FLOOD CONTROL IN BANGLORE CITY FOR SUSTAINABLE DEVELOPMENT: A CASE STUDY

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ABSTRACT

Bengaluru, the state capital of Karnataka undergoes flooding every year during monsoon. The reason for floods is due to depletion in storage capacity of water bodies (lakes). The depletion is due to the deposition of enormous amount of sediment at the bottom of the lakes. One of the solutions for this problem would be De-Siltation of lakes (Removal of sediments). De-siltation of a lake can be carried out by a process called Dredging. However, huge quantity of dredged material (sediments) is resulted from this process which is generally considered as waste and requires special handling. Further, dredged sediment (DS) cannot be used for construction because it exhibits high water content, high compressibility and low strength. This paper aims to reuse such DS as a sustainable material for construction activities in an economical way. To justify this, Hebbal Lake has been selected as a case study, which is one of the biggest lake in Bengaluru city. However, in the present study, attempts were made to stabilize the DS for uses such as embankment construction, subgrade construction and filling material. DS is stabilized using Granite Dust (GD) and Air-cooled Blast Furnace Slag (ABS) respectively, to improve its geophysical properties. Also, the stabilized sediments are characterized for its properties and it is concluded that these sediments after stabilization satisfy the required properties of construction material.

Keywords: Air Cooled Blast Furnace Slag, Characterization, Dredged Sediment, Granite Dust, Stabilisation.

1. INTRODUCTION

Flooding occurs due to overflow of water from reservoirs, lakes, rivers and seas, in which water overtops or breaks levels. One of the reasons for the flooding is due to decrease in storage capacity of lake. Depletion in the capacity of lake is due to the deposition of enormous amount of silt at the bottom of lake called sedimentation. One possible solution for this problem can be De-Siltation (removal of sediment) of the lakes. De-siltation of a lake can be done by a process called as dredging [4].

Dredging is the process of excavating the sediments from the bed of a sea, river, lake, reservoir, pond or a lagoon, and handling and transporting these sediments to the sites of interest [2], [5], [6], [8], [9], [22], [23], [26], [27], [28], [29]. Dredging not only deals with clearing the water space but also, the polluting toxicants. Thus, it helps in taking care of the marine ecosystem [3], [21], [22]. One of the applications of dredging is flood control, which can be achieved by increasing the storage capacity of lake, reservoir or a river. Further, dredging results in a huge quantity of sediments, requiring a large area to dump the same which can be a problem in a city like Bengaluru. However, dredging cost can be converted to profit, if these DS can be used for constructional activities.

Earlier, researchers have utilized the dredged sediments for beneficial purposes, but these studies were limited to laboratory scale [9], [5] and field implementation of their studies has not been discussed. Some researchers have done detailed investigation on the treated dredged sediments as fill material in transportation infrastructure related projects, by conducting a series of laboratory tests on treated dredged sediments [8], [2], [9]. Various tests conducted on stabilized dredge sediments reveal that after treatment, the material becomes inorganic low plastic silt [8] whereas the untreated sediments are classified as organic clay/silt of medium to high plasticity.

Researchers have also used wide variety of stabilizing agents (Viz., cement, lime, fly-ash etc) for stabilizing the dredged material [9], [5], [2], [8]. Since the dredged material has a general characteristic of having high water holding capacity, the usual stabilizing agents are pozzolanic in nature which makes the dredged material workable by the process called hydration. The common pozzolanic agents reported by the earlier researchers are cement, lime and fly ash.

The stabilization of dredged material by using a combination of pozzolanic agents such as lime, cement kiln dust, high alkali, slag cements and fly ash has also been reported by researchers [6], [7], [24], [8] and it has been concluded that the usage of industrial bi-products in SDM blends is possible to undertake large-scale fill constructions which are sustainable, cost-effective, and environmentally protective of human health and the environment.

The detailed study on the soil improvement using the vacuum preloading method was reported by [28] wherein, it has been observed that vacuum method of dewatering is an effective technique for consolidating very soft, highly compressible clayey soils, especially when large area needs to be treated. This concept may be useful for improvement of highly compressible dredged material with very high-water content, for land reclamation purposes.

