Strength Behaviour of Marine Clay Stabilized with Marble Dust and Quarry Dust

B. Manjuladevi and H. S. Chore

Abstract Marine clay is found widely along the coastal area and demands expensive solutions in the construction of coastal highways. Marine clay has poor supporting capacity, and it further experiences large changes in volume on variations of moisture content. Hence, such soils need to be improved to make them suitable for road construction activities. Accumulation and safe disposal of various waste materials are a major concern to the environment. India has a large network of industries which produces millions of metric tonnes of industrial waste. Various soil stabilization techniques are used to enhance the engineering properties of the soil. Waste materials such as fly ash, rice husk ash, quarry dust, marble dust, pond ash, bagasse ash, and granulated blast furnace slag may be used for stabilization purposes. It is reported that the addition of such waste materials increases the physical as well as chemical properties of the weak subgrade soil. The investigation planned to be reported in the ensuing paper aims at presenting the improvement in properties of marine clay to be used as the subgrade, with the utilization of marble dust and quarry dust as a stabilizing agent.

Keywords Marine clay · Marble dust · Quarry dust · SPT · PI · CBR

1 Introduction

The disposal of waste materials in factories and industries is posing a great environmental and ecological problem. These waste materials can be effectively used in pavement construction as they have good potential in improving the strength of subgrade soil of the pavement whereby there can be a reduction in the thickness of the

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pavement. Such construction may prove to be economical. Vast areas, particularly along the coastal region, are covered with thick soft marine clay deposits, having very low shear strength and high compressibility. In the recent past, a large number of ports and factories have been built to commercially exploit these coastal areas. The viability of land for the development of housing and industrial projects, transportation, infrastructure, etc. in urban areas is a moot question. This necessitated the use of land, which has weak strata wherein geotechnical engineers are challenged by the presence of different problematic soils with varied engineering characteristics.

Continuous efforts have been made all over the world to devise ways to solve the problems in relation to marine clay. Placement of adequate surcharge load, chemical stabilization, and use of various reinforcement techniques are some of the tried and tested remedial measures to avoid problems posed by marine clay. Expansive soils cause more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquakes and floods [1]. The selection of appropriate ground improvement techniques depends on the soil that is to be treated, the availability of materials required, and economic viability. All the techniques basically involve the introduction of different materials in the soil deposit.

In the present study, Marble dust and Quarry dust were preferred among all the wastes which are generated from industries in various forms like rice husk ash, granite fines, quarry dust, fly ash, granulated blast furnace slag, copper slag, steel slag, etc.

Quarry dust is a waste obtained in the quarrying process. Quarry dust/crusher dust is obtained as soil solid waste during the crushing of stones to obtain aggregates. The use of quarry dust is to ensure the economic stabilization of soil. It is also used under flexible pavements, to increase the load-carrying capacity of the pavement by distributing the load through a finite thickness pavement [2]. The amount of quarry dust generated is about 25% of the total output of each crushing unit. The annual production of quarry dust in India is about 200 million tonnes [3].

The production of marble (natural stone) globally was 21.7 million tonnes in the year 1986; however in 1998, this number increased to 51 million tonnes (DPT, 2001). Increasing demand for marble products leads to a rise in the generation of marble waste [4]. The proportion of marble discharged as a waste during block production at the quarries is equal to 40–60% of the overall production volume [5]. In India, Rajasthan is the richest state in the country with regards to marble deposits (1100 million tonnes), both in quality and quantity. Marble dust is generated from the cutting and polishing of marble stone. The amount of marble slurry produced every year is in the range of 5–6 million tonnes [6]. In this study, an attempt is made to analyse the effects of lime, quarry dust, and marble dust on the strength characteristics of marine clay.

2 Review of Literature

Extensive literature is available on soil improvement by the application of additives, notably cement and lime. Lately, many researchers have reported on additives that could substitute lime as a soil modifier. Such materials include rice husk [7, 8], marble dust [9], and limestone ash [10]. Many researchers [11–14] have reported that marble dust has very high lime (CaO) content up to 55% by weight.

Many Researchers [15–22] had investigated that marble dust is an effective waste material in soil stabilizing techniques, which improves the compaction characteristics, subgrade characteristics, swelling characteristics, compressive strength characteristics as well as index properties of soil like liquid limit, plastic limit, and shrinkage limit.

