Horizontal Permeability Characteristics of Granular Sub Base Layers with and without Geotextiles

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ABSTRACT: The pavement layers should be stable enough to withstand challenging loading and climatic conditions. Poor drainage conditions are frequently blamed for the development of waves, corrugations and rutting. The drainage facility particularly the sub surface drainage, should be adequately designed and constructed , by providing a permeable type of GSB layer, which primarily functions as a stress transmitting medium to spread the surface wheel loads and secondly as the drainage layer for the pavement, to avoid excess wetting and weakening of the sub grade. While it is not clear whether the different GSB mixes recommended in MORT&H have adequate drain ability, there are limitations to measure the permeability of granular mixes having normal maximum aggregate sizes (NMAS) of 25mm and above, in the laboratory, due to non-availability of standard permeameter. This paper summarizes the development of a horizontal permeameter for laboratory testing of horizontal permeability. The procured aggregates from the quarry were mixed in different proportions satisfying all the 6 grades of GSB gradations given in MORT&H 5th revision. Constant Head permeability test was conducted for horizontal flow of water through the specimen, with and without Geo-textile as a filter layer, at lower Hydraulic gradients to simulate site conditions

Keywords: GSB, Horizontal permeability, Porosity, D_{10}, Percent passing 0.3mm(P0.3), 1.18mm(P1.18) and 9.5mm(P9.5), Geo-textile.

INTRODUCTION

Background

The Granular sub base course (GSB) is provided above the subgrade of pavement to serve as a structural member of flexible pavement layer system and also as a drainage layer in both flexible and rigid pavements. In order to avoid premature failures in flexible pavements caused due to ineffective drainage, in most of the national highway development projects in India, modified specifications of GSB material have been adopted, generally by using crushed aggregates with quarry dust for the fines and avoiding the use of silt/clay/ fines with plasticity.

Specifications for Road and Bridge works by the Ministry Of Road Transport & Highways (MORT&H) 5th revision, recommends 6 types of GSB mixes, to be laid in different combinations. Grading 3 and 4 are recommended in lower sub base layer and grading 5 and 6 are used as a sub base cum drainage layer. The Ministry specifies the strength requirements, liquid limit (LL) and plasticity index (PI) values but it is silent about any specific criteria or specification requirement for effective drainage based on estimation of permeability / hydraulic Conductivity (k), so as to serve as an effective drainage layer. These specifications often fulfill the requirements of the GSB layer as a structural member with greater CBR value than the subgrade, however it is not sure whether these gradations fulfill the criteria for effective drainage. In order to ensure adequate drainage properties, it is desirable to specify the permeability of such a material. The standard permeameter available to measure permeability in the laboratory is used for materials of size less than 4.75mm and gives a measure of vertical permeability. Hence a large scale permeameter of size 0.30mX0.30mX0.60m was developed to measure the horizontal permeability of the GSB mixes compacted to its working conditions.

Since the permeability value depends largely on gradation, effective grain size D_{10}, percentage passing 75 micron sieve and the dry density, preliminary investigation were made to compare and study the permeability characteristics by varying some of these parameters using different GSB mixes. Permeability tests were carried out on GSB mixes with different gradations using the horizontal permeameter.

LITERATURES

The UK Department of Transport (1990) introduced a large permeameter consisting of a steel box capable of accepting a sample of size approximately,1.0m x 0.3m x 0.3m as shown in FIG 1 The permeameter was used to determine the horizontal permeability of embankment drainage layers, Capping materials and sub-bases which is used for road construction. A series of tests generally gave much larger measured values in the horizontal permeameter than in the vertical permeameter.

Jones and Jones (1989) HA41/90(DOT1990) introduced a horizontal permeameter to measure the permeability of aggregates used in drainage layers. This permeameter works for material having D50 up to 30mm. The permeameter cell is of dimension 1.0m x 0.3m x 0.3m. Where the sample was compacted using a vibrating hammer.

