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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

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World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Evaluation of Horizontal Permeability Characteristics of Granular Subbase Material

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Abstract

Moisture enters into the pavement structure from the surface by infiltrating through cracks and joints, laterally from shoulders, and as capillary suction from bottom. One of the predominant causes for the accumulation of moisture in the pavement structure is inadequate subbase permeability. The existence of moisture within the pavement structure reduces the structural stability of the system. Therefore, it is essential to provide the subbase layer with sufficient drainage characteristics. In the present study, drainage and strength characteristics of the unbound material of different gradations that are being used as pavement subbase layers in India are evaluated. Horizontal permeability was determined using laboratory-developed horizontal permeameter under constant head mode with different hydraulic gradients. Strength characterization was also done in terms of California Bearing Ratio (CBR) value. It is found that horizontal permeability depends on the hydraulic gradient and density of unbound material. Comparison of the laboratory obtained horizontal coefficient of permeability of different gradations was made with the values recommended in IRC: 37-2012 and found that all gradations have permeability nearer to 300 m/day with hydraulic gradient range from 0.2 to 0.3. A predictive model was developed to predict horizontal permeability from the fundamental material properties and good correlation was established within the considered range of variables and thereby this model is useful to predict horizontal permeability of granular subbase material.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Permeability; Granular Sub Base; Drainage; Moisture; Horizontal Permeameter.

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1. Introduction

Granular subbase (GSB) is one of the structural layers of flexible pavement with three major functions, which include protecting subgrade from construction traffic, arresting entry of soil from subgrade into top layers, and providing drainage for water (Yoder and Witzack (1975); Xiao et al. (2012); Haider et al. (2014)). Adequate drainage of GSB is an important requirement for maintaining the structural and functional efficiency of the road system. Pavement structure including subgrade must be protected from any ingress of water into the pavement structure. Any moisture change particularly increasing water content can have an adverse effect on the physical characteristics of the materials (Cedergren and Godfrey (1974). Numerous studies have indicated that a large percentage of highway pavements are distressed due to the excessive moisture in the pavement structure (Al-Qadi et al. (2004; Bouchedid and Humphrey (2005); Lebeau and Konrad (2009); Ceylan et al. (2013)). A typical source of moisture movement in the pavement system is illustrated in Figure 1.

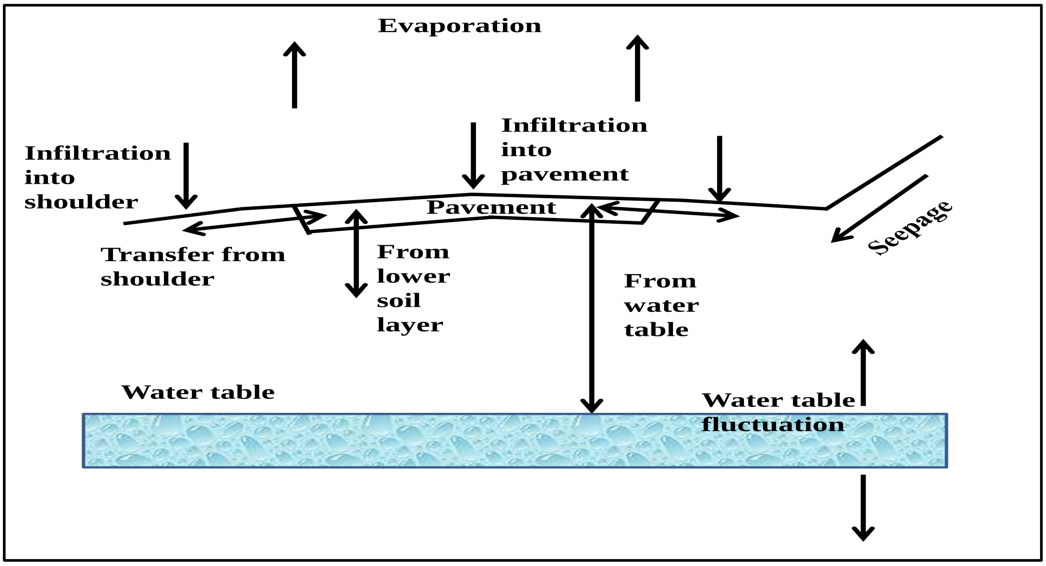

Fig. 1. Moisture movements in the pavement system.

