Final Report

on

Ameliorate Dredged Sediments

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Ministry of Ports, Shipping and Waterways

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1. **General**:

The dredging of water bodies (especially from marine sources) is mandatory to maintain navigation channels in ports and harbors. This activity produces millions of tonnes of marine dredged sediments, *MDS*, in the slurry and the lump form. Primarily, dredging is of two types maintenance and capital dredging. The latter is done annually to maintain the sufficient draft required for the cargo vessels before entering into the main channel. It is observed that total of 79.56 Million cu.m of dredged sediments is generated by all the major ports of India (Dredging guidelines for major port, 2021). These *MDS* generated in the western coast of India (viz. MbPA, JNPA, and NMPT) are usually silty and clayey with high moisture content, contaminated, and are disposed of in the dedicated open disposal facilities near the ports (Dredging guidelines for major port, 2021). However, these *MDS* after disposing of, return to these channels due to the wave actions and sedimentation occurs. This activity incurs a lot of cost and investment; hence, these *MDS* should be reused and valorized.

In this context, dredging guidelines for major port, 2021, have included ways to reuse these *MDS* that includes: (i) Engineering uses (Viz. creation of land, land improvement, shore protection, beach nourishment), (ii) Agricultural purpose (viz. topsoil for agriculture) and (iii) Environmental enhancement (viz. wildlife habitats and wetland restoration). These initiatives will lead be able to mitigate the huge demands of natural resources mostly in the civil engineering application. Such an effort will be useful to attain sustainable development goals and circular economy in the port sector. In this regard, a project to carry out field scale studies and showing the efficacy of valorization of *MDS* was submitted to the Ministry of Ports, Shipping and Waterways, and the project “Ameliorate Dredged Sediments” by Prof. D. N. Singh, Dept. of Civil Engineering, IIT Bombay. Subsequently, this project was approved by the ministry vide letter DW-01013(13)/1/2021- Development Wing, dated October 14, 2021.

Initially, for the selection of the appropriate site for pilot tests, a site visit was conducted with all the stakeholders. In this context, three sites were selected near the *MbPA* premises [refer to Figs. 1 (a), 1(b) and 1(c)].

Figure 1. Proposed sites near the MbPA premises (a) Three fingers (b) rectangular section (c) patch in front of Darukhana

However, it was realized these sites fall within the CRZ and hence permissions and clearances from the authorities like Maharashtra Coastal Zone Management Authority, *MCZMA*, were attempted. In this context, the IIT Bombay team, *JNPA*, and *MbPA* officials met the Director, Environment Department, Government of Maharashtra, in December 2022. However, it was realized that the creation of green pads would attract encroachment from the locals and hence it was decided to conduct such experiments in the *MbPA* premises (refer to Fig. 2), which would eliminate such trivial issues. It should be realized that this entire process of taking permissions, approvals and initial discussions delayed the initiation of the project for a considerable amount of time. Furthermore, the procurement of the *MDS* from the mid-sea and their transfer onto the site through a barge got delayed and severely affected due to such delays.

Before the commencement of the studies, and to realize the issues and problems being faced by different ports and inland waterway authorities in this context, the following questions were asked:

- The average quantity of the dredged sediments generated (since last 10 years)?
- Is the data related to the characteristics of the dredged sediments available? Type of sediments? Their contamination level etc.
- What is the (maximum) thickness of the sediments in the channel for which dredging is being done?
- Name the industries located in the near vicinity of the port? Distance of the industry and the type of waste generated by them.
- Are there any landfills/dumping grounds in the vicinity of the port? Their distance from the port?
- Low-lying areas in the vicinity of the port?

- Does the port have a confined disposal facility for sediments? If yes, then what is its capacity (length/width/depth), and how much of it is filled up?
- Mention the attempts (and methodology) made in the past to utilize these sediments.

The philosophy behind retrieving this information from the ports was to understand the (i) characteristics of the dredged sediments, (ii) the generation of dredged sediments in each port, (iii) the presence of low-lying areas in the port premises and (iv) the type of industry located near the ports to create a synergy between the wastes of different types.

From this exercise, it was realized that the onshore management of the *MDS* is the bottleneck for their further utilization in Civil engineering applications. Hence, it was decided to create technologies that will store and dewater the *MDS*. In this regard, *CDF*s and *VDrMsDe* were created and the details of these are given below:

2. Development of the Consortia:

A consortium with the Municipal Corporation of Greater Mumbai (*MCGM)*, Jawaharlal Nehru Port Association, *JNPA*, Mumbai Maritime Board, *MMB*, and Mumbai Port Association, *MbPA* was formed to initiate the experiments at the site. The role of *MMB*, *JNPA*, and *MbPA* was to supply the *MDS* and administrative coordination, and that of *MCGM* was to supply the landfill-mined soil-like fractions for the creation of the green patch.

2.1 The Activities at *MbPA* site:

A joint site visit was conducted by all the stakeholders, and the area at Haji Bunder, Sewree (refer to Fig. 2) measuring 50 m × 50 m was chosen to be the designated site for conducting the experiments. Such a location was strategically chosen so that the barge carrying the *MDS* could be unloaded at the site. Furthermore, a suitable methodology for technology demonstration was strategized in the form of the creation of *CDF*s and later on the creation of a **Green Patch.** Interestingly, the site chosen for the experimentation had vegetative cover (refer to Fig. 3) and hence it was cleared off and can be realized in Fig. 4. Furthermore, to commence with the experiments and storage of the *MDS*, it was decided to construct the *CDF*s for their dewatering. Wherein, it was decided to dewater them by using different techniques viz. usage of geotextiles, geocomposite, and natural dewatering, and hence 3 *CDF*s of 5m × 5m × 2m partitioned by a thick 0.6 m wall (refer to Fig. 5). To reduce the thickness of the walls of *CDF*s, it was decided to construct its half into the subsurface and half above the ground. Hence, to understand the subsurface a non-invasive technique, Multichannel Analysis Surface Waves, *MASW*, (refer to Fig. 6) was employed, and was conducted diagonally of the designated area. It can be noted from Fig. 4 that the velocity of the waves increases along the depth signifying the filled-up material at the top (5 m). Furthermore, as a confirmatory test, three boreholes were dug at an equal space along the diagonal of the designated site (refer to Fig. 7a). After such extensive analysis, construction of the *CDF*s was started as depicted in Fig. 7b and Fig.8. In addition to this it was cured by water for 10 days and later on it was decided to place the *MDS* in the CDFs. Herein, the *MDS* were supplied by the *MMB* with the help of a barge at the site. The long boom was arranged for unloading the *MDS* and placing them into the *CDF*s (refer to Fig. 9 and 10). These *MDS* were allowed to dry and desiccate in the ambient atmosphere (refer to Fig. 11). Furthermore, the top desiccated layer was scraped and lumps were brought to the laboratory, crushed into different sizes to make man-made aggregates, as depicted in Fig. 12.

