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LABORATORY PERMEABILITY TESTING OF GRANULAR SLAG AND GRAVEL SUB BASE COURSES (GSB)

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Abstract:

Granular Sub Base Course (GSB) provided as one of the structural layer of pavements should also serve as an effective drainage layer. In India current guidelines recommend using natural sand, crushed gravel, stone or slag or combination of these, in the GSB layer. While the above combinations may fulfil the structural requirement, it is not clear whether they meet the minimum drainage requirements of 300 m/day as per AASHTO specifications.

This paper summarizes the laboratory permeability carried out on 1) Crushed stone aggregates and slag in different combinations with non plastic fines such as quarry dust and 2) Gravel- Aggregate combination in the ratio 60:40. The first combination was tried for Grade III requirements as per MORT&H specification (5th Revision) for High volume roads. The second combination was tried for Grade III requirements as per rural roads Manual, IRC SP 20, used for low volume roads in India.

The objective is to compare the permeability characteristics of GSB gradations prepared with different mixes in order to assess their ability to drain, based on the permeability criteria. Horizontal and vertical permeability were tested in the laboratory for these GSB mixes and the results have been reported.

From the study it is observed that while all the combinations of crushed stone – slag mixes meet the minimum permeability criteria in the horizontal as well as vertical directions, 100% granulated steel slag (GLDS) does not meet the requirement in the vertical direction. Also while the Gravel – Aggregate combination (60:40) just meets the minimum permeability requirement in the horizontal direction, there is negligible discharge in the vertical direction.

Keywords: Permeability, Quarry dust, Slag, Gravel, Horizontal, Vertical

1. Introduction

Granular Sub base course (GSB) is an important structural layer as well as the drainage layer in pavements. Most of the pavements in India fail prematurely mainly due to ineffective functioning of this drainage layer. The current guidelines, Ministry of Road Transport & Highways, MORT&H (5th Revision)[1] recommends 6 gradations for using in the GSB layer which are mostly close graded (with more fines passing 2.36mm sieve) compared to AASHTO specifications[2]. It also recommends using natural sand, crushed gravel / stone or slag or their combinations in the GSB layer. Although these combinations are recommended in the ministry, such combinations are seldom used in actual practice. It is not clear whether these gradations and the combination of materials recommended, fulfil the minimum permeability criteria of 300 m/day (AASHTO specification) particularly when the material combination includes gravel with fines having plasticity. Also slag being available as a waste product in the iron and steel manufacturing plants may be best used in combinations in the GSB layer , if it fulfils both the strength requirement as well as drainage requirement.

Hence in the present study an attempt is made to study the permeability characteristics of

1) different combinations of crushed stone aggregate and slag with quarry dust for fines and 2) Gravel - aggregate combination with 60% gravel and 40% crushed aggregates.

2. Objectives

1. To compare the horizontal and vertical permeability of different combinations of Aggregate slag mixes and Gravel – Aggregate mixes (60:40)

2. To identify the most optimum combination based on the minimum permeability requirement of 300 m/day as per AASHTO specifications.

3. Experimental Investigations

3.1 Materials & Methods

1. Aggregates were collected from Tippagondanahalli quarry near Magadi in Bangalore District.
2. Gravel was obtained from Jigani, Bangalore and
3. Air Cooled Blast Furnace slag (ABFS) and Granulated Linz Donawitz Steel slag (GLDS) were procured from M/s Jindal Steel Works, Bellary, Karnataka

Rothfutch method of proportioning was adopted for the crushed stone aggregates (CA) and slag combinations to meet the Grade III requirements for GSB as mentioned in the MORT&H specifications (Table 1)
The following combinations were tried

i) CA : GLDS : ABFS…..50 : 25 : 25
ii) CA : GLDS : ABFS…..30 : 35 : 35
iii) 100% GLDS

Rothfutch method of proportioning was also adopted for the Gravel – Aggregate combination in 60:40 proportions, to meet the Grade III requirement as per IRC SP 20. Since Grade III being close graded is commonly provided for rural roads. The same was adopted in the present study also.
The physical properties of the aggregates tested are shown in Table 5.

