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Evaluation of hydraulic conductivity of marble dust-soil composite

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Abstract: *Hydraulic conductivity is the prime factor which decides the suitability of a material to be used as a landfill liner. It is necessary that a liner material in landfill remain nearly impervious for obstructing the leachate or waste water from contaminating the ground water and surrounding soil. In this study, a locally available clayey soil is tested for hydraulic conductivity by treating it with marble dust till 20%. The soil samples are compacted using standard and modified proctor compactive effort using moulding water contents -2, 0 and +2 percentages relative to optimum. The value of coefficient of permeability is observed upon addition of varying percentages of marble dust. The value of coefficient of permeability upon addition of a minimum stress is also studied and the effect is evaluated. The coefficient of permeability was found to decrease till 12.5 percentage marble dust addition and there after it remained relatively constant. It was also found to decrease with higher moulding water content. Using the results, compaction plane of acceptable zones were also plotted, from which marble dust addition percentages satisfying the regulatory value of coefficient of permeability ≤ 1 x 10-^{9} m/s is proposed as 25%.*

Keywords: *Compactive effort, Hydraulic conductivity, Landfill liner, Marble dust, Relative to optimum*

I. Introduction

Proper waste management is a factor which indicates the good organization and health of a society. The worldwide used method for proper waste management is an Engineered landfill, which has selected components for serving proper enclosement and treatment of waste. Only if the components of landfill work properly, will the waste management be effective. One of the most important components of landfill is a liner system, which protects the part of landfill in contact with soil. The landfill liner helps in obstructing any leakage (of leachate or waste water) from contaminating the groundwater and surrounding soil. The liner system should have certain satisfactory properties to help the proper functioning of a landfill. The basic requirement is that the liner should have least permeability i.e. the coefficient of permeability of the material should be in the range of $k \leq 1 \times 10^{-9}$ m/s. This is the basic requirement that any liner material should possess. Studies have suggested that a plasticity index greater than or equal to 7 % is also necessary for the material to be suitable as liner. Other factors include minimum load carrying capacity, volumetric shrinkage strain etc.

In the study conducted by Boynton (1985), the effect of the type of permeameter used, diameter of the specimen, storage time and desiccation cracking on permeability of compacted clay was studied. Kaolinite and Fire clay were used for the study. Permeameter like compaction mould permeameter, consolidation permeameter, rigid and flexible permeameter were used and it was concluded that there was only a slight variation in the measured values with different permeameters. It was also observed that the hydraulic conductivity of undisturbed samples increased with increase in the sample diameter. Also hydraulic conductivity decreased with increase in storage time up to 2 months and increased till 6 months [1]. Osinubi [2] in1998 conducted study on the permeability of lime treated lateritic soil. The test was done on residual lateritic soil treated up to 8% quicklime, in order to evaluate the effect of lime content, curing period and compactive effort on permeability of soil. It was ascertained that at 4% lime content the permeability increased to maximum and later on reduced. . In the case of cured specimen, permeability increased with curing period up to 14 days and decreased after that. Osinubi et al. in the year 2005 experimented the use of lateritic soil as landfill liner. Eighty four specimens were compacted at various moulding water content and permeated with water and compacted with four different compaction energy namely standard proctor test, modified proctor test, west African test and reduced proctor test. It was understood that the hydraulic conductivity decreased with increase in dry unit weight and initial saturation, especially at higher fines content [3].

Waste marble dust is the fine waste portion of marble formed through the chiseling and polishing of marble pieces. These processes are done by spraying water over it. So the waste marble is discarded as slurry, which on drying gets transported by wind and cause problems to humans and society. These wastes are also produced from buildings under construction where tiles are laid and polished. Thus the effective utilization of this waste is of high importance, and has been used as cement replacement additive in concrete blocks. Studies relating to utilization of marble dust to improve soil properties have been evolving in the recent past.

In the current study, marble dust is treated to a locally available soil collected from Thiruvananthapuram, Kerala to analyse the variation in hydraulic conductivity with different effects.

II. Materials And Methodology

2.1 Materials used

2.1.1 Soil

The soil used in this study is naturally occurring clayey soil collected Thiruvananthapuram district, Kerala which was obtained through quarrying from English Indian clay Ltd.