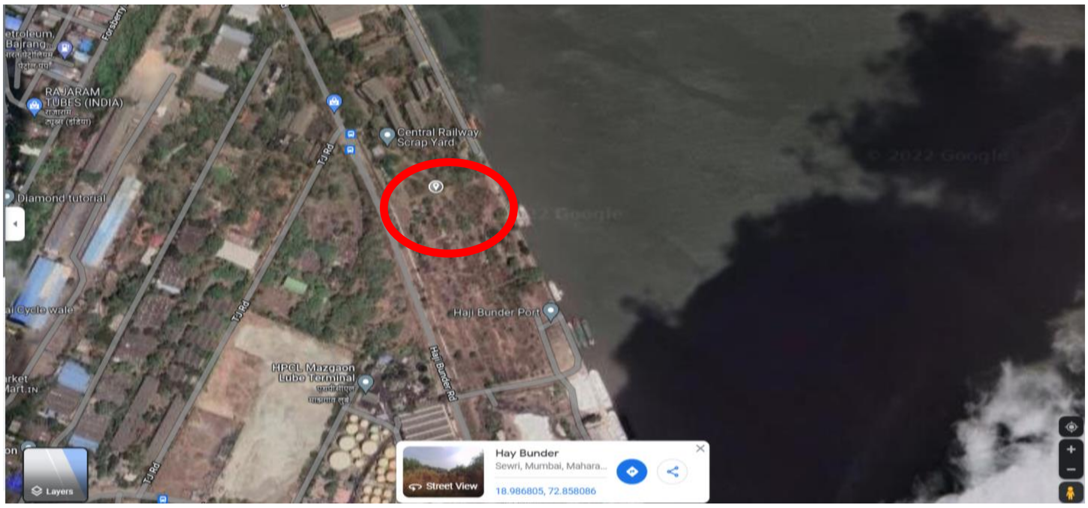


Figure 2. The selected site at the MbPA

Figure 3. Visit of the stakeholders at the site

Figure 4. Site ready for the MASW test after clearing the vegetation

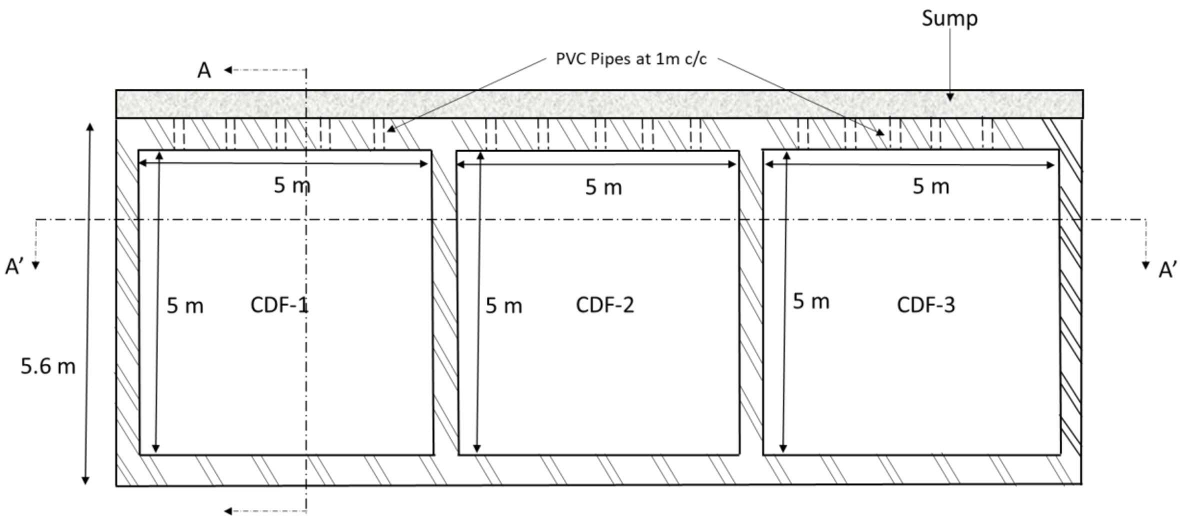


Figure 5. Typical cross-section of the Confined Disposal Facility

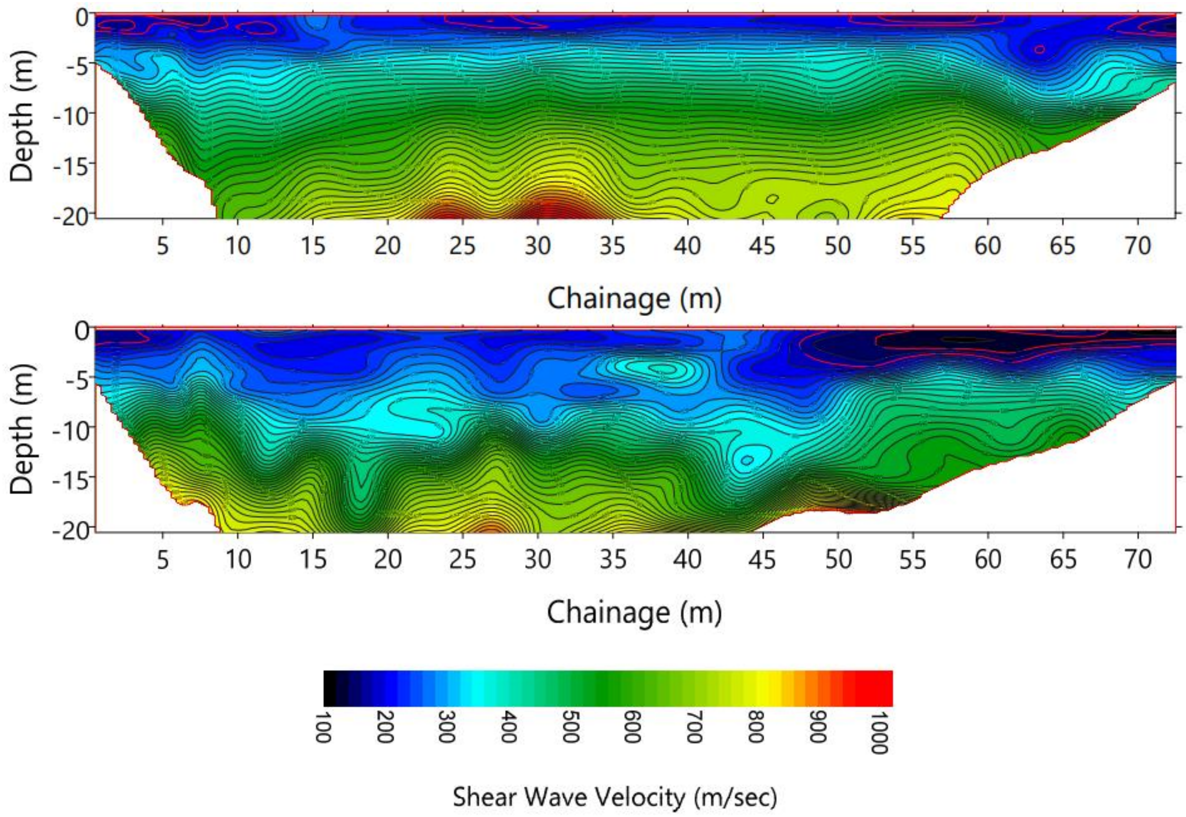


Figure 6. Typical results of the Multichannel Analysis of Surface Waves

Figure 7. (a) Construction of boreholes at the site (b) Construction of Confined Disposal Facility at the site

Figure 8. In progress construction of the Confined Disposal Facility

Figure 9. Unloading of the *MDS* from the barge at the site

Figure 10. Unloading and Storage of *MDS* in a Confined Disposal Facility at the site

Figure 11. Desiccated *MDS* at the site

Figure 12. Aggregates from the desiccated *MDS* in the Confined Disposal Facility

2.2 The Activities at *JNPA*:

The setup for dewatering of the sediments, named as *VDrMSDe* (video link attached) was fabricated by M/s Vega Industries Ltd. Hyderabad, as per the design submitted by IIT Bombay. This setup was unloaded at the 4th Container terminal at *JNPA*. Furthermore, a designated place was chosen, refer to Fig. 13, with the joint inspection with the team at the site for the placement of *VDrMsDe* by keeping in view the easy transportation of *MDS* for their processing. Later on, before placing the units of the *VDrMsDe* the ground was prepared with the help of a grader, leveler, and compactors at the desired location, as depicted in the