Due to lack of sufficient data regarding the infiltration of rainfall into the pavement, the amount of water entering road structures is often underestimated. Since it is not easy to prevent entry of moisture into the pavement system, incorporation of drainable subbase layer is necessary (Ahmed et al. (1993). Modern roadways with sufficient permeable subbase layers are predicted to extend the life of a pavement system up to two to three times over that of the undrained and impermeable layer containing pavement sections (Forsyth et al. 1987; Bouchedid and Humphrey (2005)). Thus, the determination of permeability plays a significant role in efficient design for a durable pavement. This paper aims at understanding the subbase permeability considering effects of gradation, porosity and hydraulic gradient.

The major objective of this study is to evaluate the permeability characteristics of granular subbase material. The scope of the work encompassed-

- Fabrication of equipment for evaluating permeability
- Determination of horizontal permeability characteristics of subbase materials
- Evaluation of the effect of hydraulic gradient on the permeability of GSB materials
- Evaluation of the strength characteristics of GSB materials
- Development of predictive equation for permeability coefficient considering basic properties i.e. hydraulic gradient, porosity, and coefficient of uniformity of GSB materials

Nomenclature

K	Coefficient of horizontal permeability
i	Hydraulic gradient
η	Porosity
Cu	Co-efficient of uniformity

2. Material and sample preparation

2.1. Aggregate

Aggregates used in this study were collected from Ravalkole quarry in Hyderabad. Four types of aggregate gradations from MoRT&H specification were considered in the present study. Each gradation consists of crushed coarse aggregates and non-plastic fines meeting the gradation requirements. Rothfutch method of proportioning was adopted to produce different granular subbase (GSB) gradations recommended in the MoRT&H specification. Physical properties of aggregates were tested and the results are shown in Table 1 and Table 2. Figure 2 shows the aggregate gradations considered in this study.

Table 1. Physical properties of aggregates.

S.No	Property	Values (%)	Specification (%)	Test Method
1	Aggregate Impact Value	12	Max. 24	IS:2386 Part IV
2	Los angles Abrasion Value	22	Max. 30	IS:2386 Part IV
3	Flakiness and Elongation index	27	Max. 30	IS:2386 Part I

Table 2. Specific gravity of different aggregates (IS: 2386 Part III)

Sieve size (mm)	Specific Gravity
26.5	2.630
19	2.610
13.2	2.590
9.5	2.620
4.75	2.620
2.36	2.510
0.85	2.610
0.425	2.680
0.075	2.660
<0.075	2.770

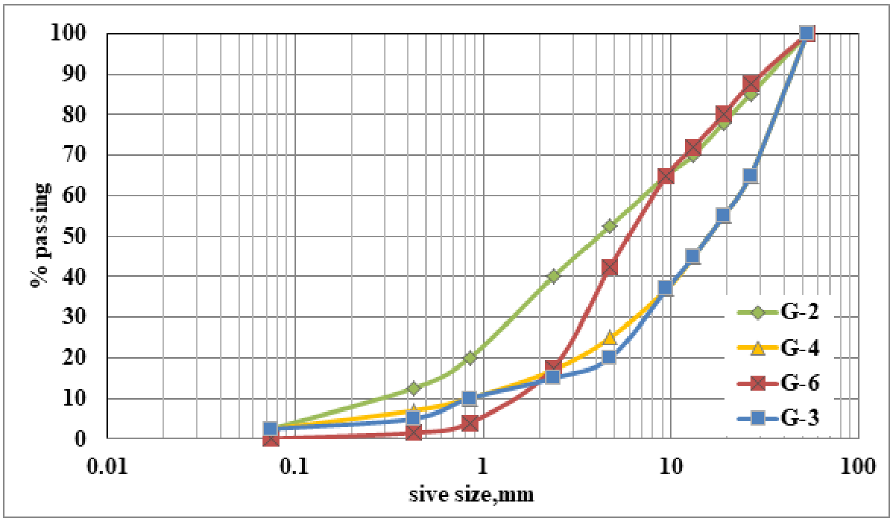

Fig. 2. Gradation of granular subbase materials considered in the present study (MoRTH, 2013**)**