2.1.2 Marble dust

The marble dust used in the study is collected from marble producing industries, Bangalore. The sample was air dried before testing. They were added to soil in varying percentages of 5, 10, 12.5, 15 and 20% of soil. The particle size distribution and specific gravity tests were done for marble dust and the results are obtained as in Table 1.

Table .1: Properties Of Marble Dust Used

Properties	Value obtained
Percentage of silt sized particles (%)	60
Percentage of clay sized particles (%)	40
Specific gravity	2.63

2.2 Methodology

2.2.1 Index properties

The tests to determine index properties of soil were done using IS 2720.1985 (Part V). They were done in soil treated with 0, 5, 10, 12.5, 15 and 20% marble dust to understand the variation in properties of untreated as well as treated soil.

2.2.2 Compaction tests

The tests to determine the optimum moisture content and maximum dry density were done using both standard proctor compactive effort and modified proctor compactive effort according to IS 2720.1980 (Part VII) and IS 2720.1983 (Part VIII) respectively. The same is repeated for soil treated with 5, 10, 12.5, 15 and 20% marble dust.

2.2.3 Hydraulic conductivity testing

Hydraulic conductivity testing was done using consolidometer apparatus and falling head method was used, according to IS 2720.1986 (Part XVII). The permeant used was water and value of coefficient of permeability was recorded once it reached a constant value after complete saturation. The value of coefficient of permeability without any stress addition and also on an additional stress application of 200kPa was also recorded; 200kPa being the minimum load bearing capacity of a liner material. The test were done in both soils compacted at OMC -2%, OMC and OMC +2% with their respective dry density.

III. Results And Discussion

3.1 Index Properties

The particle size distribution of soil is presented in Fig. 1 and the index properties of soil is summarised in Table 2. From the test results, it was identified that the soil can be classified as clay of intermediate plasticity (CI) according to Unified Soil Classification system. The soil contains 21.5% sand, 20.5% silt and 58% clay particles. The variation in Liquid limit, Plastic limit, Plasticity Index, Shrinkage limit, and Specific gravity is also provided.