Fig. 14. The setup (viz. trommel screen, cyclone separator, agitator, filter press, control panel, and diesel generator) was unloaded at the site with the help of a 2-ton capacity crane (refer to Figs. 15 and 16). The units were positioned properly according to their functions and piping systems were installed at the site. Furthermore, all the units were supplied electricity by connecting them to the diesel generator and simultaneously giving its control to the control panel. The control panel was used to control the speeds (viz., rpm) of the agitator, trommel screen, and cyclone separators. The block diagram of the *VDrMsDe* is depicted in the Fig. 17.

After the installation of the setup, they were switched on to see their efficacy and the issues associated with it. Subsequently, the whole system was washed by circulating water to check any leakages through the joints and the storage tanks.

Furthermore, the sediments freshly dredged from the *JNPA* channel were used for starting the experiments and 10-12 trials were made to obtain the soil cake from the filter press. These samples were procured from the outlet and were analyzed in the laboratory for their particle size and moisture content. Furthermore, the cakes were crushed and turned into aggregates as depicted in Fig. 18.

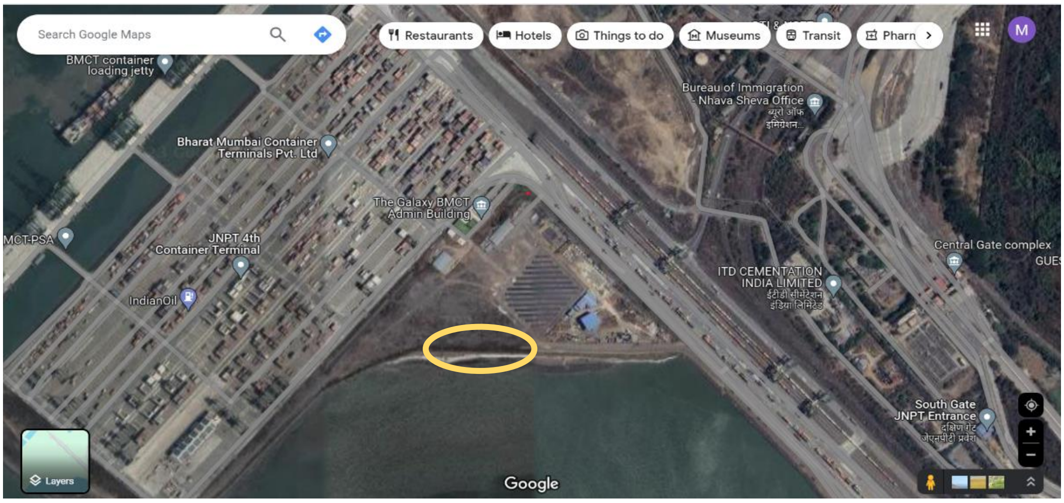


Figure 13. The location for performing the trials at the 4th container terminal, *JNPA*

Figure 14. Levelling of the ground before assembling various units of the *VDrMsDe*