3.2 Test Set up

Two Test approaches were planned in the Laboratory

1) Horizontal Permeability Test and
2) Vertical Permeability Test

3.2 Horizontal Permeability Test– was conducted in the laboratory using a horizontal permeameter[4] mould of size 0.6m X 0.3m X 0.3m specifically fabricated to accommodate GSB gradations with aggregates more than 26.5mm size.
Two perforated brass plates are provided at a distance of 0.15m from the inlet and outlet end of the flow providing an effective specimen space of 0.3m X 0.3m X 0.3m. Once the GSB mix is compacted in layers in the mould to get the required density, it is closed with a cover on top with rubber gasket of 6mm thickness to make it leak proof.
Permeability test was conducted at 3 hydraulic gradients for the different combinations of the GSB mixes after subjecting it to saturation. Permeability for the different gradations were determined by Darcy's equation.

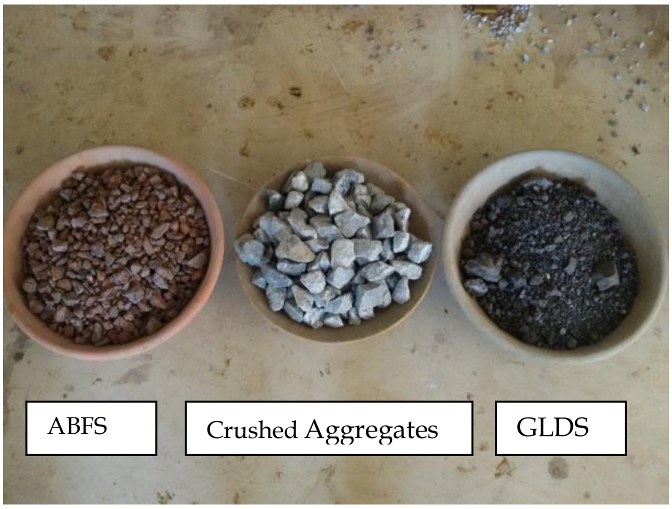

Figure 1: Slag and Crushed Aggregates selected for the Study

Figure 2: Specimen compaction in progress – Horizontal Permeability Test

Figure 3: Specimen compaction in progress

Figure 4: Horizontal permeability Test in progress

3.3 Vertical Permeability Test – was conducted in the laboratory using a Vertical permeameter[4] mould of 0.3m diameter and a height of 0.3m Two perforated brass plates are provided at a distance of 0.075m from the inlet and outlet end of the flow providing an effective specimen space of 0.3m dia and a height of 0.15m. Once the GSB mix is compacted in layers in the mould, it is closed with a cover on top with rubber gasket of 6mm thickness to make it seal proof. The entire setup was ensured leak proof during the progress of test using M.Seal on all the welded portions. Permeability test was conducted at different hydraulic gradients for all the six gradations recommended in MORT&H after subjecting it to saturation. Permeability for the different combinations of GSB mixes was determined by Darcy's equation.

Figure 5: Vertical permeability Test in progress

Table 1: – Grading of Granular Sub-base materials as per Table 400-1 of MORT&H (5th Revision)

IS Sieve Size	Grade III Percent by Weight Passing IS Sieve
75	100
53	100
26.5	55-75
9.5	…
4.75	10-30
2.36	…
0.85	…
0.425	…
0.075	<5

Table 2: Gradations of the Slag and Gravel used in the Present Study

SIEVE SIZES in mm	Blast Furnace Slag ABFS % passing	Steel slag GLDS % passing	Gravel A
75	100	100	100
53	100	100	100
26.5	93.1	76.88	100
9.5	1.6	66.05	-
4.75	0.05	35.3	70.9
2.36	0	25.13	60.7
0.425	0	13.7	45.8
0.075	0	5.15	29.1

Table 3: Components of Slag (Source: JSW, Bellary)

Components	CaO	MgO	SiO2	Al2O3	Fe2O3
BF Slag	41	6	35	14	1
LD Slag	38	9	13	3	26

Table 4: Physical properties of Slag

Property	ABFS	GLDS
Impact Test	27%	26%
Liquid Limit and Plastic Limit	Non plastic	Non plastic
Specific Gravity	2.26	2.66
Water absorption	3.93	3.58
CBR	19%	38%