Sridharan et al. [23] conducted studies on the effect of quarry dust on the geotechnical properties of soil used in highway construction and concluded that the California Bearing Ratio (CBR) value steadily increased with an increase in the percentage of quarry dust. And the improvement in CBR value can be contributed to the significant improvement in the angle of shearing resistance. Higher CBR values of soil-quarry dust mixes enhance their potential for use as a sub-base for flexible pavements.

Roohbakshan and Kalantri [24] investigated the effect of waste stone powder and lime on clayey soil. They reported that the liquid limit and plasticity index decreased with an increase in waste stone powder and lime content. There is an improvement in the geotechnical properties of soil by the addition of waste stone powder and lime. Deepiya et al. [25] investigated the application of quarry dust as an admixture during soil improvement for a more economic approach. They concluded that the use of quarry dust in soil stabilization is to improve the engineering properties of soil. Satyanarayana et al. [26] had investigated the strength characteristics of compacted crushed stone mixes through a series of CBR tests by varying the crushed dust.

The aim of the present study is to use marble dust and quarry dust as a stabilizing agent for soil subgrade material. The most important reason for using marble dust and quarry dust with subgrade soil is economy and waste utilization. A range of tests that include Standard Proctor Test (SPT), and micro-structural analyses by using X-ray fluorescence (XRF). Atterberg limits and California bearing ratio (CBR) were conducted to investigate the properties of marine clay stabilized with stabilizers in varying proportions.

3 Materials and Experimental Program

3.1 Materials

The following materials are used in this study.

3.1.1 Soil: Marine Clay

It is collected from the Jawaharlal Nehru Port Trust (JNPT), Maharashtra State, India, at approximately 50–60 m from the banks of the Uran River at a depth of 3–3.5 m. The location of the site in Google map is shown in Fig. 1.

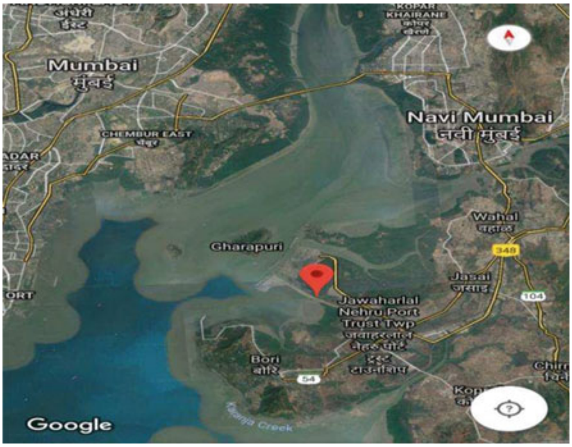

Fig. 1 Site location

Table 1 Physical properties of soil sample

Sr. No.	Parameters	Value
1	Specific gravity	2.5
2	Liquid limit (%)	80
3	Plastic limit (%)	35
4	Plasticity index (%)	45
5	Shrinkage limit (%)	22.35
6	Sand (%)	3.9
7	Silt + Clay (%)	96.1 (47.1 + 49)
8	Unified soil classification	CH
9	Soil specification as per AASHTO	A-7-5
10	Optimum moisture content (%)	31
11	Maximum dry unit weight (kN/m^3)	13.73
12	Unsoaked CBR (%)	4.54
13	Soaked CBR (%)	1.85

The index properties of soil are given in Table 1.

3.1.2 Marble Dust

Marble dust is the by-product of the marble industry, which is generated in the cutting and grinding of marble. The waste generation is approximately 40% of the total marble handled per annum. It is relevant because annually about 68 million marbles are manufactured all over the world. The disposal of marble waste on an open ground creates serious threats to public health and to the environment. It also occupies a lot of space that may be used for other purposes. Besides, marble waste

Table 2 Physical properties of Quarry Dust

Sr. No.	Parameters	Result
1	Specific gravity	2.65
2	Sand-sized particles (%)	92
3	Silt- and clay-sized particles (%)	8
4	Maximum dry unit weight (kN/m^3)	18.8
5	Optimum moisture content (%)	12.85
6	Unsoaked CBR (%)	19
7	Soaked CBR (%)	10.5

may contaminate the water and cause diseases if it gets mixed with surface water. It may also percolate through the soil and affect the groundwater. It also causes clogging of soil by lowering its permeability and reduces the productivity of the soil [27].