Figure 15. Unloading of various components of the setup *VDrMsDe* at the site

Figure 16. Setting up of the *VDrMsDe* at the site

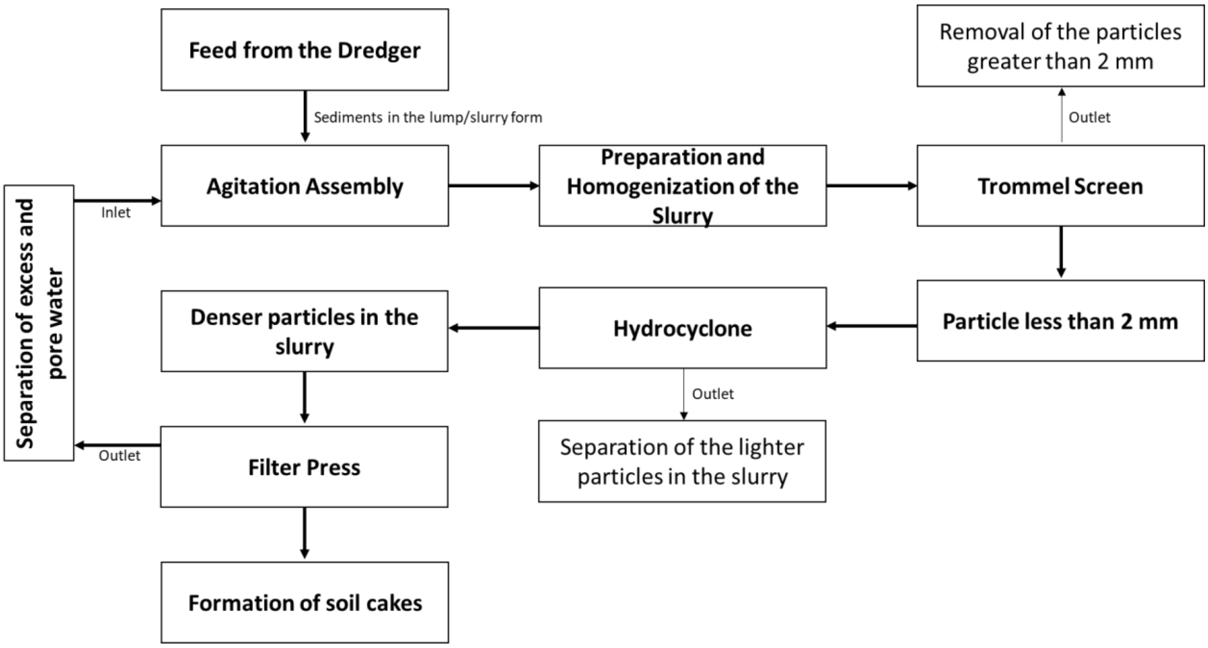


Figure 17. Block diagram of the *VDrMsDe*

Figure 18. Creation of the aggregates from the sediments retrieved from the filter press

3. Laboratory experiments

The *MDS* in lump form (saturated) were collected from the constructed *CDF* and brought to the Environmental Geotechnology Laboratory, IIT Bombay. They were characterized for physical, chemical, particle size distribution and index properties and are listed in the table below (refer Table. 1)

Table 1 Classification of the *MDS*

S.N.	Constituents	(%)	References
1.	Specific Gravity	2.49	ASTM D6903
2.	Sand size	10	ASTM D6913
3.	Silt size	40	ASTM D7928
4.	Clay size	50	
5.	Liquid limit	60-70	ASTM D4318
6.	Plastic limit	30-35	
7.	Plasticity index	30-35	
8.	Organic matter	19-23	
9.	Classification	CH-OH	USCS

It can be noted that these *MDS* are high plastic clays and dispersive. Hence, it was decided that a proper amendment of *MDS* should be done in the form of landfill-mined soil-like fractions, *LFMSF*, another waste that is been generated from the bio-mining of the landfills to create a composite. Such an exercise will solve problems of both industries viz. dredging and bio-mining. The methodology followed for the creation of composites is discussed below:

3.1 Methodology for preparation of composites:

The composites in the semi-solid state were cast in stainless-steel containers of diameter 55 mm and height 30 mm, by hand pressing. These containers were lubricated by the hydraulic oil on their interior surface to ensure minimum friction. Subsequently, these containers were left for air drying in the ambient conditions and the composite was taken out of them. Subsequently, these composites were analyzed for their physical properties such as specific gravity and shrinkage characteristics and chemical properties such as leaching characteristics, *FTIR* spectroscopy, *pH*, electrical conductivity, *EC*, Salinity, *S*, and total dissolved solids, *TDS*, and loss on ignition

4. Results and discussions

The physical characteristics such as specific gravity, *G*, loss on ignition, *LOI*, crumb test, and shrinkage characteristics have been analysed according to the ASTM D4892-14, ASTM D2974-20, and ASTM D6572-21 respectively.

4.1 Specific gravity

Specific gravity, *G*, of composites, are measured following the guidelines, ASTM D6903 (2016) using a helium gas pycnometer, ULTRAPYC 1200e (Quantachrome Instruments) and it is been depicted in Figure 19. The specific gravity is found to be in the range of 2.49 to 2.66.

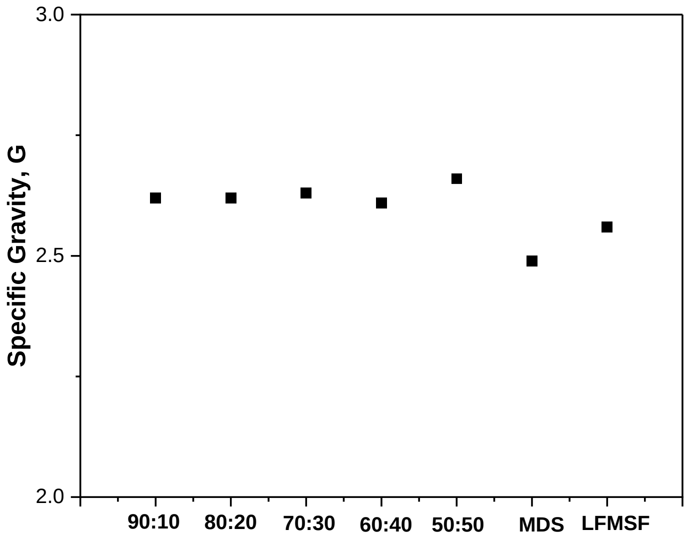


Figure 19. The specific gravity of *MDS*, *LFMSF* and various composites

4.2 Loss on Ignition

The method of loss-on-ignition was employed to quantify the organic content present in the *DS*, *LFMSF*, and composite. Samples are to be kept in the muffle furnace at a temperature of 440 ^{o}C for 2.5 hours and percentage loss in mass is determined which corresponds to the percentage of organic matter present in the sample. The results obtained are presented in Figure 200.