2.2. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) determination

Modified Proctor compaction test was used to determine the OMC and MDD of granular material of the four different gradations. The test procedure followed in this study is as per IS: 2720 – part-8. Figure 3 (a), (b), (c) and (d) shows curves of dry density versus water content to determine OMC and MDD from which the OMC and MDD are determined and are reported in Table 3.

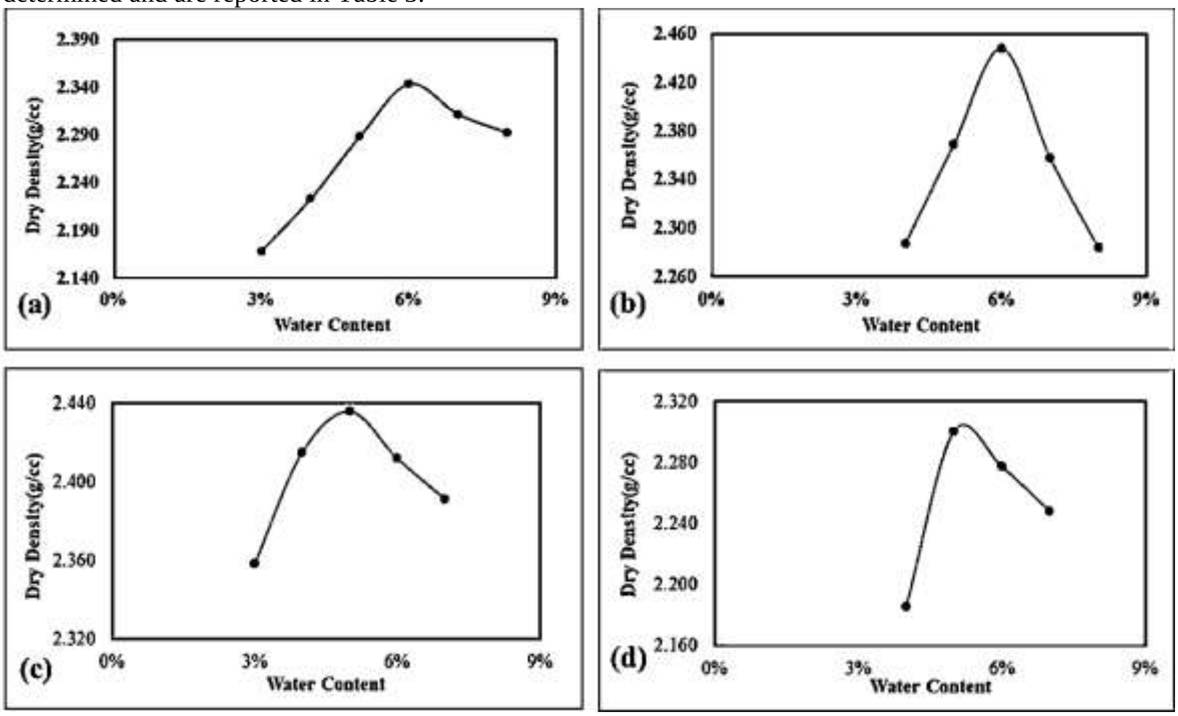

Fig. 3. Dry density Vs water content for (a) gradation I, (b) gradation III, (c) gradation IV and (d) gradation VI

Table 3. OMC and MDD of different Gradations

Gradation	OMC (%)	MDD(gm/cc)
Gradation II	6.0	2.344
Gradation III	6.0	2.448
Gradation VI	5.0	2.436
Gradation IV	5.0	2.300