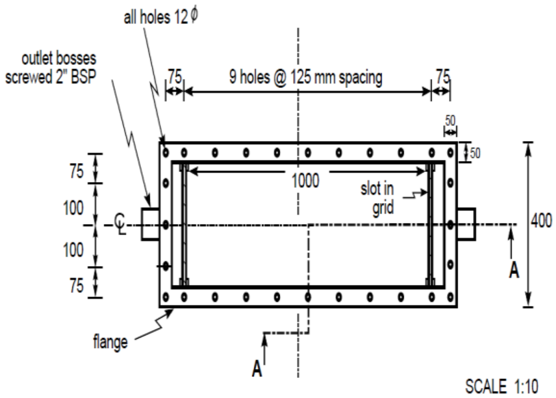


Figure 1: Plan of horizontal aggregate permeameter box without top lid

This permeameter works for material having D50 up to 30mm. The permeameter cell is of dimension 1.0m x 0.3m x 0.3m. Where the sample was compacted using a vibrating hammer. A lid with bar stiffeners and neoprene foam placed on top of the aggregate surface was used to seal the top of the compaction mould. After the specimen was saturated, tests were conducted at various hydraulic gradients. Test results showed a satisfactory basis for the measurement of permeability.

Richardson (1997) performed multi-regression analysis on various parameters influencing hydraulic conductivity including particle sizes, and effective porosity of the mix and developed equations. Equations were developed using results reported for a wide variety of materials, and gradations by various researchers.
Sherard et al. (1984) developed a simple equation correlating permeability with particle size at which 15% of the base by weight is smaller (D_{15}). This was determined by conducting 6 tests

on each of 15 different sands and gravels. Using a similar method Hazen (1930) developed an equation correlating the coefficient of permeability with the effective grain size (D_{10}) of saturated sands. The disadvantage of both these equations is their dependency on gradation without considering the degree of packing or porosity.

Moulton (1980) developed a regression equation from statistical analysis and a nomograph correlating the coefficient of permeability to the effective particle size (D_{10}), porosity, and percent passing No. 200 sieve. The equation was derived using unbounded aggregate bases using a specific gravity value of 2.70

David et al., (1997) undertook a study to determine the drainability characteristics of several types of unbound granular materials that are used in pavement bases. The testing issues were noted and examined. We measured the hydraulic conductivity and effective porosity of aggregates from two crushed stone and two gravel sources. Two open gradations for each material were tested in a rigid wall permeameter. Additionally, a flexible wall permeameter was used to measure the permeation of one dense gradation of each material at two levels of compaction. Both the potential for flow along the rigid wall permeameter's sides and the issue of air bubbles were addressed. For the open and dense-graded materials, the average hydraulic conductivities were 3.6 X 10-1 and 3.0 X 10-4 cm/s, respectively. The open and dense-graded materials had effective porosities that were 68 and 27% of the nominal porosities, respectively.

Experimental Investigations

Materials

Crushed Aggregates: Aggregates to be used for drainage layers should be durable. And they should satisfy the specifications of GSB as specified in MORT&H. In the present study the Aggregates of different sizes are procured from Thippagondanahalli granite Quarry near Ramnagar. The basic properties of aggregates were determined suiting the requirements of GSB materials as specified in MORT&H 5^{th} Revision and the results are tabulated in Table 1. Routhfutch method of proportioning was carried out to meet the gradation requirements as per MORT&H, 5^{th} revision.

GEO-TEXTILES

In the present study non-woven Geo-textile fabric with thickness of 1.2mm, mass per unit area of $200g/m^2$, grab tensile strength of 485N, and CBR Puncture strength of 1585KN has been used as a filter medium to line the porous plates on both sides of the GSB specimen, in order to prevent the flow of fines and clogging of plates.

EXPERIMENTAL SETUP FOR TESTING

Horizontal Permeameter

Horizontal Mould - A horizontal mould with a cross section dimension of 0.3m X 0.3m X 0.6 m was fabricated. This permeameter cell has a perforated brass plate of 3mm thick with 2mm diameter holes at a distance of 0.15m from both the inlet and outlet end of the flow, thus providing an effective space of 0.3m X 0.3m X 0.3m for the specimen compaction. 2 inch piezometre pipes connected to weirs were provided at the inlet and the outlet. The brass plates were lined with non-woven geotextile of 200 GSM to prevent the fines from flowing out through the holes in the brass plates, along with the water .This arrangement resulted in settling of the fines at the edge, thus clogging the geotextile and hindering the flow. This condition was particularly observed while testing the permeability of dense grades with greater amount of

fines (FIG 5). The mould is provided with a cover on top which is tightened along with a rubber gasket of 6mm thickness to the mould, once the specimen is compacted, in order to seal the mould from the top. The mould is made leak proof using M.Seal on all the welded portions. GSB mix is compacted vertically in the mould and the horizontal movement of water is measured, thus simulating the field conditions. The horizontal permeability of the material is determined by Darcy's equation using the head loss and the quantity of water discharged through the sample.
The following are the components of the fabricated permeameter

 Porous Plate of 3 mm thick – 2 no
 Inlet of 50.8 mm diameter
 Outlet of 50.8 mm diameter
 U tube of 50.8 mm diameter fitted with additional pipe and Weir at one end – 2 no
 Vertical Air release valve of 10 mm diameter and
 Rubber gasket.
An engineering drawing of the apparatus is shown in Figure 2.