Marble dust, obtained from a marble cutting and polishing industry located in Mumbai region, has a specific gravity of 2.65, sand-sized particles 74.716%, silt-sized particles 25.28%, maximum dry unit weight 18.87 kN/m^3, and optimum moisture content 12.48%.

3.1.3 Quarry Dust

Quarry dust/stone dust is obtained as a soil solid waste in the crushing of stones to obtain aggregates. It has recently gained prominence as an effective Stabilizer. The quarry dust which is used for this investigation was collected from a nearby crusher unit located in Navi Mumbai, Maharashtra. The quarry dust passing through a 4.75 mm sieve was collected and mixed with the expansive soil from 0% to 30% at an increment of 5%.

The geotechnical properties of the quarry dust are given in Table 2.

3.2 Testing Procedure

To find out the optimum percentage of marble dust for the stabilization of marine clay, it was varied from 5% to 30% by dry weight of soil, in increments of 5%. Various tests such as Standard Proctor, Atterberg limits, and CBR were conducted on these samples/mixes, according to the relevant Indian Standard codes. The above-mentioned procedure was repeated with various types of quarry dust. To establish the mineralogical composition of marine clay, quarry dust, and marble dust, X-ray fluorescence (XRF) tests were performed. Table 3 lists the different admixtures and their respective contents used in the present study.

Table 3 Different percentages of admixtures and their respective contents

Sr. No.	Type of soil	Admixtures	Percentages of stabilizers
1	Marine clay	Marble dust	5,10,15,20,25,30
2	Marine clay	Quarry dust	5,10,15,20,25,30

Table 4 Chemical composition of raw materials

Sample	MC	QD	MD
SiO2 (%)	39.10	54.40	16.96
Al2O3	13.30	15.00	0.12
Fe2O3	10.80	11.60	0.39
CaO	9.62	9.32	27.10
MgO	3.39	4.18	16.10
MnO	0.13	0.15	–
TiO_2	1.51	1.10	–
Na_2O	8.60	2.54	–
K_2O	1.53	1.04	–
P_2O_5	0.47	0.16	–
SO_3	5.90	0.10	–
Cl	4.63	0.03	–
LOI	–	–	39
$CaCO_3$	–	–	48.4
$MgCO_3$	–	–	33.81
$SiO_2 + Al_2O_3 + Fe_2O$	63.2	81	37.37

X-ray fluorescence (XRF)

The results of the chemical analysis carried out using X-ray fluorescence spectrometry (XRF) of the raw materials are summarized in Table 4.

The values of the combined percentages of silica, alumina, and iron oxide in the quarry dust are more than 70% which indicates their usefulness as a natural pozzolana, as per ASTM C618 (ASTM 1999).

4 Results and Discussions

The values of Optimum Moisture Content (OMC), Maximum Dry Unit Weight (MDU), Liquid Limit (LL), Plastic Limit (PL), Plasticity Index PI), and CBR of soil admixtures are given in Tables 5, 6, and 7.

Table 5 Standard proctor, LL, PL, PI test results for marine clay-marble dust

Marine Clay + Marble Dust	Optimum moisture content (%)	Maximum dry unit weight (kN/m^3)	L.L (%)	P.L (%)	P.I (%)
(100 + 0)%	0.31	13.729	80	35	45
(95 + 5)%	0.3	14.249	67	34	33
(90 + 10)%	0.29	14.435	63	33.05	29.9
(85 + 15)%	0.27	14.611	58	32	26
(80 + 20)%	0.25	14.906	53	27	26
(75 + 25)%	0.245	15.102	50	26.1	23.9
(70 + 30)%	0.24	15.396	48	25	23

Table 6 Standard proctor, LL, PL, PI test results for marine clay-marble dust-quarry dust

Marine Clay + Quarry dust	Optimum moisture content (%)	Maximum dry unit weight (kN/m^3)	L.L (%)	P.L (%)	P.I (%)
(100 + 0)%	31	13.729	80	35	45
(95 + 5)%	28.26	14.27	74	31	43
(90 + 10)%	27.49	14.74	68	29	39.9
(85 + 15)%	26.88	15.18	63	28.10	34.9
(80 + 20)%	25.79	15.59	59	27	32
(75 + 25)%	24.39	15.79	54	25	29
(70 + 30)%	25.03	15.61	55	23.4	31.6

