Compaction characteristics of red earth and quarry dust combinations

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Abstract. Quarry dust is a waste material obtained during the quarrying process. It exhibits high shear strength and good permeability. An efficient method to dispose it off is by using it in combination with red earth to strengthen the soil. This paper presents effects of addition of quarry dust on properties of red earth and the relationship between water content and dry density of quarry dust-red earth mixes. Preliminary studies concluded that the optimum proportion of quarry dust-red earth mixes was found as 40% and 60% respectively. The optimum values of the mixes are defined with respect to the dry density of quarry dust alone. It is observed that there was an increase of 11.61% in the dry density when 40% of the red earth is replaced with quarry dust. The optimum value of quarry dust to be mixed with red earth so as to have maximum shear strength is also determined. The shear strength of the mix was found from direct shear tests and it was observed that there is a reduction in the shear properties when quarry dust was mixed with red earth. However, quarry dust can be a sustainable solution to sub-base stabilization especially in case of highways.

Keywords: - Compaction characteristics, quarry dust-red earth mix, shear parameters.

1 Introduction

Laterite, also known as red earth is a non-expansive soil having kaolinite as the major constituent. It is found abundantly in and around south India. It is a mix-ture of clayey iron and aluminum oxides and hydroxides formed as a result of the weathering of basalt under humid, tropical conditions. Incidence of laterite is reported in Indian states of Karnataka, Maharashtra, Gujarat and Kerala. The intense southwest monsoon rainfall in Kerala coupled with the high temperature and lush vegetation has accentuated the chemical process over the base rocks, which has resulted in the formation of laterites. Thick deposits of red earth are found in Alappuzha, Kollam, Thiruvananthapuram, Kottayam, Thrissur, Palakkad and Kannur districts of Kerala. Kerala is a coastal region and have soft soils throughout the boundary line along the coast and hence, due to the desirable properties of red earth, it is needed in bulk quantities to construct subways by filling the site with red earth. However, scarcity of lateritic soil had led to the adoption of technically viable and economically feasible solution to address this problem.

Aggregate crusher units produce large quantities of quarry dust, during crush-ing of gravel and rock such that about 20-25% of the byproducts of the crushing rock operation is quarry dust. It amounts to nearly 250million tonnes of the total output of quarrying operations. Disposal of these large quantities of quarry dust produces serious problems in the environment and health hazards. There is much requirement to utilize these waste materials in an effective manner.

Studies have revealed that quarry dust can be used to improve the properties of lateritic soil in case of sub base construction works. This can potentially re-duce the usage of red earth.. This paper aims at the judicious usage of red earth and effective ness of quarry dust which is a waste material with in the field of civil engineering.

2 Literature Review

Road construction is an area where the industrial wastes can be utilized in bulk with advantage. Quarry dust, is a waste material which can be effectively utilized to minimize the usage of red earth. As the gradation of the material doesn’t satisfy the specification requirements for concrete works due to large specific surface, they can be effectively mixed with soils to enhance its properties. Owing to high shear strength and permeability, variation in water content doesn’t seriously affect its desirable properties. The test results revealed the dry density-water content relationship is comparatively flat at peak values and the effect of variation in water content from optimum moisture content on dry density is marginal. [14] A study involving the use of laterite stabilized with cement using quarry dust as additive for use as base course material showed that Liquid Limit, plastic Limit, Plasticity Index, and maximum dry density (MDD) decreases with increase quarry dust content, in all the cement proportions used. [2] A study on the variation of Atterberg limits on mixing the admixtures with red earth yielded that the addition of the chemical admixture can improve the engineering properties of soil. The soil liquid limit is found to decrease with an increase in cement and fly ash content while the soil void ratio was found to decrease with increase in admixtures. [12]

A study on the use of industrial byproduct mixtures as construction materials concluded that when fly ash is mixed with fine grained soils, it resulted in an improvement in the properties of both fly ash and fine grained soils. Results from lab tests indicate the improved material properties of combined fly ash aggregate waste which proved that a composition of fly ash and aggregate can be used as highway materials in flexible pavements [13].

Studies suggest that lime has a significant effect on the engineering properties of red earth treated with mine tailings. There is significant increase in strength due to long term pozzolanic reaction of the calcium oxide present in mine tailings with red earth resulting in the flocculation of particles. This encourages the effective utilization of mine tailings for geotechnical applications. [11] From the immediate compaction and unconfined compressive strength test up to 30 days of curing, black cotton soil with 3% $CaCl_2$ (by weight of soil) combination has higher factor of safety with higher curing periods for an embankment slope of 1:2.5[9]. Lateritic soil-cement mixture combinations revealed that as the amount of the added chemical calcium silicate hydrate (CSH) increased, the unconfined compressive strength (UCS) of the sample also exhibited corresponding increase. Hence, Improved lateritic soil can be used instead of crushed rock, as the base course material for highway pavement construction. [15]

The use and application of direct shear tests to determine the cohesion and angle of internal friction for angular soils yielded that adding clay contributed in increasing the dry density of the mixture and rendered the increase as well. [10]

3 Materials and Methods

Two types of soils were used in the present study and the preliminary material characterizations of these two soils were done. The preliminary studies on this soil such as grain size distribution, liquid limit, plastic limit, shrinkage limit, direct shear, standard proctor test were conducted. The physical properties of red earth and quarry dust samples taken for study is as given in Table 1 and Table 2 respectively.

Table 1. Properties of Red earth.

Property	Value
Specific Gravity	2.57
Grain size distribution	
Sand size (0.075-4.75 mm) (%)	62.1
Silt and clay size (<0.075) (%)	37.9
IS Specification	SW
D_{10} (mm)	0.165
D_{50} (mm)	1.25
C_u	9.41
C_c	1.46
Consistency limits	
Liquid limit (%)	45
Plastic limit (%)	23.76
Shrinkage limit (%)	29.16
Plasticity Index (%)	21.24

Table 2. Properties of Quarry Dust.