Over Head tank

Over Head tank of capacity 220 liter. was kept at a higher level than horizontal mould. Head tank helps in avoiding aerated water which means water is allowed to settle before used for testing.

METHODOLOGY

- Specimens were prepared using the coarse aggregates blended with crusher run dust mixed in the proportion to fulfill the gradation requirements as per MORTH specification (5th revision) for GSB grade I, II, III, IV, V and VI respectively. Also for comparison purpose AASHTO 57(American Association of state highway & Transport officials), was also adopted. Routhfutch's method of proportioning was done to match the gradation range of recommended GSB mixes as per the Ministry specifications. The gradations of the GSB mix adopted are shown in TABLE 2 & 3. For these GSB mixes, moisture – density relations were determined.
- The number of layers were fixed as 5 layers, each of 6cm thick and the blows required to achieve the desired maximum dry density (MDD) of each grade was found to be 150 blows/layer.
- Specimens thus prepared were kept for saturation before testing for permeability.

Constant Head Permeability Test

- Constant head permeability test was carried out to determine horizontal permeability. The test setup was arranged as shown in figure 1
- Water was allowed to permeate horizontally through the compacted specimen of 300mm thick in the permeameter, at a low hydraulic gradient of 0.025 to simulate field conditions. Complete saturation of the GSB specimen is ensured before conducting the permeability test.
- The time taken to collect 1000ml discharge of water was noted for every half an hour interval, until the time taken to collect the discharge was almost constant. Temperature of water flowing in the permeameter at each interval is also noted.
- The coefficient of permeability was then determined using Darcy's equation.
- The test was carried out for all the GSB gradations recommended by the Ministry (5th revision) and AASHTO 57.
- The tests were conducted with and without the Geo-textile lining, in order to study the compatibility of Geo-textiles with the different GSB gradations.

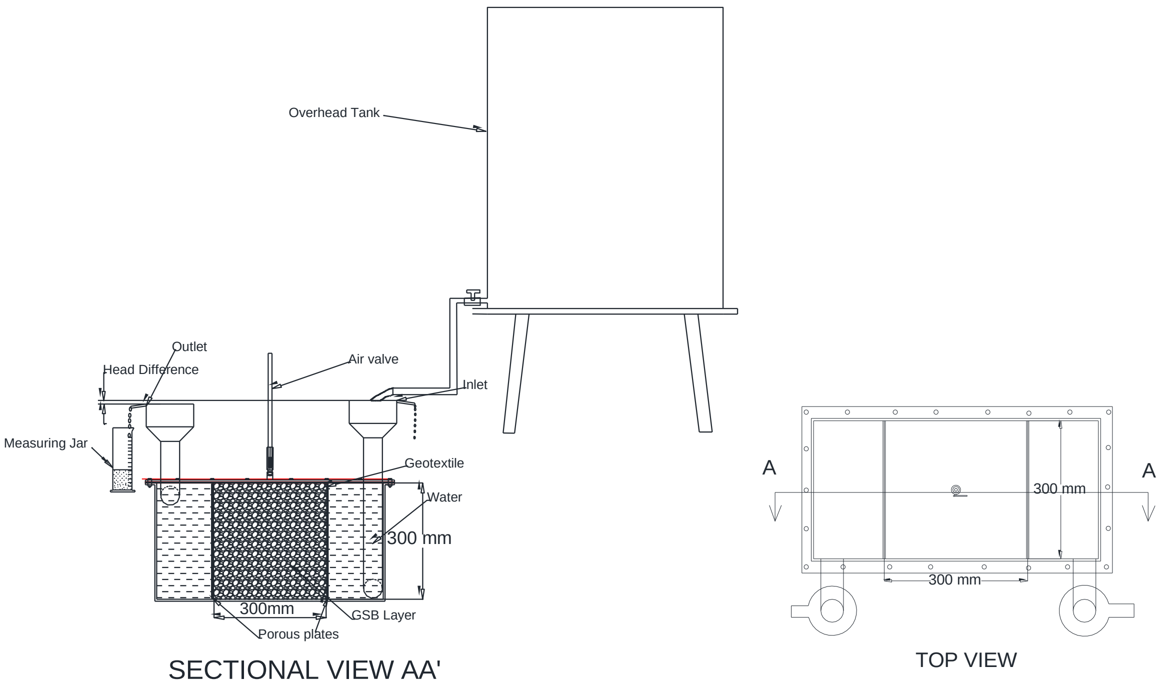


Figure 2: Horizontal Permeameter

Table 2: Grading for GSB materials as specified in MORTH 5th Revision(2013)