3. Fabrication of equipment and testing

Figure 4(a) shows the designed sketch of the permeameter that was fabricated in the laboratory. A horizontal mould to carry water with dimensions of 0.6 m×0.3 m×0.3 m was fabricated. This permeameter mould has perforated brass steel plates of 3.5 mm thickness at a distance of 0.15 m from the inlet and outlet end of the flow. Thus it provides an effective space of 0.3 m×0.3 m×0.3 m for the GSB specimen. Dimensions of the outlet tank collecting the discharge were 0.4 m×0.3 m. Three outlets were provided at distances of 0.43 m, 0.325 m, and 0.23 m in the fabricated mould in order to maintain constant head. The discharge was calculated from the outlet tank. The perforated plates have 2 mm diameter holes and are in line with a porous plate to prevent the fines from escaping and clogging the perforated plates. This may increase the hydraulic gradient which affects the permeability results. Darcy's law is applicable to laminar flow. But, flow through granular materials is turbulent at higher hydraulic gradients. As hydraulic gradient increases, flow velocity and Reynolds number will increase which indicates the region of turbulence. Thus the GSB mixtures were tested at lower hydraulic gradients to ensure the laminar flow criterion. Suitable provisions were made to vary the hydraulic gradient. Constant head was maintained throughout the sample specimen during the permeability test at the inlet side. The time required for the water to travel from the inlet of the constant head to the outlet tank was measured. Figure 4 (b) shows the fabricated horizontal permeability test setup.

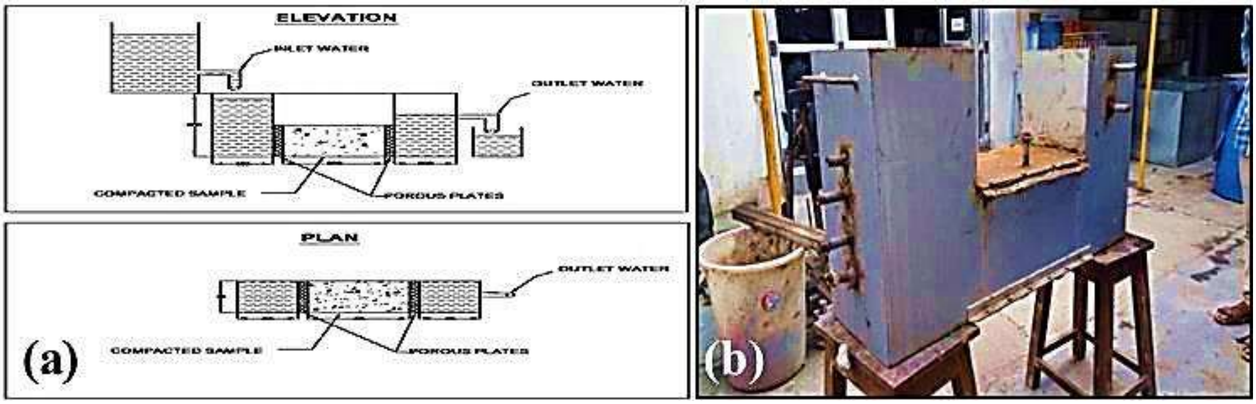

Fig. 4. (a) Sketch and (b) fabricated experimental setup to measure horizontal permeability.

Tests were carried out for different heads which were maintained by using small pipes on the inlet side. Six different hydraulic gradients such as 0.07, 0.22, 0.3, 0.4, 0.45, and 0.63 were achieved. The mould was provided with a cover on the top which was tightened with a rubber gasket of 8 mm thickness in order to seal it after the specimen was compacted. The mould was made leak proof using M-Seal and silicone gel on the entire welded portion.

4. Results and analysis

4.1. Determination of strength

The strength characterization of different GSB gradations was performed using the California Bearing Ratio (CBR) test. Both soaked and unsoaked CBR tests were conducted on the samples prepared with the four GSB gradations at their respective obtained OMCs. From figure 5, it has been observed that for all the GSB gradations considered, there is an insignificant reduction in the value of CBR of un-soaked samples. The reason could be because of the presence of coarse aggregates in major proportions.