It must be noted that the biggest consideration in using the dredged material for beneficial use is its environmental impact and sustainable development. However, stabilization of the dredged material is one of the methods by which dredged material can be used as fill material for land reclamation and road works. But, the stabilizing agents used by earlier researchers are carbon rich compounds which in turn create long term environmental hazards. Hence, there is a need to explore new methodologies and materials (viz., construction debris, slag based micro-fine cements and industrial bi-products) for dredged material stabilization, which are environment friendly.

2. MATERIALS

Following materials have been used for the present study:

2.1 Dredged Sediments (DS)

The DS used were obtained from Hebbal Lake, Bengaluru. They are obtained by the process of dredging at a depth of 2-3m below the water level. The samples collected from this depth are highly disturbed in nature and were blackish in colour with undesirable smell. Fig 2.1. shows the location of sediment extracted.

Figure. 2.1: Location of sediment extracted (Source: Google map)

2.2 Air-Cooled Blast Furnace Slag (ABS)

When iron ore or iron pellets and flux are melted together in a blast furnace, the new compound formed is called blast furnace slag and is considered to be a waste material. Blast furnace slag formed is in a molten state and is cooled at atmospheric temperature. Hence, it is termed as Air-Cooled Blast Furnace Slag and the same has been used as stabilizer in the present study. ABS used in the present study is collected from Hosapet Steel Limited, which is a world class steel plant located at Ginigeri in the Koppal district of northern Karnataka, India

2.3 Granite Dust (GD)

Granite belongs to igneous rock family and Granite dust is the fine powder obtained during sawing process of granite rock. It is considered to be a waste material and is generally not used for any engineering purpose. Further, disposal of GD has become an environmental issue. Such GD has been used as a stabilizer in the present study. The granite dust used in the present study is obtained from Jigani, Anekal Taluk Bengaluru Dist. Karnataka. Generally, the density of the granite is between 2.65 to 2.75 g/cm^3 and compressive strength will be greater than 200MPa.

3. METHEDOLOGY

The DS and stabilizers obtained are then characterized to know the various properties and their behaviour in different environmental conditions. Stabilization of DS is done by replacing GD and ABS in suitable quantities respectively. The sequence of which is explained in the following sections.

3.1 Physical Characterization

To know the various physical properties of DS and stabilizers the physical characterization is carried out.

3.1.1 Moisture content

Natural water content of DS and stabilizers is determined by oven drying technique. The test is conducted as per the guidelines of [12]. The results of which is given in table 4.1, table 4.5 and table 4.8 respectively.

3.1.2 Specific Gravity

The specific gravity of DS and stabilizers are determined by pycnometer method. The test procedure is followed as per guidelines of [14]. The results of which is tabulated in table 4.1, table 4.5 and table 4.8 respectively.

3.1.3 Consistency limits

Consistency limits such as liquid limit W_L, plastic limit W_P of DS and stabilizers are determined according to guidelines of [17]. The result of which are tabulated in table 4.1, table 4.5 and table 4.8 respectively.

3.1.4 Gradational Characteristics

THE PARTICLE SIZE DISTRIBUTION CHARACTERISTICS OF THE DS AND STABILIZERS WERE DETERMINED BY CONDUCTING THE GRAIN SIZE ANALYSIS TEST AS PER [15]. THE RESULT OF THE SAME ARE LISTED IN TABLE 4.1, TABLE 4.5 AND TABLE 4.8 RESPECTIVELY. ALSO, THE GRAIN SIZE DISTRIBUTION CURVE FOR DS AND GD ARE SHOWN IN FIG 4.1 AND FIG 4.4 RESPECTIVELY.

3.1.5 Organic content test

The presence of organic content in the DS, ABS and GD are determined by conducting loss on ignition test as per the guidelines of [1]. The result of which are tabulated in table 4.1, table 4.5 and table 4.8 respectively.