IS sieve designation (mm)	**Percent by weight passing the IS sieve(%)**					
	Grading I	**Grading II**	**Grading III**	**Grading IV**	**Grading V**	**Grading VI**
75	100	-	-	-	100	**-**
53	80-100	100	100	100	80-100	100
26.5	55-90	70-100	55-75	50-80	55-90	75-100
9.5	35-65	50-80	-	-	35-65	55-75
4.75	25-55	40-65	10-30	15-35	25-50	30-55
2.36	20-40	30-50	-	-	10-25	10-25
0.85	-	-	-	-	2-10	-
0.425	10-15	10-15	-	-	0-5	0-8
0.075	<5	<5	<5	<5	-	0-3

Table 2: AASHTO 57 grade of GSB specified by AASHTO

Sieve sizes (mm)	**Percent weight passing (%)**
37.5	100
25	95-100
19	-
12.5	25-60
9.5	-
4.75	0-10
2.36	0-5
1.18	-
0.3	-
0.075	-

RESULTS

TEST RESULTS

The permeability (K_{20} value) was determined after applying correction for temperature, (20°C was considered as standard temperature) at a low hydraulic gradient of 0.025. The results are given in Table 3 for with and without Geo-textile. The permeability results for GSB specimens with and without Geo-textiles clearly indicate that the open grades such as grade III, IV and AASHTO 57 have higher permeability compared to other dense grades such as grade I, II, V and VI, in both cases. A regression model was developed considering the parameters such as porosity, D_{10} size, %passing 9.5mm($P_{9.5}$), 1.18mm($P_{1.18}$), and 0.3 mm($P_{0.3}$). The model was developed for the permeability results obtained in case of GSB specimens without Geo-textile lining. The model thus developed was evaluated with the model developed by David N Richardson (ASCE, Journal of Transportation Engineering, 1997) for open graded materials with hydraulic gradient greater than 0.1 cm/sec. The values obtained from the experimental tests and those obtained using Richardson model are given in Table 6 as observed and estimated values respectively.

Table 3: Results of Horizontal Permeability test

GSB Gradings	K_{20} cm/s(m/day) without Geo-textile	K_{20} cm/s(m/day) with Geo-textile	Permeability Ratio Kr=K_{20} without/ K_{20} with
Grading I	0.614(531)	0.1157(100)	5.31
Grading II	0.398(344)	0.111(95)	3.58
Grading III	0.784(678)	0.680(588)	1.153
Grading IV	0.530(458)	0.380(328)	1.4
Grading V	0.415(359)	0.186(161)	2.23
Grading VI	0.608(526)	0.123(107)	4.91
AASHTO 57	1.041(900)	0.710(613)	1.466

Table 4: Parameters Affecting Permeability

GSB Gradings	Porosity/n	D_{10}(mm)	$P_{0.3}$(%)	$P_{1.18}$(%)	$P_{9.5}$(%)	MDD(g/cc)
Grading I	0.16	0.2	10	20	57	2.2
Grading II	0.14	0.14	20	34	83	2.29
Grading III	0.19	0.85	7	1.51	41	2.14
Grading IV	0.18	0.5	7.5	12.63	53.6	2.16
Grading V	0.17	1.43	6	9.5	62.6	2.2
Grading VI	0.172	0.5	7.5	13	74.4	2.19
AASHTO 57	0.23	6.71	0.3	0.5	19.5	2.03