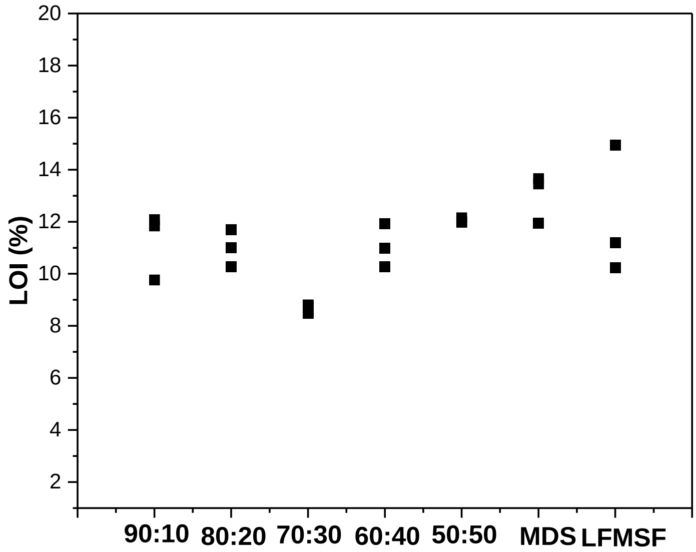


Figure 20**.** Loss on Ignition of *MDS*, *LFMSF* and various composites

4.3 Leaching Characteristics

The *MDS*, *LFMSF*, and composites were analysed for various chemical characteristics viz. *pH*, total dissolved solids (*TDS*), salinity, *S*, electrical conductivity, *EC*, and concentration of various heavy metals after air drying in the ambient conditions after 15 days. The samples were prepared at three different liquid-to-solid ratios, *L/S* viz.,10, 15, and 20. They were placed in a mechanical shaker for 24 hours so that the leaching of constituents takes place from the solid to the liquid phase, primarily called as batch test. Subsequently, the supernatant was filtered using Whatman filter paper No. 40 and the filtrate was analyzed for its chemical characteristics as mentioned above. The *pH* of the filtrate was measured by employing (Eutech instruments pH 700, United Kingdom) whereas *TDS*, salinity, and *EC* were determined by employing Oakton, PC 2700 (USA) and results are shown in Figure *21*.21. The concentration of various metals was also determined by employing *ICP-AES*. The results obtained are presented in Table *2*2.

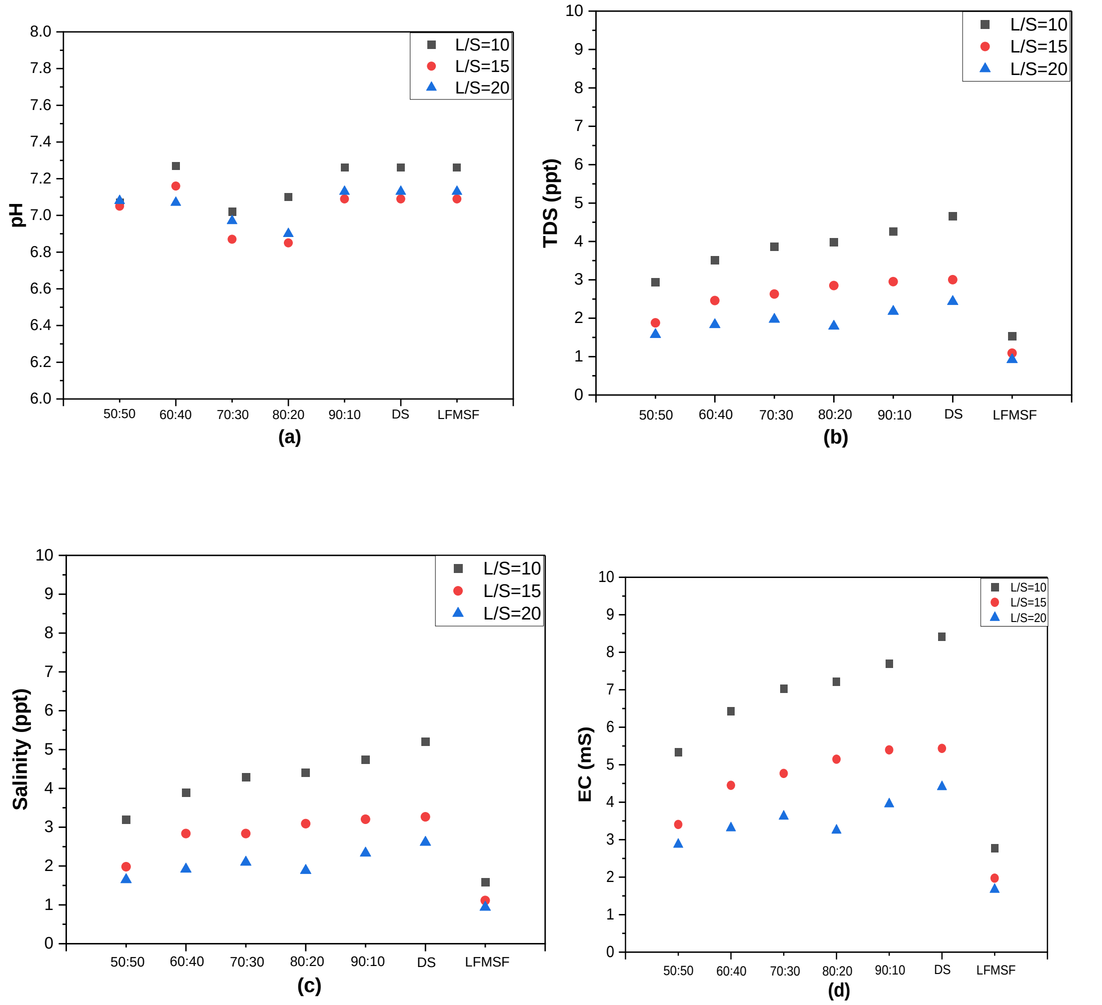


Figure 21**.** The variation in (a) *pH*, (b) *TDS*, (c) Salinity, and (d) *EC* of filtrate with change in composition (*DS: LFMSF*) and *L/S* ratio.