Table 7 CBR test results for marine clay-marble dust-quarry dust

Marine Clay + Marble Dust	CBR (%) (Un Soaked)	CBR (%) (Soaked)		Marine Clay + Quarry Dust	CBR (%) (Un Soaked)	CBR (%) (Soaked)
(100 + 0)%	4.54	1.85		(100 + 0)%	4.54	1.85
(95 + 5)%	5.07	2.07		(95 + 5)%	7.08	3.43
(90 + 10)%	7.84	2.82		(90 + 10)%	10.43	4.78
(85 + 15)%	9.45	2.95		(85 + 15)%	12.35	5.05
(80 + 20)%	9.59	3.03		(80 + 20)%	13.7	6.85
(75 + 25)%	7.84	2.45		(75 + 25)%	15.35	8.25
(70 + 30)%	6.057	2.08		(70 + 30)%	14.98	5.95

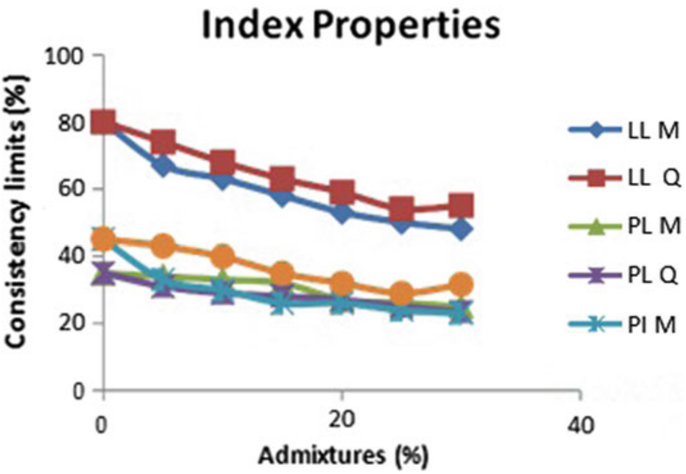

Fig. 2 Variation of consistency limit values of marine clay treated with different % of marble dust and quarry dust. (M) and (Q) represent marble dust and quarry dust, respectively

4.1 *Effect of Quarry Dust and Marble Dust on Index Properties*

The variation of Liquid Limit and Plastic Limit and Plasticity Index with different percentages of admixtures is represented in Fig. 2.

It is observed that an increase in the percentage of marble dust leads to a decrease in liquid limit and plastic limit. However, as the percentage of quarry dust increases, the liquid limit and plastic limit is found to decrease up to 25% of admixtures. Beyond 25%, liquid limit and plastic limit start to increase. This can be attributed to the fact that large contents of quarry dust that segregate the particles and this subsequently increases the consistency limits.

A similar trend is observed with respect to the variation of Plasticity Index, with the addition of soil admixtures in increasing percentages. With the addition of admixture replacing the same percentage of the clay, the compressibility of the mix is found to decrease as indicated by the reduction in consistency limits. The reduction in consistency limits is found to be on the higher side for marble dust. This is due to filling of voids of the flocculated soil, thereby reducing water holding capacity.

4.2 *Effect of Quarry Dust and Marble Dust on Compaction Properties*

The variation of maximum dry unit weight (MDU) of expansive soil with the addition of different percentages of marble dust and quarry dust is indicated in Figs. 3 and 4, respectively. It is seen that as the MDU goes on increasing, the OMC goes on