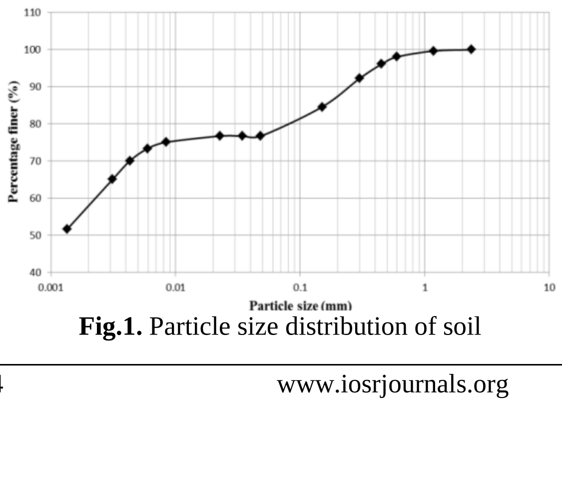


Fig.1. Particle size distribution of soil

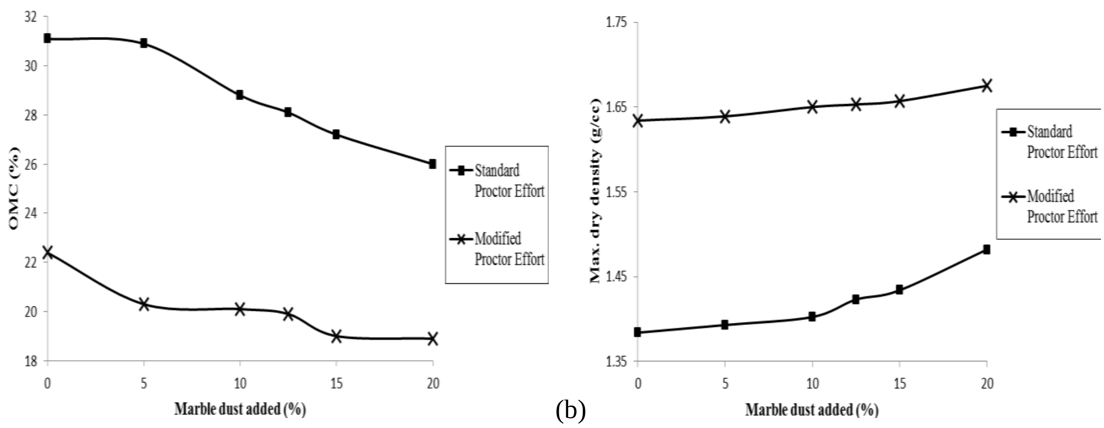
Table.2. Properties Of Soil

Properties	Value obtained					
	0	5	10	12.5	15	20
Natural water content (%)	22.5					
Liquid limit (%)	47	43.1	42.2	42.1	42	40.75
Plastic limit (%)	25.3	34.1	34.8	34.9	35	36.7
Shrinkage limit (%)	19.4	27.9	28.7	29.1	29	28.8
Plasticity index (%)	21.7	8.94	7.38	7.1	6.9	4
Specific gravity	2.48	2.49	2.5	2.51	2.52	2.53
Optimum moisture content (%)						
Standard Proctor	31.1	30.9	28.8	28.1	27.2	26
Modified Proctor	22.4	20.3	20.1	19.9	19	18.9
Maximum dry density (g/cc)						
Standard Proctor	1.384	1.393	1.4	1.423	1.434	1.48
Modified Proctor	1.634	1.64	1.65	1.653	1.657	1.675
Colour	White					

3.2 Compaction characteristics

The maximum dry density and optimum moisture content of untreated and marble dust-treated soil is obtained through standard as well as modified proctor method. As the percentage of marble dust addition increases from 0% to 20%, it was observed that the maximum dry density increased from 1.384g/cc for 0% marble dust to 1.552g/cc for 20% marble dust and the optimum moisture content decreased from 31.1% for 0% marble dust to 24% for 20% marble dust addition with standard proctor effort. With modified proctor effort the trend was same, with optimum moisture content decrease from 22.4% at 0% marble dust addition and 18.9% at 20% addition. The variation in maximum dry density also indictaed increase from 1.634g/cc at 0% dust addition to 1.675g/cc at 20% marble dust addition.

The decrease of optimum moisture content is accounted to the fact that the replacement of soil with marble dust reduces the attraction to water particles. The increase in maximum dry density is related to the increased specific gravity of marble dust (2.63) replacing soil with lower specific gravity (2.5) [4]. The variations of optimum moisture content and maximum dry density with different marble dust additions using both compactive efforts are presented in Fig. 2a and 2b.



(a) (b)

Fig.2. Variation with marble dust addition in (a) optimum moisture content, (b) maximum dry density

3.3 Hydraulic Conductivity testing

The results of the hydraulic conductivity for the various compactive efforts and marble dust treatment as monitored through the various soil parameters that can affect the hydraulic conductivity, which includes moulding water content, water content relative to optimum, additional stress application and the marble dust content, are discussed.

3.3.1Effect of marble dust addition at OMC

The variation of hydraulic conductivity with varying percentages of marble dust addition is shown in Fig. 3. It can be seen that the hydraulic conductivity decreases to a minimum till 12.5% marble dust addition in soil and there after remains relatively constant for both compactive efforts. The initial decrease in hydraulic conductivity is due to the reduction in pore spaces as the fines from the marble dust filled the voids thus reducing water flow. After this, the added marble dust particles remain unbonded with soil which results in a flocculated mix and thereby permeability increased slightly.

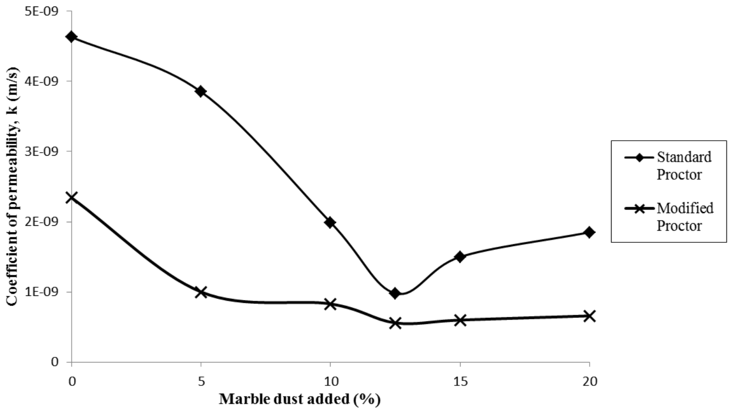


Fig.3. Variation in coefficient of permeability with varying percentage of marble dust content

3.3.2 Effect of moulding water content

The effect of moulding water content with coefficient of permeability is indicated in Fig. 4a to 4f. It can be seen that the k value decreases as the moulding water content increases for both standard proctor compaction as well as modified proctor compaction.