3.1.6 Free Swell Index

The swelling potential of soil is estimated by free swell index, the same is determined for DS as per the guidelines of [16]. The result of the same are tabulated in table 4.1, table 4.5 and table 4.8 respectively.

3.2 Chemical Characterization

To know the various chemical properties of DS and stabilizers the chemical characterization is carried out. Further, by knowing the chemical properties of DS and stabilizer it is possible to understand the chemical reactivity between DS and stabilizers when are mixed together.

3.2.1 pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS)

The pH of DS and stabilizers are determined as per [20] by using digital pH meter (Elico Pvt Ltd. Make, model L1-120) The pH value was established corresponding to liquid to solid ratio, L/S, as 20.

The same instrument with automatic temperature compensator (corresponding to 25^0C) was employed for measuring EC [11] and TDS of DS and stabilizer with L/S ratio of 20. The results of which are presented in table 4.2a, table 4.6a and table 4.9a respectively.

3.2.2 X-ray Fluorescence (XRF)

The chemical composition of DS and stabilizers in their oxide form was determined by employing XRF instrument (Philips 1410, Holland). The results of the same is tabulated in table 4.2b, table 4.6b and table 4.9b respectively.

3.2.3 Chloride, Hardness and Sulphates

The chloride, hardness and sulphates for DS are determined as per the guidelines of [13]. The results are tabulated in table 4.2a, table 4.6a and table 4.9a respectively.

3.3 Geotechnical Characterization

Geotechnical Characterization of DS and stabilizers are carried out to determine the strength properties. The result obtained from these tests are required to know the strength characteristics of DS and stabilizers. These are very essential to decide the applications for which these materials can be used.

3.3.1 Compaction test

The optimum moisture content and maximum dry density are determined by conducting light compaction test. The test procedure is followed as per [18] where water content is added to the soil in the percentage increments and corresponding densities are determined. The results obtained are tabulated in table 4.3 and table 4.7 respectively.

3.3.2 California Bearing Ratio (CBR) test

It is one of the important parameters for construction of highways and runways. The test is conducted as per the guidelines of [19]. According to the IS code norms, the CBR value at 2.5mm and 5mm penetration are determined for a given sample. The penetration value at 2.5mm should be higher than 5mm penetration and the same is accounted as CBR value of the sample. The CBR test is conducted for DS and stabilizers the results are tabulated in table 4.3 and table 4.7 respectively.

3.3.3 Unconfined Compression (UCC) test

The compressive strength of soil is determined by conducting UCC test. The test procedure is followed as per [10]. The DS is tested for UCC and the results of which are tabulated in in table 4.3 and table 4.7 respectively.

4. RESULTS AND DISCUSSIONS

The results of detailed Physical, Chemical and Geotechnical Characterization are as given below:

4.1 Dredged Sediment Characteristics

Following are the various characteristics of DS

Table 4.1: Physical Characteristics of dredged sediment

Name	W %	% Fraction			C_u	C_c	IS Classification	G	OC %	consistency Limit			FSI %
		Gravel	Sand	Silt& clay						W_L	W_P	I_p	
DS	29	0	89.8	10.2	8.08	0.68	SL-SP	2.48	6.34	34	24	10	12.8

W=water content, G=specific gravity, OC =organic content, W_L=liquid limit, W_P=plastic limit, I_P=plasticity index, FSI= free swell index, C_u=coefficient of uniformity, C_c=coefficient of curvature.