Regression Statistics	
Multiple R	0.927786243
R Square	0.860787312
Adjusted R	0.164723875
Standard E	177.6834517
Observatio	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	195214.0196	39042.80391	1.236650664	0.590261782
Residual	1	31571.409	31571.409		
Total	6	226785.4286			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-870.8938841	2899.06669	-0.300404916	0.814216375	-37707.02878	35965.24101	-37707.02878	35965.24101
n	8250.766274	14090.48493	0.585555878	0.662762698	-170785.8201	187287.3527	-170785.8201	187287.3527
D10	-13.04175535	89.63289398	-0.145501889	0.90801612	-1151.935657	1125.852146	-1151.935657	1125.852146
P0.3	10.4520974	38.14408225	0.274016224	0.829735168	-474.2144211	495.1186159	-474.2144211	495.1186159
P1.18	3.076547102	24.26989088	0.126763945	0.919727707	-305.3016553	311.4547495	-305.3016553	311.4547495
P9.5	-2.838729155	9.293916141	-0.305439506	0.811280648	-120.9291304	115.2516721	-120.9291304	115.2516721

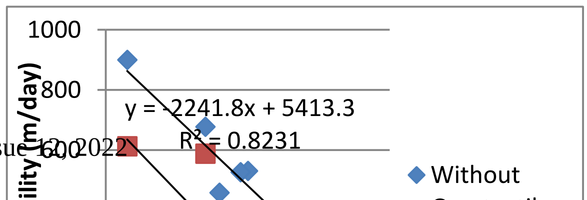
RESIDUAL OUTPUT

Observatior	*Predicted K20*	*Residuals*	*andard Residuals*
1	450.8647229	80.13527707	1.10472043
2	360.4175782	-16.41757819	-0.226327714
3	647.0885885	30.91141147	0.426135268
4	572.8148053	-114.8148053	-1.582801804
5	427.3220091	-68.32200914	-0.94186633
6	448.9014311	77.0985689	1.0628573
7	888.5908648	11.40913518	0.15728285

PROBABILITY OUTPUT

Percentile	*K20*
7.142857143	344
21.42857143	359
35.71428571	458
50	526
64.28571429	531
78.57142857	678
92.85714286	900

Table 5: Statistical Generation of Model



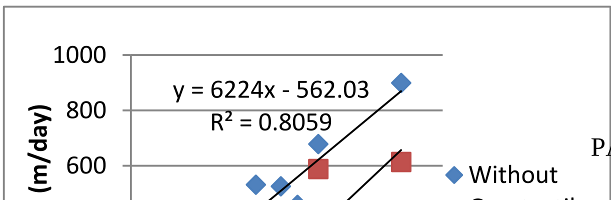


Figure 3: Permeability verses Maximum Dry density **&** Permeability verses Porosity

A multiple linear regression model is developed using the all effective parameters and permeability readings without Geo-textile which is as follows K_{20}= -1.0078+9.549 n-0.01509 D_{10}+0.01209 $P_{0.3}$+0.003561 $P_{1.18}$-0.00329 $P_{9.5}$. This is compared with David Richardson's model of Permeability K_{20}=-2.873+23.923n+1.005D_{10}-0.107$P_{9.5}$-0.2141$P_{0.3}$+0.218$P_{1.18}$. this is as shown in Table 5.

Table 6: Comparison with Richardson model

GSB Grading	**K_{20}(cm/s) from laboratory studies**	**K_{20}(cm/s) for present model**	**K_{20}(cm/s) for Richardson model**
Grade I	0.615	0.522	-2.723
Grade II	0.398	0.417	-5.132
Grade III	0.785	0.749	-3.029
Grade IV	0.530	0.663	-2.651
Grade V	0.416	0.494	-3.280
Grade VI	0.609	0.519	-4.988
AASHTO 57	1.042	1.028	7.331

DISCUSSIONS

1. The important finding is that if Geo-textile is used for studies it hinders the Horizontal flow of water through the specimen. It is seen from reduced values of Permeability with Geo-textile compared to permeability without Geo-textile. The permeability values without Geo-textile is more than that with Geo-textile. Also by the higher then unity values of Permeability ratios for all grades.
2. The grade III and IV recommended by MORT&H and AASHTO 57 grade specified by AASHTO, fulfills the minimum permeability requirement of 300 m/day(0.35 cm/s) (as per AASHTO specifications), in case of with Geo-textile. But all the GSB grades showed permeability of more than 300m/day(0.35 cm/s) in case of without Geo-textile. The highest K value obtained in case of dense mixes is 0.186 cm/s in case of with Geo-textile and it is 0.614 cm/s for without Geo-textile.
3. The permeability ratio K_r is lower for open graded materials Like Grade III, Grade IV and AASHTO 57. But it has increased to a large extent for dense graded mixes.

4. All the Indian Grades from Grade I to Grade VI underestimates the Richardson's model of permeability compared to present study model and permeability of AASHTO 57 overestimates Richardson's model.

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