From the results, it can be observed that with 0% marble dust addition, a maximum value of k = 1 x 10^{-9}m/s was not achieved with both standard and modified Proctor effort. With 5% marble dust addition, k = 1 x 10^{-9} m/s was achieved at 20.2% moulding water content using modified Proctor effort and none with standard Proctor effort. With 10% marble dust addition, k = 1 x 10^{-9} m/s was achieved at 19.8% moulding water content using modified Proctor effort. Soil samples compacted using standard Proctor effort with 5% and 10% marble dust addition did not give the desired value. Using 12.5% marble dust addition, maximum value of k = 1 x 10^{-9} m/s was achieved at 28% moulding water content using standard Proctor effort. With modified Proctor, it was obtained at 18.4% moulding water content. Upon adding 15% marble dust, maximum value of k = 1 x 10^{-9} m/s is obtained at 28.7% water content using standard Proctor and using modified Proctor, 17.7% moulding water content gave k = 1 x 10^{-9} m/s. With 20% marble dust addition, 27.85% moulding water content using standard Proctor and 18% water content using modified Proctor gave k = 1 x 10^{-9} m/s..

3.3.3 Effect of water content relative to optimum

The variation in coefficient of permeability with water content relative to optimum upon addition of different percentages of marble dust is given in Fig. 5a to 5f. From the trend obtained, it can be understood that k decreased with higher moulding water content and vice versa. This is so because the soil compacted at higher moulding water content resulted in soil having lesser voids which conduct flow since the soil becomes more deflocculated. Higher water content also helped in formation of soil matrix in a closed pattern resulting in lower hydraulic conductivity.

From the results, it can be observed that with 0% marble dust addition, a maximum value of k = 1 x 10^{-9} m/s was not achieved using either standard or modified proctor effort. With 5% marble dust addition, maximum value of k = 1 x 10^{-9} m/s was achieved at optimum moisture content using modified proctor effort. With 10% marble dust addition, maximum value of k =1 x 10^{-9} m/s was obtained at 0.4% relative to optimum moisture content at dry side of optimum using modified proctor. Addition of 5% and 10% marble dust in soil compacted using standard proctor effort did not produce the required result. Using 12.5% marble dust addition, with standard proctor 0.1% relative to optimum moisture content at dry side of optimum gave a maximum value of k = 1 x 10^{-9} m/s. With modified proctor, k = 1 x 10^{-9} m/s is obtained at 1.6% relative to optimum moisture content at dry side of optimum. Upon adding 15% marble dust, maximum value of k = 1 x 10^{-9} m/s is obtained at 1.5% relative to optimum moisture content at wet side of optimum using standard proctor. Using modified proctor, 1.3% relative to optimum moisture content at dry side of optimum gave k = 1 x 10^{-9} m/s. With 20% marble dust addition, 1.7% relative to optimum moisture content at wet side of optimum using standard proctor and 0.85% relative to optimum at dry side of optimum using modified proctor gave k = 1 x 10^{-9} m/s.