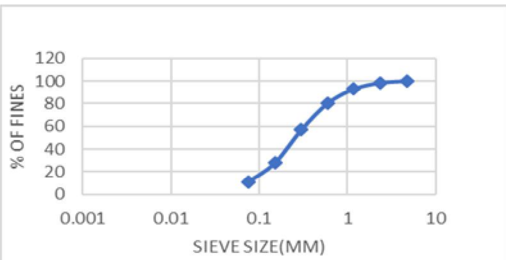

Figure 4.1: Particle size distribution curve of dredged sediment

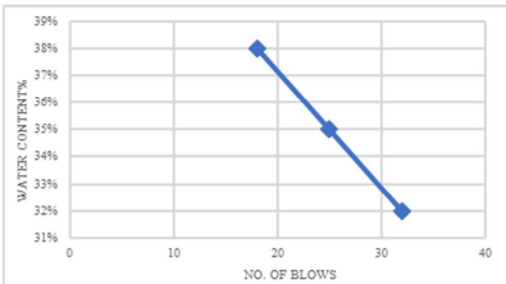

Figure 4.2: Liquid limit curve of dredged sediment

Table 4.2a: Chemical Properties of dredged sediment

Name	pH	EC (Microohms/Cm)	TDS µs/Ppm	Chloride (Ppm)	Water Soluble Sulphates (So4) (%By Weight)	TH Ppm	CH Ppm
DS	6.9	8.2	570	<0.010	<0.05	94	49

TH= Total hardness, Ch=Calcium hardness

Table 4.2b: chemical composition of dredged sediment (XRF)

	Chemical composition (% by weight)									
Name	SiO_2	Al_2O_3	K_2O	Na_2O	CaO	Fe_2O_3	MgO	TiO_2	P_2O_5	MnO
DS	76.95	12.82	1.83	0.43	1.22	4.33	0.56	0.20	<0.10	0.052

Table 4.3: Geotechnical Properties of dredged sediment

Name	MDD (g/cc)	OMC (%)	CBR (%)		UCC (kN/m^2)
			soaked	Un-soaked	
DS	1.82	17.10	1.09	2.31	7.9

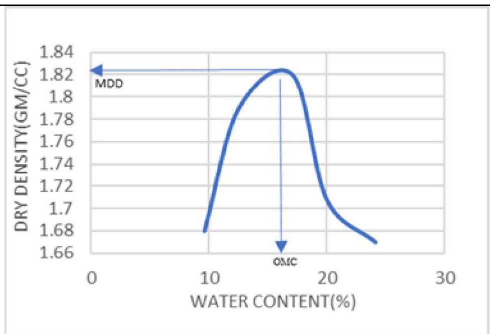

Figure 4.3: Compaction curve for dredged sediment

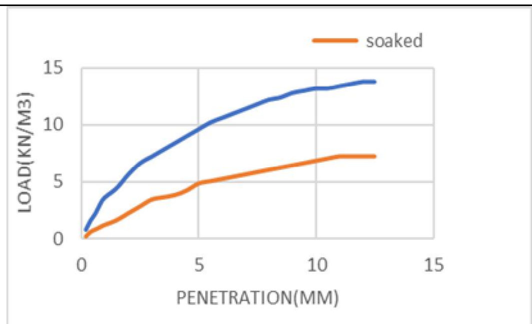

Figure 4.4: Load-penetration curve for dredged sediment

It is quite evident from the results obtained from DS that these sediments are well graded sandy in nature with less plasticity. The sediments have less water holding capacity and have negligible organic content (table 4.1). Further, the DS have FSI of about 13% which exhibits less swelling and shrinkage with presence or absence of water. However, this character may be due to presence of less number of fines in the sediments.

Moreover, Hebbal lake being a storage for drain water and these sediments being present in the water body for longer duration, there is a possibility that these sediments could be contaminated. Further, to verify this a detailed chemical analysis was carried out on these sediments. It was evident from chemical characterization that DS are not contaminated. However, TDS and hardness of DS was found to be on a higher side and pH of sediments was slightly acidic in nature (table 4.2a and 4.2b). Geotechnical characterization on these sediments revealed that these sediments possess strength lesser than (table 4.3) required for construction of subgrade or embankment which was specified by [25]. This situation of DS will call for the stabilization.

Stabilization of DS is enhancing its properties which are not as per the standards. However, enhancement of properties can be achieved by adding suitable additives to the DS. In the present study, Granite Dust (GD) and Air-cooled Blast Furnace Slag (ABS) are used as additives. GD and ABS are selected as additives because these are bi-products obtained in huge quantity during granite cutting and manufacturing of iron respectively. Moreover, these industries are facing tremendous problem in disposing these bi-products. However, an attempt has been made to use such bi-products as a stabilizer to stabilize the DS and to make it suitable for construction.
DS, a waste material obtained during cleaning up of lakes is mixed in suitable quantity with a bi-product such as **GD or ABS which are also considered to be a waste material** thus**,** making a useful construction material **enhancing the sustainable growth of the country.**
Further, properties of GD and ABS are studied in detail before being used as a stabilizer and the same are listed in the further sections.