Table 5: Basic Physical Properties of Aggregates

Description of tests conducted	Test Method	Test Result	Requirements as per MORT&H 5th Revision
Aggregate impact value (%)	IS 2386 (Part-4)	27.6	Maximum 40%
Water absorption (%)	IS 2386 (Part-5)	0.43	Maximum 2 %
Atterberg Limits	IS 2720 (Part-5)	Non Plastic	LL-25% maximum PL-6% maximum

Table 6: Properties of Granular Slag Combinations

Property	**30% (aggregate)+35%(GLDS)+35%(ABFS)**	**50% (aggregate)+25%(GLDS)+25%(ABFS)**
Modified Compaction Test OMC (%), MDD (gm/cc)	OMC - 3.0% MDD – 2.15	OMC - 2.0% MDD – 2.12
CBR (%)	62	69

Table 7: Physical properties of Gravel

Property	
Wet Sieve Analysis	
Gravel (%)	29
Sand (%)	38
Fines (%)	33
Atterberg Limits	
Liquid Limit (%)	23
Plastic Limit (%)	15
Plasticity Index (%)	8
Compaction Test	
Maximum Dry Density (g/cc)	1.97
Optimum Moisture Content (%)	11
CBR	15%

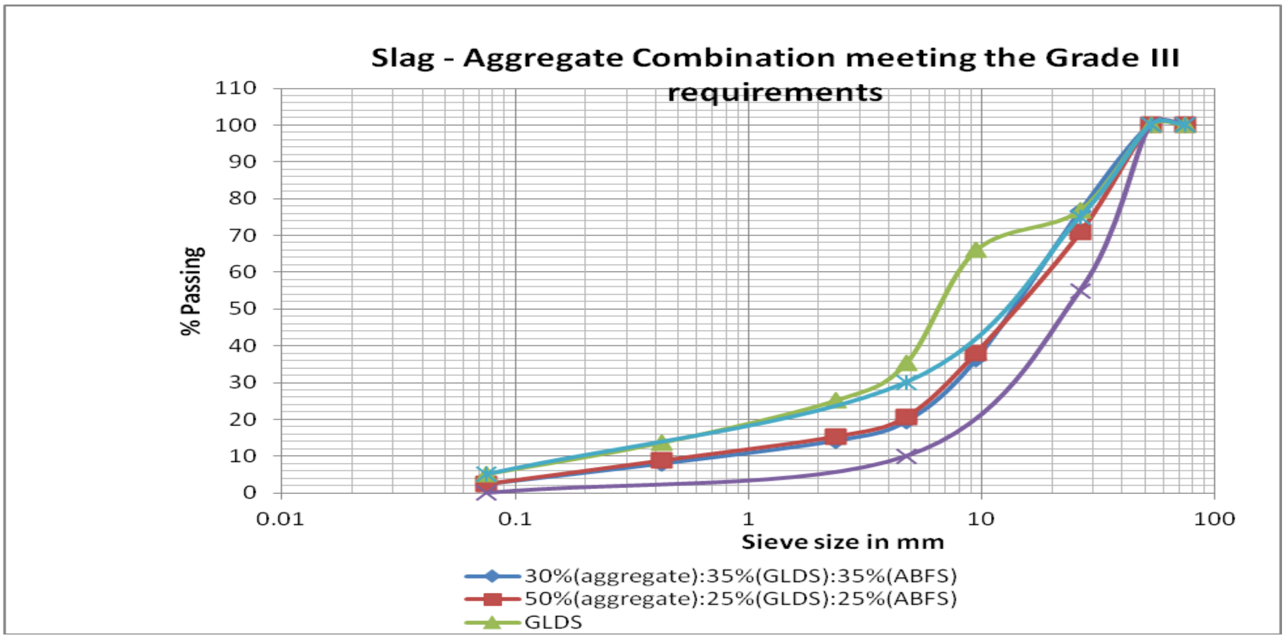

Figure 6: Gradation curves of Slag Aggregate combinations meeting Grade III requirements