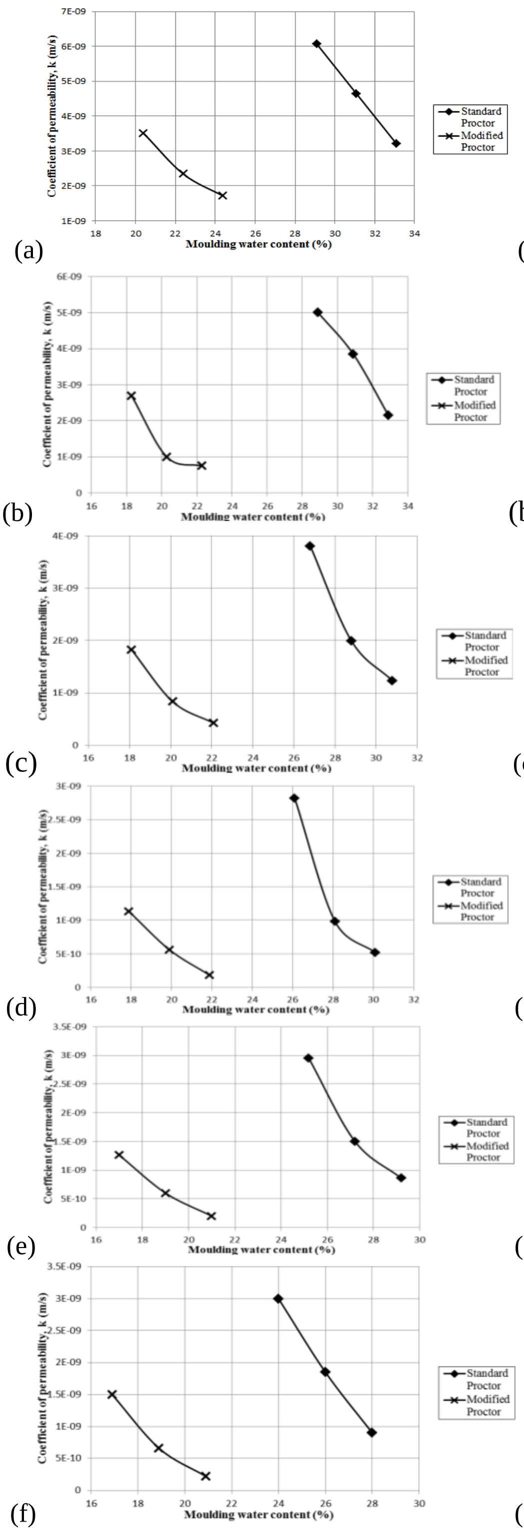


Fig.4: Variation in k with moulding water content (a)0% (b)5% (c)10% (d)12.5% (e)15% and (f)20% marble dust

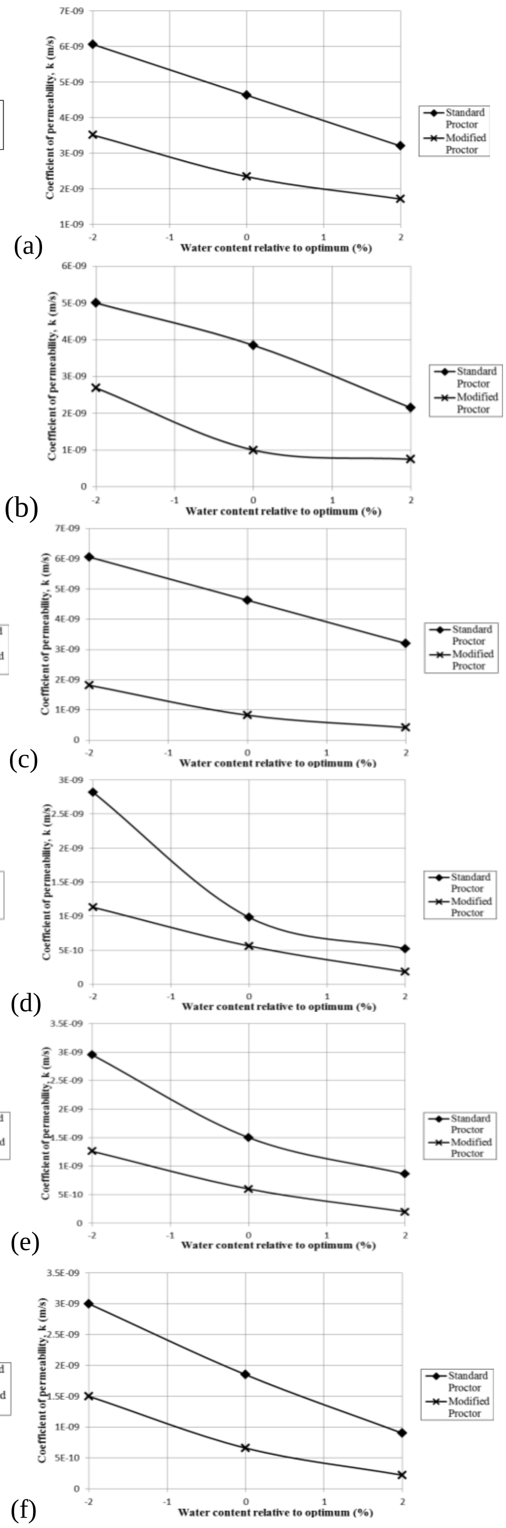
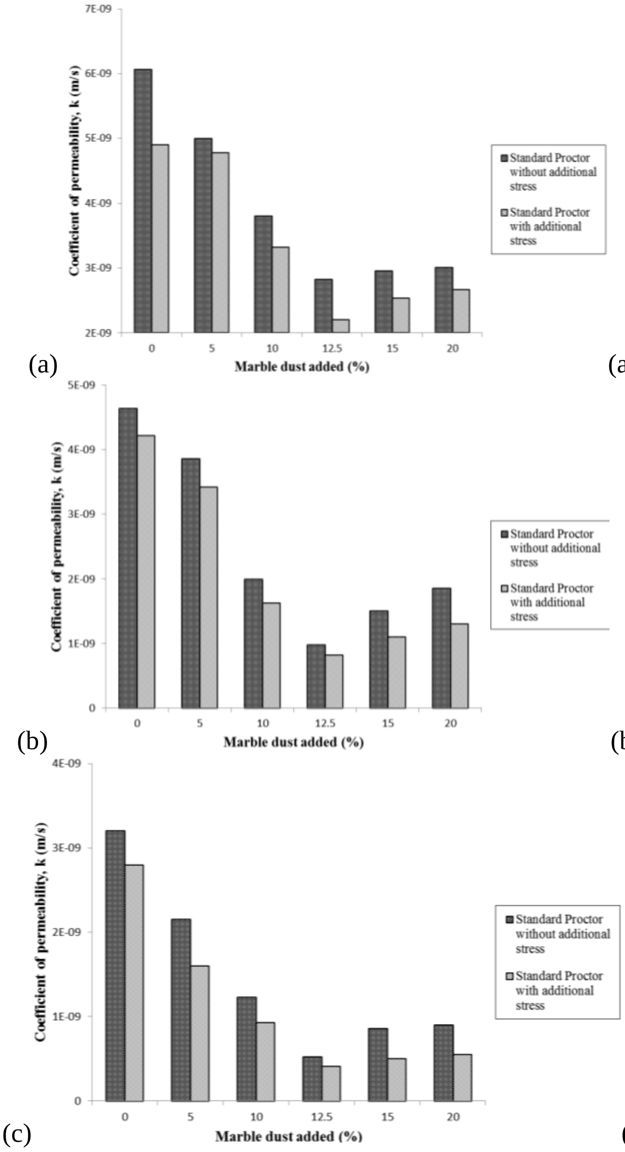


