was observed for any of gradients. In case of Grade I also flow of water is observed because it is denser than Grade II in particle distribution.

AASHTO-57

AASHTO-57 is open grade amongst all foreign grades of Granular Subbase gradations available; this grade is selected in this study and tested for Coefficient of Permeability at different hydraulic gradients of 2.5%, 3.5% & 4.0% as conducted for Indian grades to compare with them. MDD & OMC for this grade are 2.03 gm/cc & 1.73% respectively. Obtained maximum hydraulic conductivity is 3186.70 mm/day at optimum gradient of 2.5% which is less than predicted from regression model.

Optimum Gradient

By test results on all grades it is observed that all most all grades having optimum gradient of 2.5% at which maximum permeability can be expected and for many grades higher hydraulic gradient was causing turbulence in flow of water due to this obtained coefficient of permeability was less at that respective gradient as shown in Figure 7.

CONCLUSION

Grade III gives highest coefficient of permeability amongst all gradations specified in the MoRT&H for GSB at optimum gradient of 2.5% because of it has most open material gradation. So Grade III can be effectively used for heavy monsoon regions for best performance of GSB layer as a Drainage layer. Along with effective drainage property, Structural stability of this grade can be improved by working on combination grade III+V because it is showing good performance as compared to other combination grade.

Test conducted on Grade I & Grade II at all gradients, showed no flow, it is because of dense material gradation, there is thick particle interlocking. These grades showed good structural stability than drainage property. Therefore for better performance of these grades it is suggested to use them in areas where there is need of structural support to pavement rather than drainage requirement.

For Grade V and Grade VI even though there is specification to use them as structural layer in combination grade, both fulfils the drainage requirement with providing full thickness of 300 mm also, by viewing all data obtained from study conducted it can be inferred that they can also be used as drainage come structural layer in medium rainfall areas. But while proving these grades for full thickness gradient or camber provision must be over looked.

Combination grades as specified in the MoRT&H 5th revision gives satisfactory permeability results.

AASHTO-57 is the most open grade in foreign specification for GSB layer, by test result for this grade shows that it is satisfy drainage requirement so can be used in heavy rainfall regions. But comparing to Indian grades, Grade III is giving much more better result at same optimum gradient than AASHTO-57 so is it suggested to go with Indian grade only rather than foreign.

It was observed that at higher side of hydraulic gradients flow of water was becoming turbulent so by this it is conclude that gradient is the one of the effective parameter affecting permeability of GSB, as higher the gradient provision there may be decrease in the 'K' value.

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