4.2 Granite Dust Characteristics

Table 4.5: Physical properties of granite dust

Name	W %	% Fraction			C_u	C_c	IS Classification	G	OC %	Consistency Limit			FSI %
		Gravel	Sand	Silt& clay						W_L	W_P	I_P	
GD	2.16	0	100	0	6.2	1.8	Well graded sandy type	2.8	1.16	Non-Plastic			0

W=water content, G=specific gravity, OC =organic content, W_L=liquid limit, W_P=plastic limit, I_P=plasticity index, FSI= free swell index, C_u=coefficient of uniformity, C_c=coefficient of curvature.

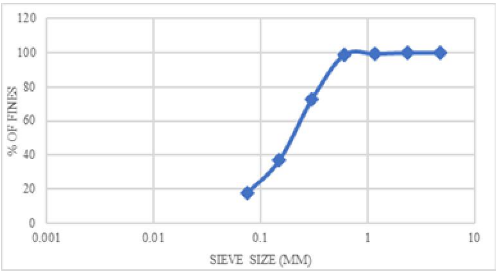

Figure 4.5: Particle size distribution curve of granite dust

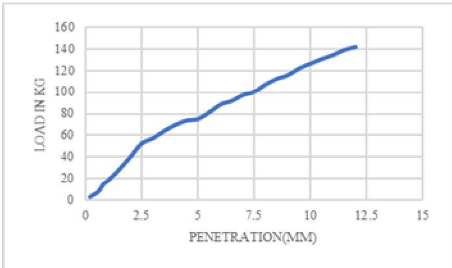

Figure4.6: Load-penetration curve of granite dust

Table 4.6a: Chemical Properties of Granite Dust

Name	pH	EC (Micro ohms/Cm)	TDS µs/Ppm	Chloride (Ppm)	Water Soluble Sulphates (So4) (%By Weight)	TH Ppm	CH Ppm
GD	7.9	345	221	<0.010	0.1	145	98

TH= Total hardness, Ch=Calcium hardness

Table 4.6b: Chemical composition of granite dust (XRF)

Name	Chemical composition (% by weight)										
	SiO_2	Al_2O_3	K_2O	Na_2O	CaO	FeO	Fe_2O_3	MgO	TiO_2	P_2O_5	MnO
GD	72.04	14.42	4.12	3.69	1.82	1.68	1.22	0.71	0.50	0.12	0.05

Table 4.7: Geotechnical properties of granite dust

Name	MDD (g/cc)	OMC (%)	CBR (un-soaked) (%)
GD	1.90	12.82	16.89

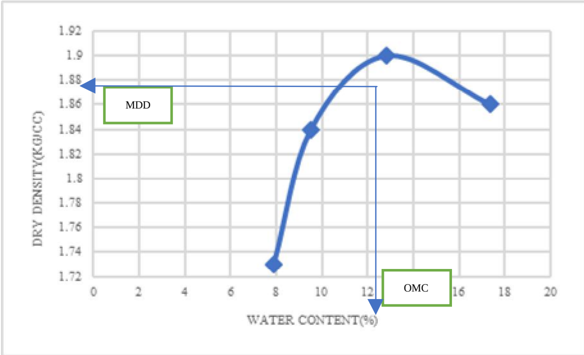

Figure 4.7: Compaction curve of granite dust

It has been observed from characterization data that Granite Dust is well graded sandy in nature with zero plasticity and less water holding capacity. The specific gravity is at higher side with less or no organic content and no swelling potential. Further, chemical composition of GD reveals that it contains maximum proportion of silica and alumina which are essential to enhance the strength properties of sediment. Also, it contains considerable quantity of iron (FeO, Fe_2O_3) because of which higher specific gravity of GD is observed. However, geotechnical properties of GD are quite promising and it is expected to enhance the strength characteristics of DS when mixed with GD.