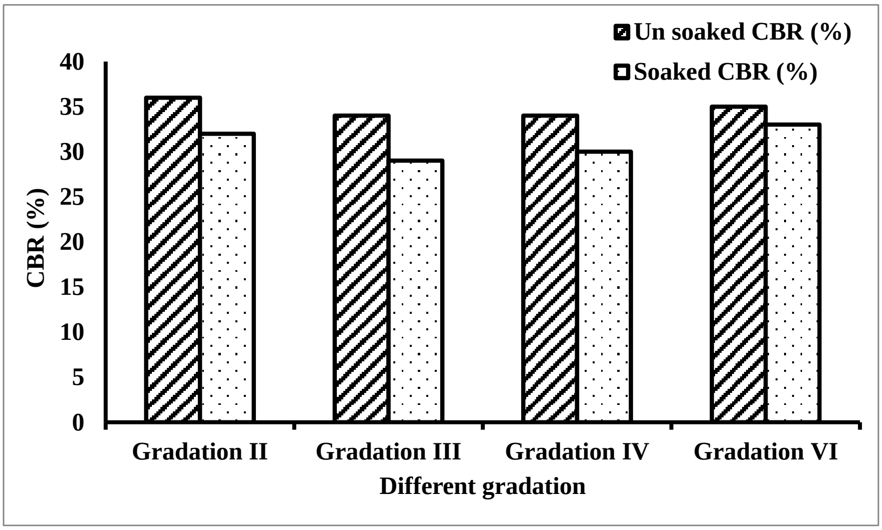

Fig. 5. Soaked and Un-soaked CBR of different gradations

4.2. Horizontal permeability determination

Darcy's principle was applied to calculate the coefficient of permeability in the laboratory fabricated equipment. The results of the coefficient of permeability for four gradations at six different hydraulic gradients are given in Table 4.

Table 4. Coefficient of horizontal permeability with different hydraulic gradients

Hydraulic gradient	0.07	0.22	0.3	0.4	0.45	0.63
Gradations	Co-efficient of permeability K (m/day)					
Gradation II	1103	307	225	160	150	97
Gradation III	1726	454	417	249	238	163
Gradation VI	1378	417	320	241	231	156
Gradation IV	1172	365	255	210	202	109

There has been a significant dependency of permeability on the hydraulic gradient (i) and it follows a negative power relationship (Figure 6). Gradation-III has the highest permeability for all gradients. Gradations-II and VI have lesser values of permeability compared to gradations III & IV which could be due to the presence of more quantity of fines.

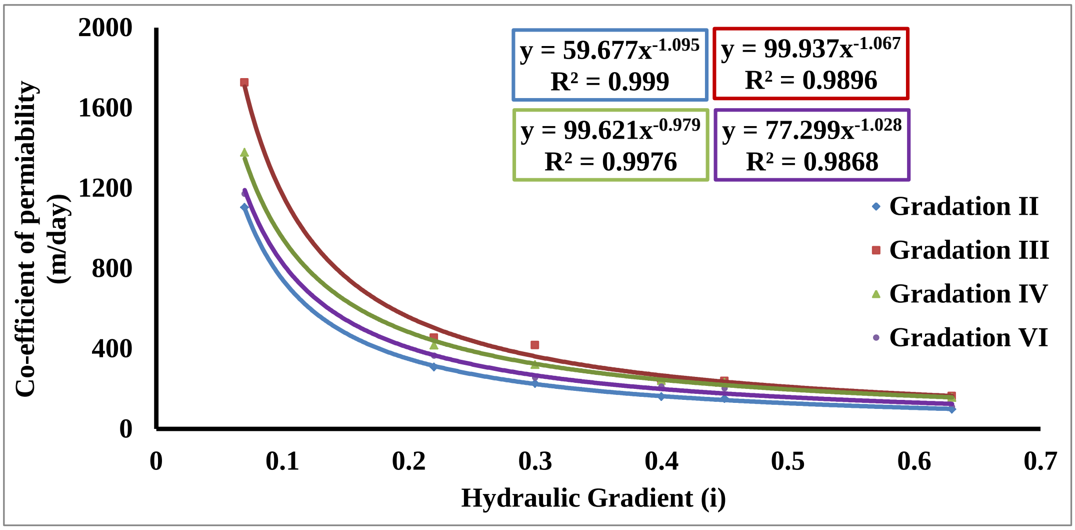

Fig. 6. Coefficient of horizontal permeability at different hydraulic gradient.