Table 2. The concentration of heavy metals in leachate by employing ICP-AES

Concentrations of Elements in Leachate (*L/S=10*) in ppm								
Elements	IS 10050*	Samples Name						
		50:50	60:40	70:30	80:20	90:10	*MDS*	*LFMSF*
Na	250	**706.409**	**858.005**	**972.664**	**1032.94**	**1121.48**	**1239.89**	109.681
Ca	75	**100.793**	**119.863**	**101.495**	**85.73**	**87.333**	65.452	**349.659**
K	-	72.323	80.915	76.046	70.584	65.064	67.9	58.176
Mg	30	**55.999**	**74.611**	**73.245**	**73.074**	**75.625**	**75.49**	**42.205**
Sr	-	0.796	1.016	0.926	0.861	0.96	0.843	1.592
Mn	0.1	**0.223**	**0.293**	**0.291**	**0.34**	**0.352**	**0.325**	0.071
P	-	0.211	0.187	0.226	0.386	0.376	0.347	ND
Ba	0.7	0.098	0.111	0.095	0.079	0.064	0.029	0.1
Mo	-	0.095	0.112	0.123	0.14	0.149	0.156	0.02
Zn	5	0.079	0.104	0.077	0.084	0.055	0.045	0.126
Cu	0.05	**0.066**	**0.066**	0.049	0.046	0.034	0.028	**0.072**
Li	-	0.031	0.04	0.043	0.043	0.048	0.052	0.011
Ni	-	0.023	0.02	0.017	0.018	0.012	ND	0.028
Fe	0.3	0.021	0.013	0.014	0.027	0.021	0.011	0.03

*Permissible limit for drinking water.

It can be noted that the *pH* of the filtrate of the composite is in the range of 7.02-7.26, which is in the neutral range. On the other hand, the *EC*, *S*, and *TDS* of the filtrate increase with the increase in the percentage of *MDS* in the composite. Furthermore, from the it can be noted that the amount of Na ions in the filtrate is beyond the permissible limits as per IS 10500. This is due to the presence of Na^+ ions in the *MDS* and it is also responsible for the dispersive behaviour of the composite that was visualized by performing the crumb test.

4.4 FTIR Analysis

The *FTIR* analysis of the composites were performed by employing an ATR-FTIR spectrophotometer (make Shimadzu, QATR-S, Japan) and results are presented in Fig. 22. The peak obtained in the graph corresponds to various bonds such as (a) 3690 cm^{-1} represents the presence of O-H stretch, (b) 1810- 1350 cm^{-1} represents the presence of C=O bond, (c) 1000 cm^{-1} represents the presence of S-O bond, and (d) 500 cm^{-1} represents the presence of Si-O bond. The presence of these bonds indicates the presence of hydroxide, carbonate, sulphate, and silicate (Papliaka et al., 2015) signifying the presence of Calcium carbonate, sulphates, and silicates in the *LFMSF* and *MDS*.

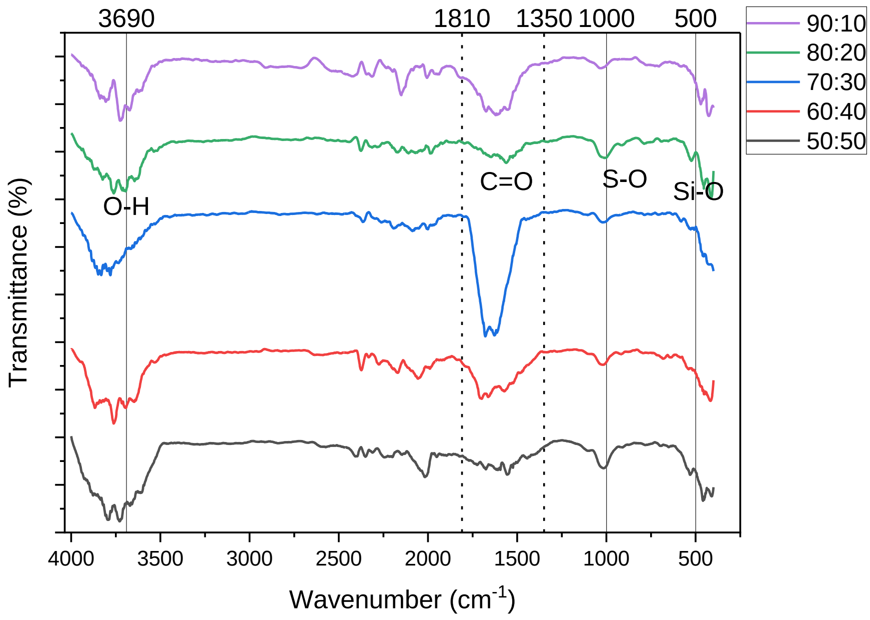


Figure 22**.** FTIR Analysis of various Composites (*MDS*: *LFMSF*).

4.5 Shrinkage Characteristics

The shrinkage characteristics of *MDS*, *LFMSF*, and their composites have been determined by employing IS: 2720 (Part VI) – 1972. *MDS* and *LFMSF* were dried and sieved through a 425-micron sieve and were mixed accordingly. Furthermore, 0.8×W (W is the weight of dry sample) de-ionized water was added to the samples and was mixed thoroughly using a spatula followed by pouring the homogeneous mix into Petri dishes having a diameter of 45 mm and a depth of 15 mm with proper tamping to remove any entrapped air and the top surface was finished properly using a spatula. Triplicate samples of each composition were then kept for air drying followed by oven drying at 50 °C. Upon drying, samples and Petri dishes were measured for their volume by employing the mercury displacement method. Using the wet and dry weight of the samples, shrinkage limit, and volumetric shrinkage, were computed and it was found that the volumetric shrinkage decreases as the proportion of *LFMSF* increases in the composition. This can be attributed to an increase in shrinkage limit as the proportion of

LFMSF is increasing which is causing the replacement of *DS* particles which have more tendency to shrink due to fines. Hence, 50:50 composition was selected as an optimal composition which will experience minimal shrinkage stress and hence less susceptible to cracking.