Fig.5. Variation in k with relative water content(a)0% (b)5% (c)10% (d)12.5% (e)15% and (f)20% marble dust

3.3.4 Effect of additional stress application

For making a soil suitable as liner material, it should have a minimum load carrying capacity of 200kPa. Effect of such an additional stress on soil is studied, to understand the variation in coefficient of permeability induced by it. The variation in coefficient of permeability was found to reduce upon addition of external stress. The additional stress application resulted in more denseness of soil matrix, leading to unavailability of pores to conduct flow. Thus k value was found to reduce further upon stress application. The variation in coefficient of permeability with different percentages of marble dust addition at 2% dry of optimum moisture content, at optimum moisture content and 2% wet of optimum moisture content using both compactive efforts is shown in fig.6 (a, b and c) and fig.7 (a, b and c).



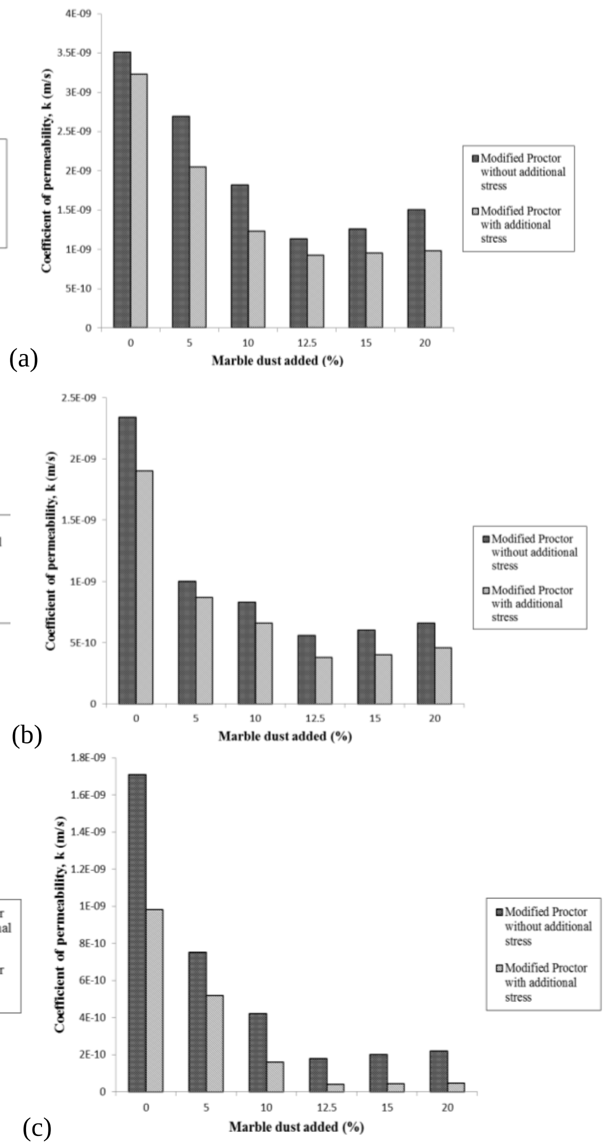
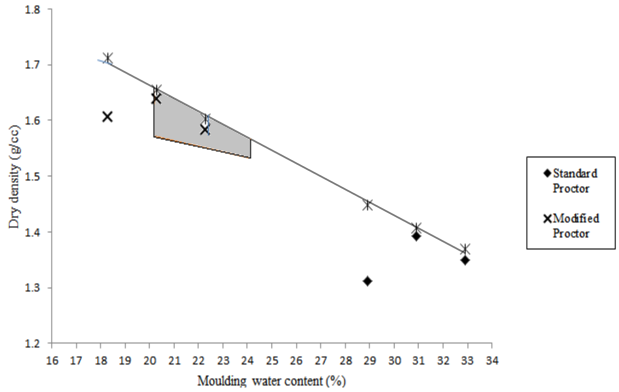


Fig.6. Variation in coefficient of permeability using standard proctor effort at (a) 2% dry of optimum (b) optimum (c) 2% wet of optimum

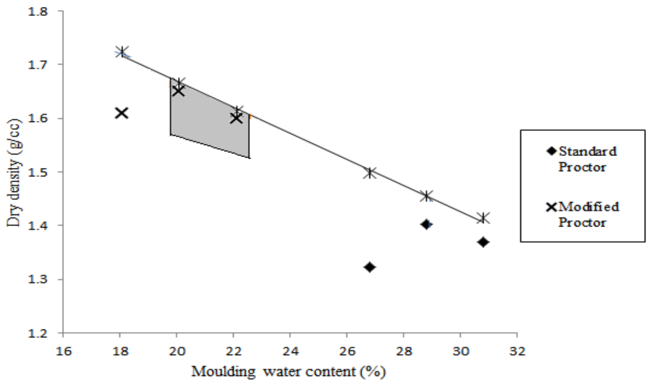
Fig.7. Variation in coefficient of permeability using modified proctor effort at (a) 2% dry of optimum (b) optimum (c) 2% wet of optimum

3.3.5 Acceptable zones

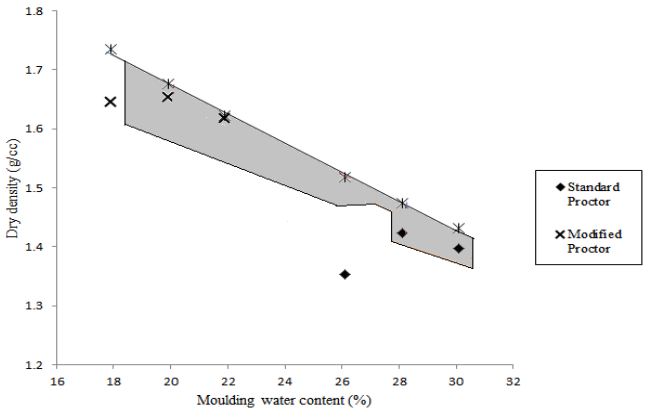
A zone of acceptance was plotted for each of the marble dust addition percentages. This was done by relating dry density and moulding water content with the desired value of coefficient of permeability i.e. $k \leq 1 \times 10^{-9}$ m/s. The compaction planes were used for the purpose and the acceptable zones for each percentage of marble dust addition is given in Fig. 8a to 8e.