4.3 Air-cooled Blast Furnace Slag Characteristics

Table 4.8: Physical properties of air cooled blast furnace slag

Name	W %	% Fraction			C_u	C_c	IS Classification	G	OC %	Consistency Limit			FSI %
		Gravel	Sand	Silt& clay						W_l	W_p	I_p	
ABS	2.6	0	100	0	5.1	11.9	Well graded sandy type	3.15	1.45	Non-Plastic			0

Table 4.9a: Chemical properties of air cooled blast furnace slag

Name	pH	EC (Micro ohms/Cm)	TDS µs/Ppm	Chloride (Ppm)	Water Soluble Sulphates(So_4) (%By Weight)
ABS	11.2	576	357	<0.010	0.30

Table 4.9b: Chemical composition of air cooled blast furnace slag.

Name	Chemical composition (% by weight)					
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	MnO
ABS	19.35	2.01	24.35	43.95	4.36	1.48

Characterization of ABS reveals that ABS is well graded sandy in nature with zero plasticity and less water holding capacity. The specific gravity is at higher side with less or no organic content and no swelling potential. Further, chemical composition of GD reveals that it contains maximum proportion of iron content followed by calcium and silica. Due to presence of high content of iron, specific gravity of ABS is very high. However, since iron, calcium and silica form the maximum proportion of ABS, it is best suitable material for stabilization.

4.4 Stabilization/Replacement of DS with GD

To enhance the properties of DS, the DS is replaced in suitable proportion with GD. The replacing proportion of DS with GD are selected based on trial and error method until mixture (DS+GD) achieves maximum strength. The Replacing proportion is as shown in table 4.10.

Table 4.10: Replacing proportion of GD with DS

Sl No.	Replacement Proportion
1	90%DS +10% GD
2	80%DS +20% GD
3	70%DS +30% GD
4	60%DS +40% GD

GD replaced DS with replacement ratios of 10%, 20%, 30% and 40%. For each replacement ratio, both physical and geotechnical properties are determined and compared to evaluate optimum replacement ratio for which it exhibits maximum strength and the same has been tabulated in the table 4.11. Also, Fig 4.8 and Fig 4.9 show variation of strength of DS when replaced with GD. It has been observed that, the strength of DS increased with increase in replacement ratio up to 30% replacement of GD, further replacement of DS with GD showed decrease in strength of DS.

Table 4.11: Test result after stabilisation/replacement of DS with GD

%Replacement	W_L (%)	W_P (%)	MDD (g/cc)	OMC (%)	CBR @ 2.5mm penetration	UCC (kN/m^2)
40	24.34	7.69	2.04	10.86	11.18	14.16
30	27.77	9.09	2.16	12.32	11.94	14.38
20	29.51	11.11	1.96	13.21	8.88	12.99
10	30.30	14.28	1.88	15.35	4.11	11.91