4.6 Dispersion Characteristics

4.6.1 Crumb test

A crumb test is performed on the composites to understand their dispersive nature following ASTM D6572-21. A cube of composite having an approximate dimension of 15 mm was cut with the help of a geotechnical knife. Later on, the cubes were placed in porcelain dishes containing 300 mL of de-ionized (*DI*) water. The temperature of the ambient condition and DI water was recorded by employing a thermometer and was found to be 25.1 ^{o}C. The cubes were gently immersed into the water and after immersion of the cubes, pictures were taken after 2 minutes, 60 minutes, and 360 minutes which are shown in Plate 2.

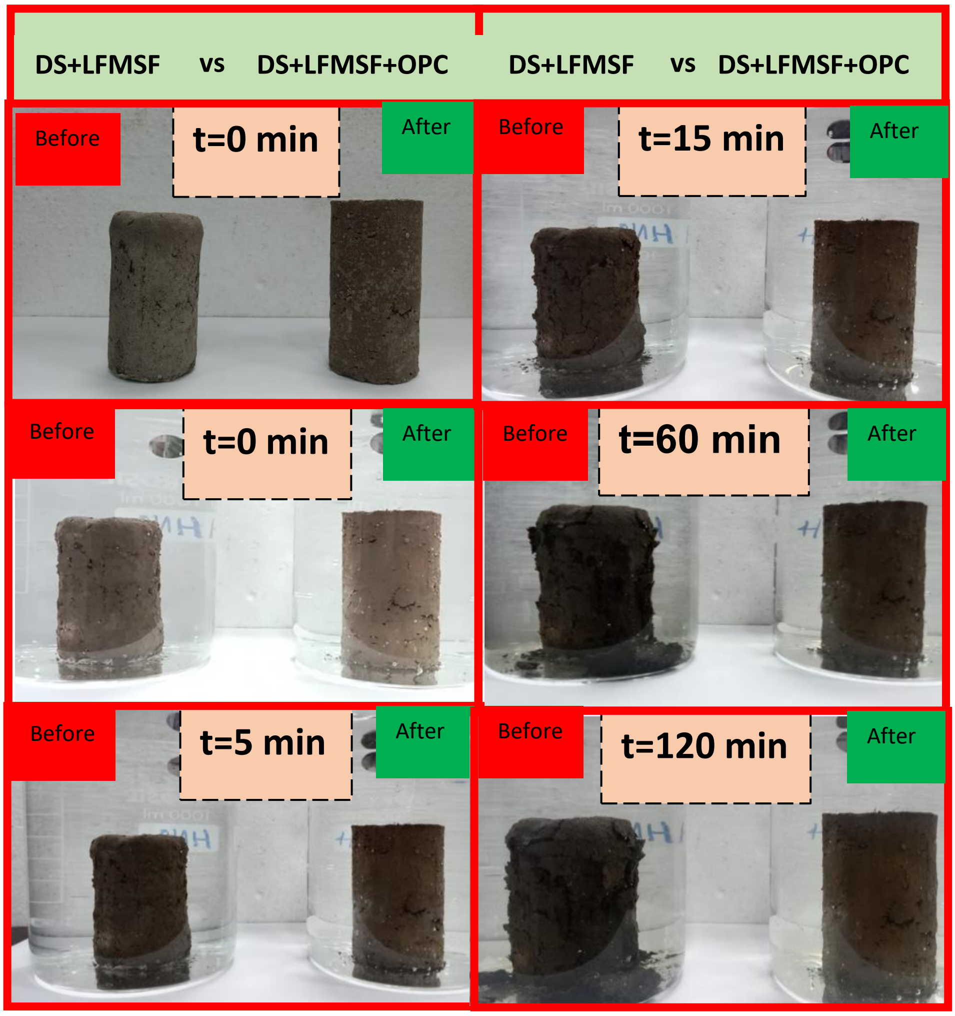
It has been observed that all the compositions got disintegrated within 2 hours duration. This observation demands for the inclusion of cementitious binder in the form of *OPC* into the composite to increase their durability when contact in water. Henceforth, it was to add 10 % *OPC* in 50:50 (*MDS*: *LFMSF*) composition for further assessment. In this context, triaxial samples were made of the above-mentioned compositions and cylindrical crumb test and unconfined compression strength were performed and is discussed in the subsequent sections.

Plate 1. Image depicting the result of crumb test.

Sample / Time (min)	DS	90:10	80:20	70:30	60:40	50:50
2						
60						
360						

4.6.2 Cylindrical Crumb Test

The Cylindrical Crumb Test was performed on the optimal composition (50:50) after adding 10% *OPC* by combined weight of *MDS* and *LFMSF*.



4.7 Unconfined Compressive Strength

The unconfined compression test was performed on specimens consisting of a mixture of *MDS*, *LFMSF*, and *OPC*. The specimens were prepared by taking the dredged sediments in their as-received form, with a moisture content of around 100%. The *LFMSF* was dried and sieved through a 2 mm sieve. Subsequently, the *LFMSF* was mixed with the dredged sediments using the existing moisture only, and then 10% OPC of the combined dry weight was thoroughly mixed by hand. The specimens were cast in a triaxial sampler with a diameter of 38 mm and a height of 76 mm, and the samples were cast by pressing into the mould. The specimens were kept for curing in a desiccator containing water in the bottom of the desiccator

Subsequently specimens were tested for UCS after 3, 7 14, and 28 days of curing. The testing was conducted on a compression testing machine supplied (make Humboldt) having a loadcell capacity of 10 kN and linearly varying differential transducer (*LVDT*) to measure load and displacement, respectively during testing. Data were recorded using a data acquisition system and a software supplied by KAPTL shown in Fig. 23.