Dry density (g/cc)
Moulding water content (%)
Standard Proctor
Modified Proctor

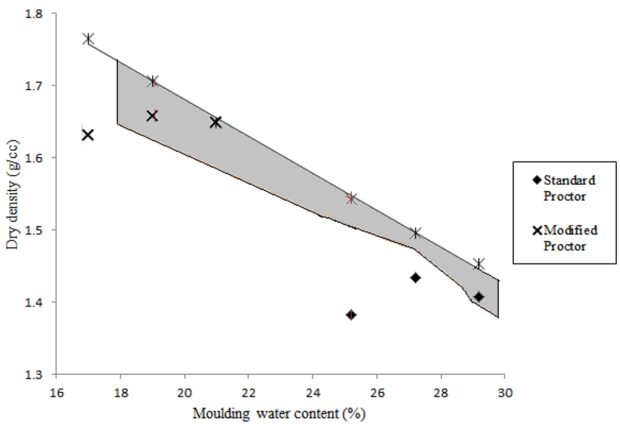
(a)


Dry density (g/cc)
Moulding water content (%)
Standard Proctor
Modified Proctor

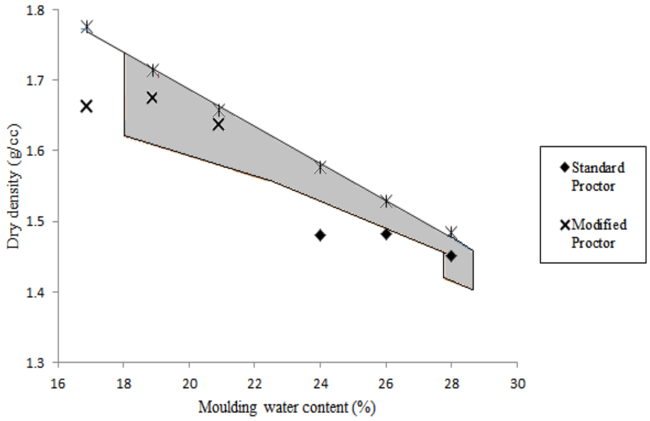
(b)


Dry density (g/cc)
Moulding water content (%)
Standard Proctor
Modified Proctor

(c)


Dry density (g/cc)
Moulding water content (%)
Standard Proctor
Modified Proctor

(d)



(e)

Fig.8. Acceptable zones for (a)5% marble dust, (b)10% marbe dust, (c)12.5% marble dust, (d)15% marble dust, and (e)20% marble dust

The acceptable zone for coefficient of permeability for untreated soil could not be plotted since none of the values obtained gave the desired value. For 5% marble dust addition, soil compacted at moulding water content ranging from 20.2 to 24.4% fell within acceptable zone (Fig. 8a). For 10% marble dust treatment, moulding water content from 19.8 to 22.6% fell within acceptable zone (Fig. 8b). With 12.5% dust addition, soil compacted at moulding water content from 18.4 to 30.4% came inside the acceptable zone (Fig. 8c). Moulding water content from 17.7 to 29.2% came under the acceptable zone with 15% marble dust addition (Fig. 8d). For 20% marble dust addition, moulding water content from 18.2 to 28.2% t gave necessary results (Fig. 8e).

The plots of acceptable zones show that 12.5, 15 and 20% marble dust addition gave the best suitable compaction plane on which coefficient of permeability, $k \leq 1 \times 10^{-9}$ m/s is mostly satisfied. Out of the 6 specimens tested, 3 lie within the acceptable zone. Considering the range of water content falling within acceptable zone and plasticity index (≥ 7%), 12.5% marble dust addition can be considered as optimum.

IV. Conclusion

Locally available soil was treated with waste marble dust to evaluate the variations in hydraulic conductivity. The compacted soil samples using Standard and Modified Proctor effort were tested in consolidometer and an additional stress was also applied to study the effect. From the results obtained, the following conclusions can be arrived upon.

- Compaction using marble dust resulted in higher maximum dry density and lower optimum moisture content.
- The coefficient of permeability was found to decrease till 12.5% marble dust addition and it later on remained relatively constant.
- Application of additional stress resulted in reduced hydraulic conductivity, due to formation of dense soil matrix.
- Soil compacted using modified proctor effort gave better results when compared to that compacted with standard proctor effort.

Based on the plots of acceptable zone and plasticity index value, addition of 12.5% marble dust in soil provided the most optimum results considering volumetric shrinkage strain values.

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