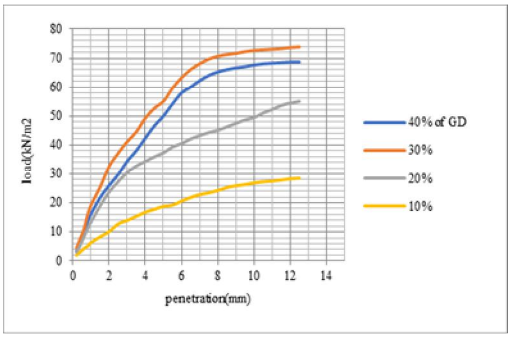

Figure 4.8: load-penetration curve for different proprtion of GD with DS

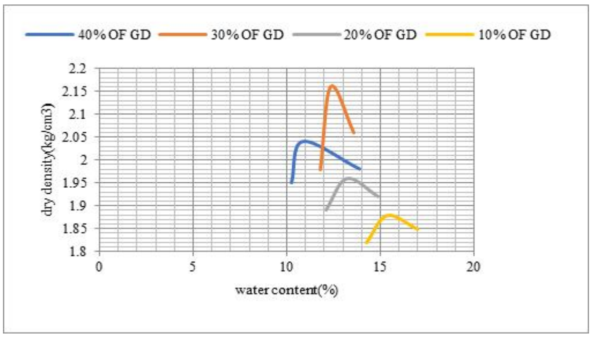

Figure 4.9: variation of compaction curve for replacement of GD to DS

4.5 Stabilization/Replacement of DS with ABS

To enhance the properties DS, the DS is replaced in suitable proportion with ABS. The replacing proportion of DS with ABS are selected based on trial and error method until mixture (DS+ABS) achieves maximum strength. The Replacing proportion is as shown in table 4.12.

Table 4.12: Replacing proportion of ABS with DS

Sl No.	Replacement Proportion
1	95%DS +5% ABS
2	85%DS +15% ABS
3	75%DS +25% ABS
4	65%DS +35% ABS

ABS replaced DS with replacement ratios of 5%, 15%, 25% and 35%. For each replacement ratio both physical and geotechnical properties are determined and compared to evaluate optimum replacement ratio to which it exhibits maximum strength and the same has been tabulated in the table 4.13. It is quite promising from the test results that, as the replacement ratio increased from 5% to 25%, the strength parameter of DS-ABS mixture has increased. Further, increase in replacement ratio to 35% shows decrease in strength parameters of DS-ABS mixture, the same has been shown in Fig 4.10 and 4.11.

Table 4.13: Test result after stabilisation/replacement of DS with GD

%Replacement	W_L (%)	W_P (%)	MDD (g/cc)	OMC (%)	CBR @ 2.5mm penetration	UCC (kN/m^2)
35%	20.32	5.87	2.06	11.56	8.12	13.84
25%	24.32	7.69	1.96	12.9	8.67	14.98
15%	27.18	12.5	1.92	13.88	5.73	12.31
5%	29.17	14.7	1.83	16.8	3.27	10.61

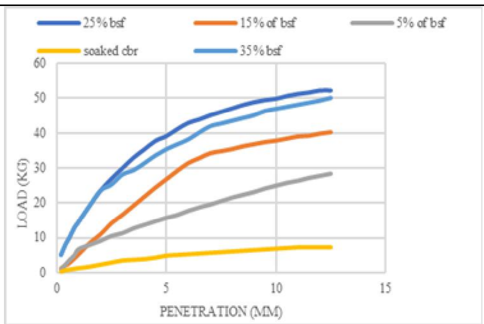

Figure 4.10: variation in CBR value with replacement of ABS

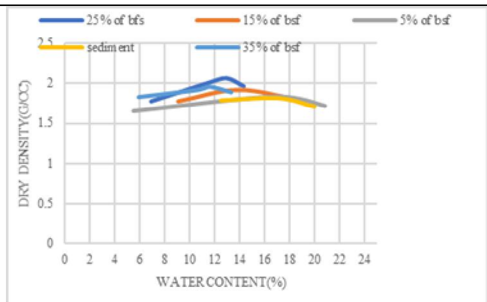

Figure 4.11: variation in compaction curve with replacement of ABS

4.6 Comparison of stabilizers GD and ABS in stabilizing DS

It has been observed from comparison that, the water required to achieve maximum strength is more when DS is replaced with GD than ABS (or ACBS) the same has witnessed in Fig. 4.12. Also, when DS achieves maximum strength when it replaced with GD than ABS (or ACBS) the same has been shown in fig. 4.13.