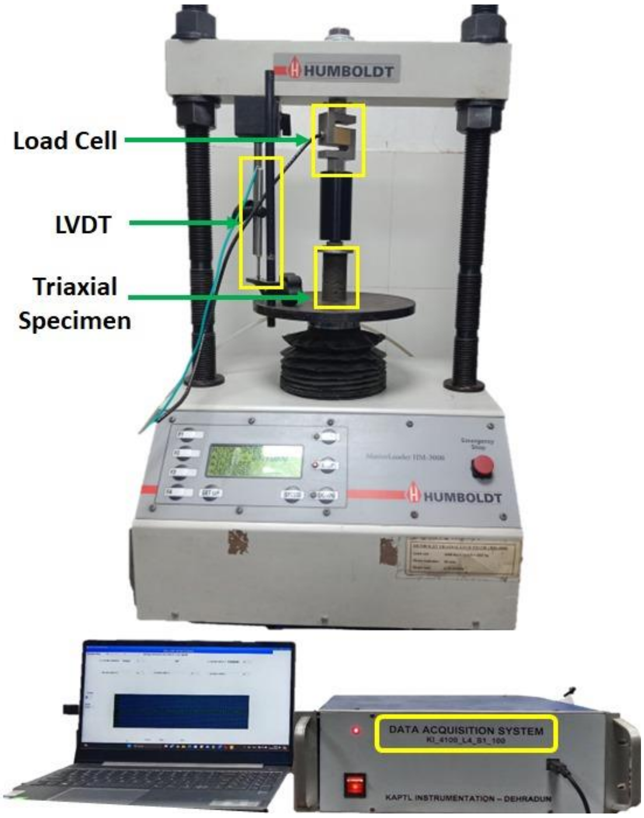


Figure 23. Compression testing machine and data acquisition system

After the aforementioned curing period, specimens were placed on loading frame and compression testing was conducted at a constant strain rate of 1% and the stress vs strain curve and the average UCS values are plotted as shown in Fig. 24.

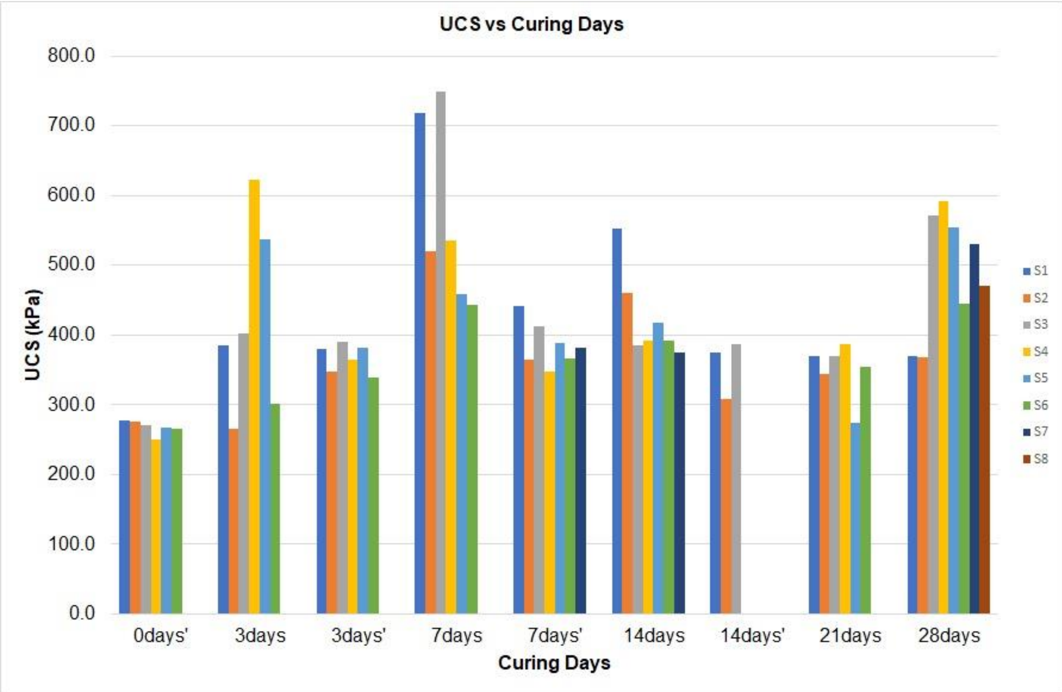


Figure 24. Unconfined compressive strength of the triaxial samples (*MDS*: *LFMSF*) bound with *OPC*

It can be noted that a maximum strength of 700 kPa has been achieved by the composites that were created by amending 50: 50 by weight of the *MDS* and *LFMSF*, respectively and 10 % of the OPC. From the above results, it can be noted that this strength could be utilized for the creation of landand foundation of roads in the port areas. However, the long-term effect on the UCS of the composites needs to be investigated.

5. Recommendations and the way forward

The amelioration of the *MDS* was attempted by creating two types of aggregates, designated as *MDSagg*, from the *CDF*s and the filter press which is an integral part of the setup *VDrMsDe*, and creating composites by utilizing the *MDS*: *LFMSF* and *OPC* in an appropriate amount as mentioned. These aggregates when coated with polymer can be used to replace the natural aggregates in the construction industry. Furthermore, a test patch should be tried at the field scale at various ports with the above-mentioned composition of *MDS*: *LFMSF* and *OPC*.

However, it was realized that the valorization of *MDS* also depends on their basic characteristics (physical, chemical, mineralogical, organic matter, and level of contamination), which might vary from port-to-port and inland waterways of the country. In this context, though the efficiency of the *VDrMsDe* has been demonstrated, its versatility needs to be ensured for the sediments of varied types being retrieved at other ports and if required, *VDrMsDe* should be upgraded to enhance its functionality and the desired outcome. Such an arrangement, and its upscaled version to cater to the demands of the dredging industry in India, would be a great boon. Furthermore, efforts should be made to employ supplementary cementitious materials and/or polymers to replace *OPC* from the composites, to enhance their suitability & integrity as an aggregate for infrastructure development.