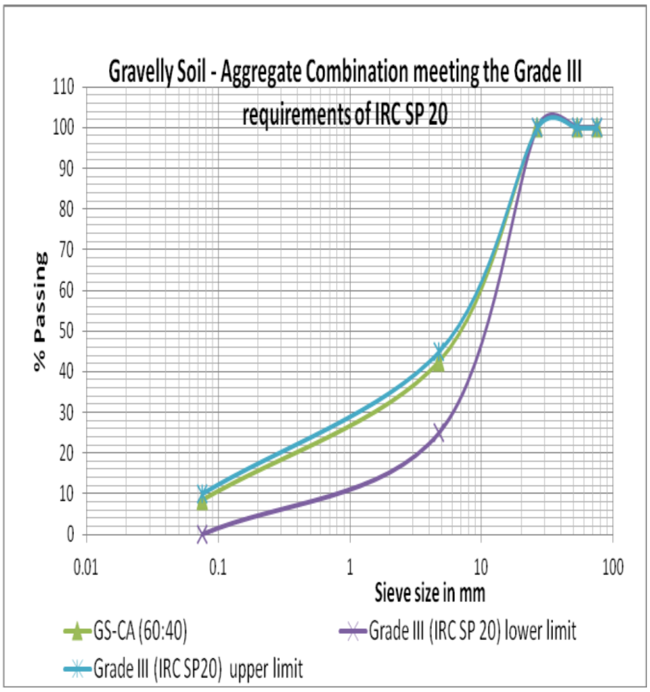

Figure 7: Gravelly soil and aggregate combination meeting the Grade III requirements (IRC SP 20)

Table 9: Results of Vertical permeability at different hydraulic Gradients

Vertical permeability, k_{20}, cm/s (m/day)			
GSB Gradation	**Hydraulic gradient**		
	0.025	**0.04**	**0.05**
CA:ABFS:GLDS -50:25:25	0.67 (579)	0.63 (544)	0.72 (622)
CA:ABFS:GLDS -30:35:35	0.79 (683)	0.58 (501)	0.58 (501)
only GLDS	No Traceable discharge		
Crushed aggregates	0.75 (648)	0.89 (769)	0.87 (752)

Table 8: Horizontal Permeability of various Granular slag and aggregate combinations

Horizontal permeability, k_{20}, cm/s (m/day)			
GSB Gradation	**Hydraulic gradient**		
	0.025	**0.04**	**0.05**
CA:ABFS:GLDS -50:25:25	0.73 (631)	0.79 (688)	0.88 (760)
CA:ABFS:GLDS -30:35:35	0.90 (775)	0.89 (766)	0.87 (748)
only GLDS	0.82 (709)	0.82 (709)	0.81 (700)
Crushed aggregates	0.89 (772)	0.80 (691)	0.81 (700)

Table 10: Permeability values of Gravel aggregate combination

60% gravel + 40% aggregate meeting Grade III, as per IRC Sp 20			
Permeability k_{20}, cm/s (m/day)	Hydraulic gradient		
	0.025	0.04	0.05
Horizontal	0.37 (316)	0.41 (350)	0.43 (375)
Vertical	No traceable discharge		