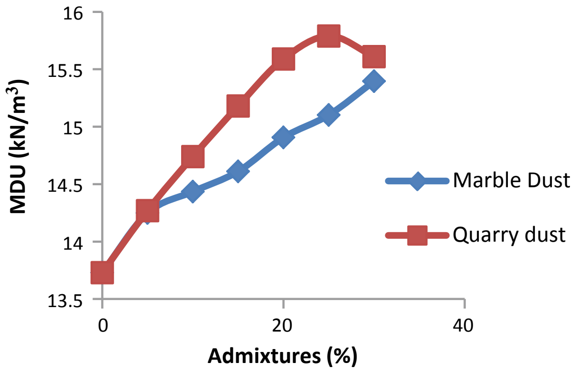

Fig. 3 Variation of maximum dry unit weight with percentages of admixtures

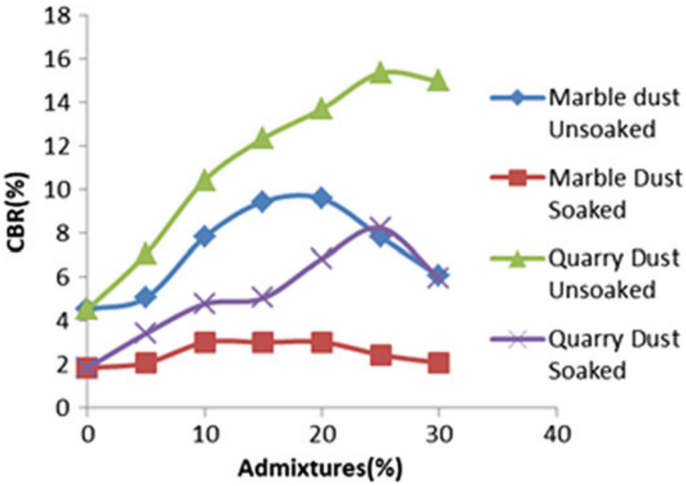

Fig. 4 Variation of CBR with percentages of admixtures

decreasing, irrespective of the increase in the percentage of the addition of marble dust. The MDU of soil increases from 13.72 kN/m^3 to 15.396 kN/m^3 for stabilized soil with 30% marble dust. The increase in MDU is an indication of the improved properties of stabilized soil. In the case of the quarry dust, the MDU of soil increases from 13.72 kN/m^3 to 15.79 kN/m^3 for stabilized soil with 25% of the quarry dust. Further, the addition of quarry dust increases the OMC and decreases the MDU. The reduction in dry density is attributed to the mixing of heavy particles beyond the addition of 25% quarry dust in soil. The strength decreases since the contents of the quarry dust segregate the particles and this, further, decreases the maximum dry unit weight.

4.3 Effect of Quarry Dust and Marble Dust on CBR

Figure 4 shows the variation of CBR with the percentage of admixtures in soil. It is observed that the soaked CBR attains the highest value when 20% of marble dust is added to the soil and, thereafter, it decreases. The reason behind the increase in CBR value is the presence of lime in the waste marble dust which behaves as the cementatious material. Owing to this, the bond between the clay particles and waste marble dust becomes strong, and it increases the load-bearing capacity of the mix.

The formation of a cation exchange reaction, followed by the Pozzolanic reaction, seems to be responsible for the increase in the CBR. The reduction in the CBR when the marble dust exceeds the optimum percentage indicates that the excess marble dust does not contribute significantly to the marble dust-soil reaction. On the contrary, the addition of quarry dust up to 25% increases the CBR since silica present in all the finer particles of soil and the quarry dust are used up to this value, and the addition of more quarry dust actually becomes counter-productive, thereafter.

5 Conclusions

There are several soft soil stabilizers that can be used to treat soft problematic soils. However, different types of soil and their location play an important role in order to determine the suitability and quantity of additives that will be used. Some of the broad conclusions deduced from the present experimental work entailing the stabilization of the marine clay using marble dust and quarry dust are given below.

- The liquid limit of the marine clay is found to be decreased by 33.86%, PL 22.85%, and PI 42% on the addition of 20% marble dust. In the case of 25% addition of quarry dust, liquid limit of the marine clay is found to be decreased by 32.5%, PL decreased by 28.57% and PI decreased by 35.55%.
- The OMC of the marine clay is found to be decreased by 19.33% on the addition of 20% marble dust and decreased by 21.32% on the addition of 25% quarry dust.
- The MDD of the marine clay is found to be improved by 8.57% on the addition of 15% marble dust and by 15% on the addition of 25% quarry dust.
- The CBR value of the marine clay is found to be increased by 32.4% on the addition of 20% marble dust and 346% on the addition of 25% quarry dust.
- For the best stabilization effect, the optimum proportion of marble dust is found to be 20% and that of quarry dust is 25%.

Both marble dust and quarry dust will improve the dry density and soaked CBR values, blending with different percentages in marine clay and changing the soil structure and improving the geotechnical properties. Hence, the use of marble dust and quarry dust in geotechnical applications is economically beneficial and environmentally advantageous. It will also substantially save the cost of construction. Based on the CBR value, quarry dust is satisfying the requirements of MoRTH [28] (5Th Revision, 2013). However, it does not satisfy the PI.

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