4.3. Porosity determination

Table 5 shows the summary of porosity and densities of four gradations that were considered in this study along with the actual densities that were obtained in the laboratory apparatus during the test. The porosity was calculated from equation (1). The values of porosity and permeability were obtained for different values of gradients from the experiment and for all gradients; permeability was increased with an increase in porosity (Figure 7).

$$\text{Porosity} = (\text{volume of voids} / \text{total volume}) \times 100 \quad (1)$$

Table 5. Porosity and densities of different gradations.

Gradations	Density from compaction test (g/cc)	Density achieved in lab model (g/cc)	Porosity (%)
Gradation II	2.305	2.32	9.5
Gradation III	2.34	2.351	8.7
Gradation VI	2.432	2.452	6.98
Gradation IV	2.441	2.44	6.24

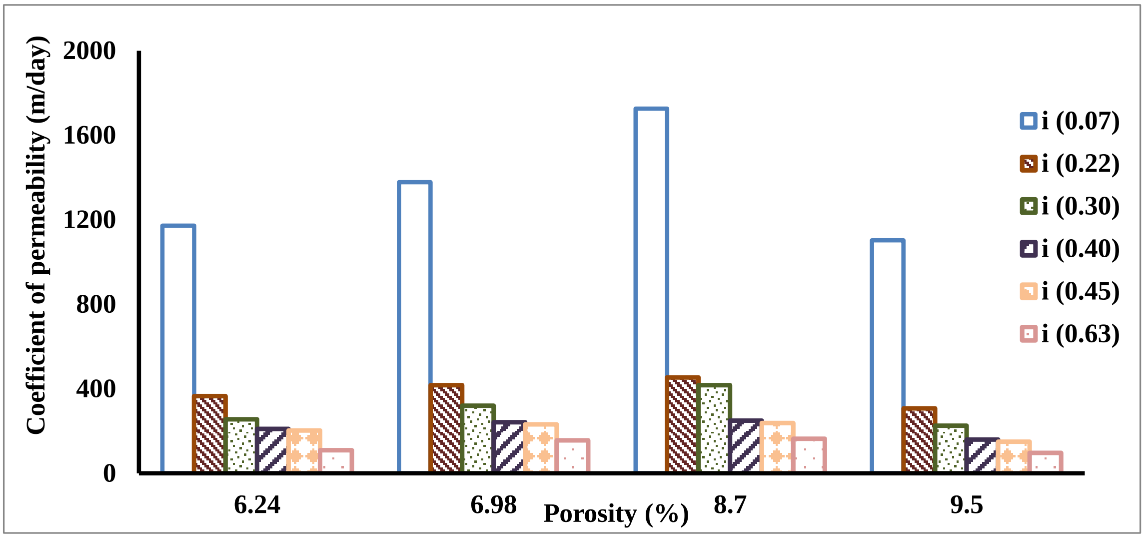

Fig. 7. Porosity versus coefficient of permeability of different gradations at different hydraulic gradient

5. Development of predictive equation

An effort was made in this study to develop a regression equation for predicting the horizontal coefficient of permeability from the fundamental properties of GSB materials. This equation will be useful to estimate the coefficient of permeability without performing the horizontal permeability test. Porosity (η), Co-efficient of uniformity (C_u) and hydraulic gradient (i) were selected as the fundamental properties. Co-efficient of uniformity (C_u) was considered as a parameter to represent the particle size distribution in an aggregate gradation which is defined as the ratio of D60 to D10. Porosity (η) was selected as it represents the volume of voids present in a compacted material, which contributes towards the permeability of the material. As the dependency of hydraulic gradient (i) on coefficient of permeability was identified in the study, it is also considered to predict *K*. Statistical Package for the Social Sciences (SPSS) version 20.0, statistical data analysis software was used to develop the multilinear regression equation (2). All the variables considered were found to be statistically significant at 89% level of significance.

$$K = 162.26 - 84.97 \times Cu + 2.62 \times Cu^2 + 3.12 \times \eta^2 + 95.311 \times (i)^{-1} \quad (2)$$

Table 6 shows the coefficients of independent variables along with their respective t-stat values inferring the statistical significance of the variables.