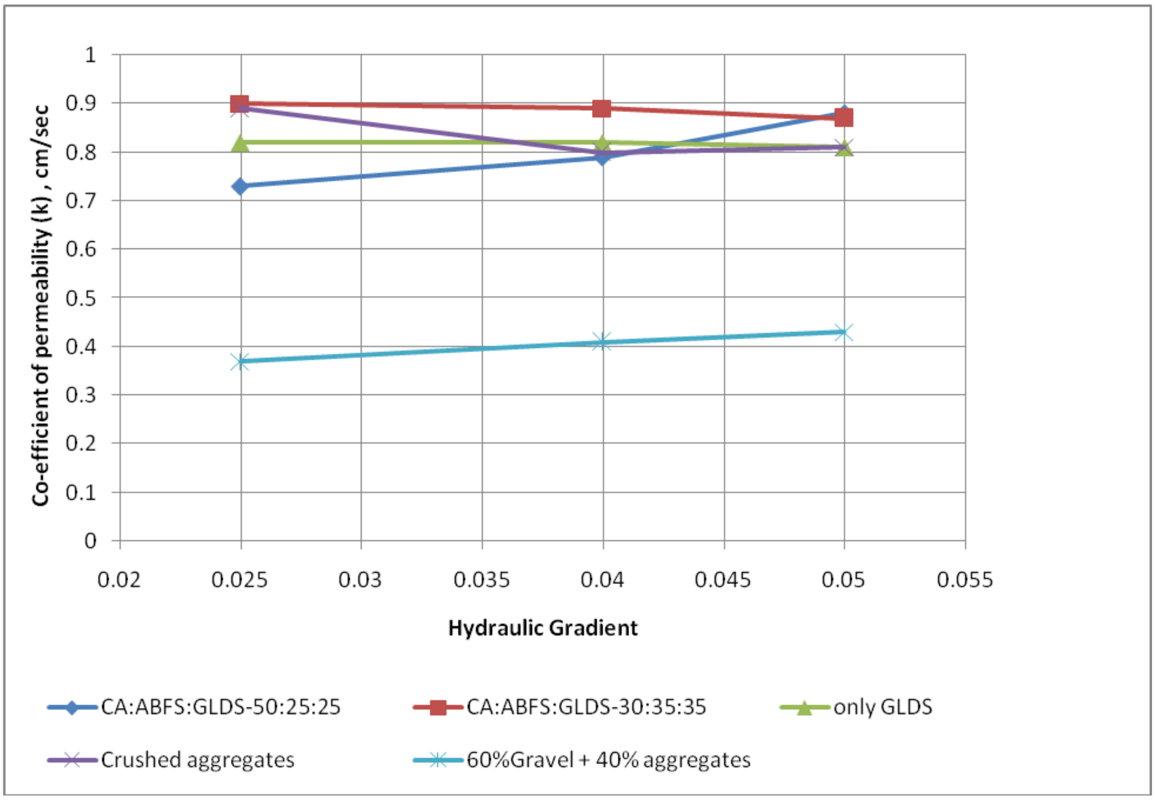

Figure 8: Horizontal Permeability with hydraulic gradients for various combinations

4 Discussions

i) The horizontal permeability values (Table 8) obtained for the different combinations of Slag and aggregates such as CA:ABFS:GLDS – 50:25:25, (50% slag replacement) CA:ABFS:GLDS – 30:35:35 (70% slag replacement) and only GLDS (100% slag), show values almost equal to or even greater compared to the horizontal permeability values obtained for crushed aggregates meeting grade III requirements.

ii) The vertical permeability values (Table 9) obtained for the above combinations of slag and aggregates is lesser compared to that obtained for crushed aggregates meeting grade III requirements.

This may be due to stratification and greater segregation of particles along the vertical flow that results in possible settling of fines at the bottom, and hindering the flow.

iii) Vertical permeability Tests on GLDS (100% slag) also showed negligible discharge at all gradients.

This may be because in addition to the stratification and segregation of particles along the vertical flow, the cementing action of the granulated steel slag which is hydraulic bound in nature may result in an impervious matrix. Further, it was also observed that during compaction there was break down of particles under the impact of the rammer, which could further speed up the self binding process.

iv) Permeability tests results on the gravel aggregate combination (Gravel:aggregate-60:40) , as per the requirements of rural roads specification IRC SP:20 from Table 10 indicates that while the horizontal permeability of the gravel aggregate combination meets the minimum permeability criteria of 300 m/day, there is negligible discharge in the vertical direction.

5 Conclusions

The horizontal permeability values obtained for 50% and 70% slag in the slag- aggregate combinations meet the minimum permeability criteria; hence can be tried for use in the GSB layer. However there is a need to check the long term permeable characteristics of these slag – Aggregate combinations as their permeability may reduce gradually in the due course of time due to cementing action of the slag.

The combination of gravel and aggregates in 60:40 proportions were just meeting the minimum threshold for permeability only in the horizontal direction. Hence care should be taken in selecting the right combination of crushed aggregates, gravel and moorum , for using it as GSB in low volume roads, as it may not meet the minimum desired permeability criteria and hence may not be effective in draining.

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