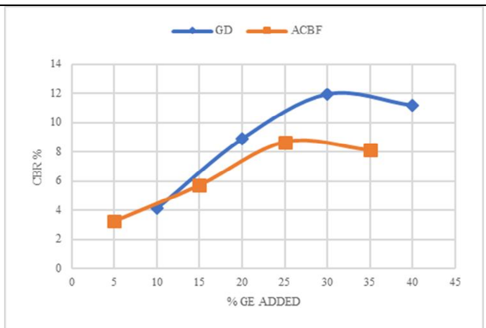

Figure 4.12: OMC comparison between ABS and GD

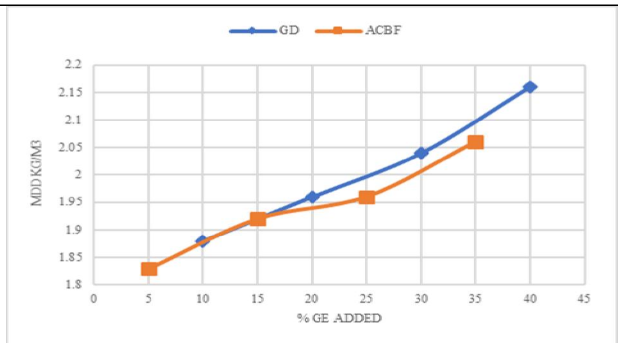

Figure 4.13: MDD comparison between ABS and GD

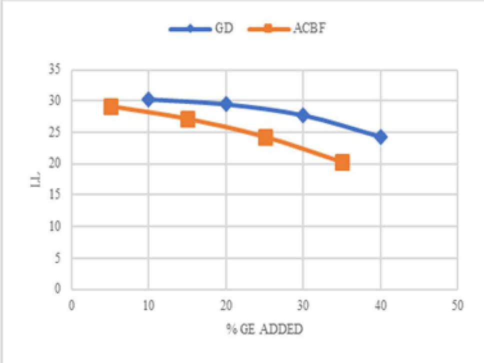

Figure 4.14: comparison of LL between addition ABS and GD to DS

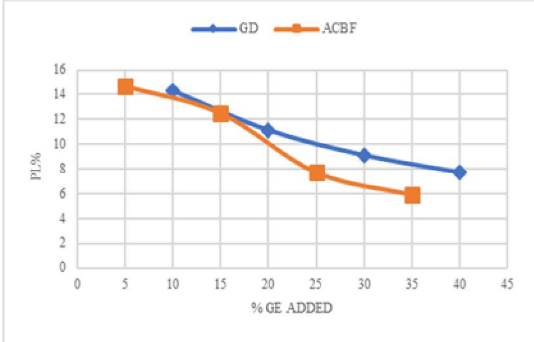

Figure 4.15: PL comparison between ABS and GD

When DS is replaced with ABF (or ACBS) the liquid limit and plastic limit of DS reduces more than when it is replaced with GD the same has shown in Fig. 4.14 and Fig. 4.15.

5. CONCLUSION

The following are some of the outcomes of the present investigation:

Removal of DS can increase the storage capacity of lake drastically due to which overflow of lakes (Flooding) can be dramatically reduced. Further, Sediments dredged will be in huge quantity and will need special attention for re-utilization of such sediments as a construction material.

It has been observed from characterization of DS that sediment obtained from Hebbal lake does not possesses enough strength characteristics required for construction material. Also, these sediments contain hardness and TDS at slightly higher level. Further, these sediments as such cannot be used as a construction material. However, it can be used with prior treatment/ stabilization.

Granite Dust (GD) and Air-cooled Blast Furnace Slag (ABS) are used as stabilizers in the present study for enhancing the properties of DS. However, GD and ABS are bi-products of Granite and Iron manufacturing industries.

In first stage of stabilization process, replacing 30% of DS with GD yielded maximum strength. Similarly, in the second method 25% replacement of DS with ABS yielded maximum strength. Hence, these are concluded as optimum dosage.

Further, comparing both first and second method shows that 30% replacement of DS with GD yields more strength than 25% replacement of DS with ABS. Thus, both ABS and GD are found to be good stabilizers.

In the present study an attempt has been made to use Dredged Sediments for construction purpose by stabilizing with Granite Dust and Air-cooled Blast Furnace Slag respectively. However, Dredge Sediments are considered to be a waste material which is blended with Granite Dust and Air-cooled Blast Furnace Slag respectively which are also waste material, making into useful construction material thus, encouraging sustainable development of the country.

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