Table 6.Coefficient and statistical significance of the regression equation

Model	Unstandardized Coefficients		Standardized Coefficients	t-stat	Sigma
	B	Std. Error	Beta		
Constant	162.26	88.36		1.83	0.080
Cu	-84.97	28.80	-1.90	-2.95	0.001
Cu^2	2.622	0.82	1.92	3.17	0.001
P2	3.11	1.88	0.14	1.65	0.100
i-1	95.31	4.11	0.96	23.18	0.001

Correlation parameter R^2 is found to be high with a value of R^2=0.967 along with low biasness parameter (Se/Sy=0.18). Thus, this model can be used to predict the horizontal permeability of the GSB gradations from the fundamental material properties. However, this model is valid within the range of values given in Table7.

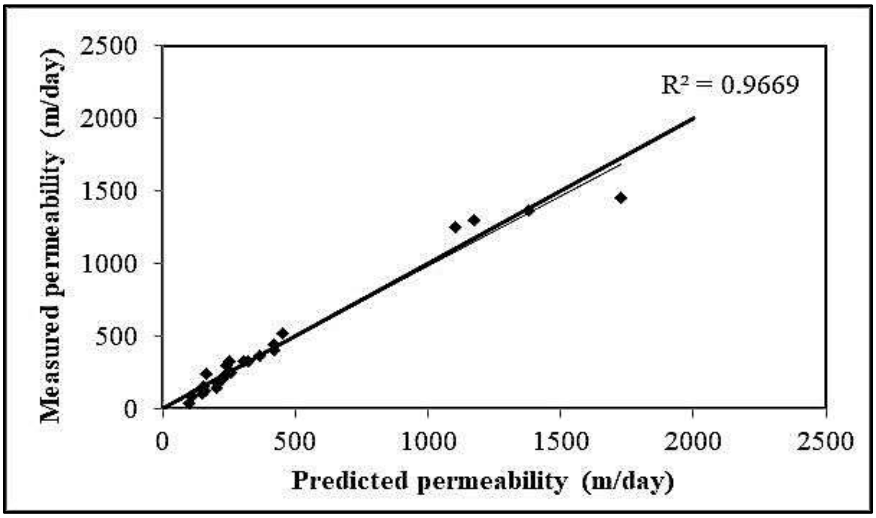

Fig. 8. Predicted permeability versus measured permeability.

Table 7. Valid range of parameters for the use of the regression model.

Parameter	Valid range
Co-efficient of uniformity (C_U)	4.84 to 23
Porosity (η)	6.24 to 9.5
Hydraulic gradient (i)	0.07 to 0.63

6. Conclusions

This research study was conducted to evaluate the strength and drainage properties of different gradations of GSB materials utilizing laboratory fabricated horizontal permeameter. The conclusions are summarized as:

- Among the four MoRTH gradations of GSB materials considered, Gradation III is observed to have better permeability with satisfactory strength requirements. From the limited study conducted, gradation III is considered as the best suitable gradation for drainage layers.
- All the GSB gradations considered in the present study satisfy the coefficient of permeability nearer to 300 m/day at i=0.2 to 0.3.
- From the horizontal permeability tests conducted at different gradients, it was observed that all combinations of mixes had higher values of permeability at lower hydraulic gradients and lower values of permeability at higher gradients.
- A predictive model for predicting the coefficient of permeability was developed by considering the hydraulic gradient, porosity and coefficient of uniformity of GSB mixtures as influencing variables. This will be useful for the designers to estimate the coefficient of permeability in absence of the testing facility.

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