Property	Value

Specific Gravity	2.62
Grain size distribution	
Sand size (0.075-4.75 mm) (%)	60.12
Silt and clay size (<0.075) (%)	39.88
D_{50} (mm)	0.086
Relative Density	
ρ_{max} (g/cc)	1.512
ρ_{min} (g/cc)	1.175
Bulking	
Maximum bulking (%)	62.96
Water content for maximum bulking(%)	6

3.1 Light Compaction Test

The light compaction test was conducted on various proportions of red earth (laterite soil) and quarry dust as per IS 2720(Part 7):1980[18]. For each compaction test about 3kg of soil was used. Required amount of water was added to the soil and mixed thoroughly. The test code is tabulated in Table 3. In case of $Q_{100}R_0$, the test mix contains only quarry dust and no traces of red earth. Whereas, the test code $Q_{80}R_{20}$ has quarry dust and red earth mixed in 4:1 ratio. The same is shown in Fig.1. Standard proctor test for light loads were conducted on these proportions and the dry density and optimum moisture content for red earth and quarry dust is shown in Table 4.

Table 3. Test code

Test code	Quarry dust (%)	Red earth (%)
$Q_{100}R_0$	100	0
$Q_{80}R_{20}$	80	20
$Q_{60}R_{40}$	60	40
$Q_{40}R_{60}$	40	60
$Q_{20}R_{80}$	20	80
Q_0R_{100}	0	100

Fig. 1. Quarry dust-Red Earth mixes

Table 4. Dry density and optimum moisture content for Quarry dust-Red Earth mixes

Quarry dust-Red soil mixes	Maximum Dry Density (g/cc)	Optimum Moisture Content (%)
Q_0R_{100}	1.76	18
$Q_{100}R_0$	1.584	21

Direct Shear Test

The direct shear test was conducted as per IS 2720(Part 13):1986 [19]. The sample was oven dried and used for the test. The soil sample was prepared by mixing it with distilled water at various water contents. The coulomb envelope was plotted between normal stress and shear stress at failure to get the value of c as well as Φ. The direct shear test was conducted to investigate the influence of red earth-quarry dust mixtures on shear strength properties of the soil and to find out the optimum value of quarry dust to be mixed with red earth so as to obtain maximum shear strength. The tests were conducted on red earth and quarry dust to get the c and Φ values at optimum moisture contents. The results are shown in Table 5.

Table 5. Shear stress values for Quarry dust and Red Earth mixes

Quarry dust-Red soil mixes	Cohesion(c) (kg/cm^2)	Angle of shearing friction (degrees)	Normal stress (kg/cm^2) $\sigma = \Upsilon x1m$	Shear stress (kg/cm^2) $S= c+\sigma\tan\phi$
$Q_{100}R_0$	0	29.59	1.584	0.899
Q_0R_{100}	0.4804	39.76	1.76	1.464

On conducting direct shear test, it was seen that this mix yielded no cohesion but had a lower value of angle of shearing friction. The shear strength of this soil proportion at a depth of 1m was found to be 0.899kg/cm2.This shows poor shear strength. Hence quarry dust alone cannot be used for the purpose of soil stabilization.

4 Results and Discussions

4.1 Influence of percentage of red earth on the compaction and shear characteristics of quarry dust

The standard Proctor test and direct shear tests were conducted on these proportions and the normal stress and shear stress for red earth and quarry dust is shown in Table 6.

Compaction tests were conducted in different proportions of soil and is shown in Fig 2. From the graph, it was seen that all mixes had maximum dry density greater than quarry dust ($Q_{100}R_0$). The maximum dry density for red earth was 27% more compared to the density obtained for quarry dust alone. When quarry dust was mixed with red soil, a reduction in the optimum moisture content was observed with increase in dry density. Three mixes namely, $Q_{100}R_0$, $Q_{80}R_{20}$, and Q_0R_{100} had flatter peaks whereas remaining mixes, $Q_{60}R_{40}$, $Q_{40}R_{60}$, $Q_{20}R_{80}$ had well defined peaks for the dry density. When the graphs of $Q_{20}R_{80}$ and $Q_{60}R_{40}$ are considered it was seen that there was not much of a difference in their dry densities. Maximum dry density was obtained for the mix $Q_{40}R_{60}$.

Table 6. Normal stress and shear stress for Quarry dust-Red earth mixes

Test code	Cohesion (c) (kg/cm^2)	Angle of shearing friction (degrees)	Normal stress (kg/cm^2) $\sigma = \Upsilon x1m$	Shear stress (kg/cm^2) $S = c+\sigma\tan\phi$
$Q_{100}R_0$	0	29.59	5.28	0.899
$Q_{80}R_{20}$	0.0495	21.06	5.19	0.675
$Q_{60}R_{40}$	0.329	35.13	5.304	1.537
$Q_{40}R_{60}$	0.1529	24.09	5.154	0.943
$Q_{20}R_{80}$	0.4347	38.81	4.875	1.825
Q_0R_{100}	0.4804	39.76	4.644	1.944

The dry density and optimum moisture content for Quarry dust-Red Earth mixes are shown in Table 7.

Table 7. Dry density and optimum moisture content for Quarry dust-Red Earth mixes

Test code	Maximum Dry Density (g/cc)	Optimum Moisture Content (%)
$Q_{100}R_0$	1.584	21
$Q_{80}R_{20}$	1.625	20
$Q_{60}R_{40}$	1.718	19
$Q_{40}R_{60}$	1.768	18
$Q_{20}R_{80}$	1.73	18
Q_0R_{100}	1.76	18

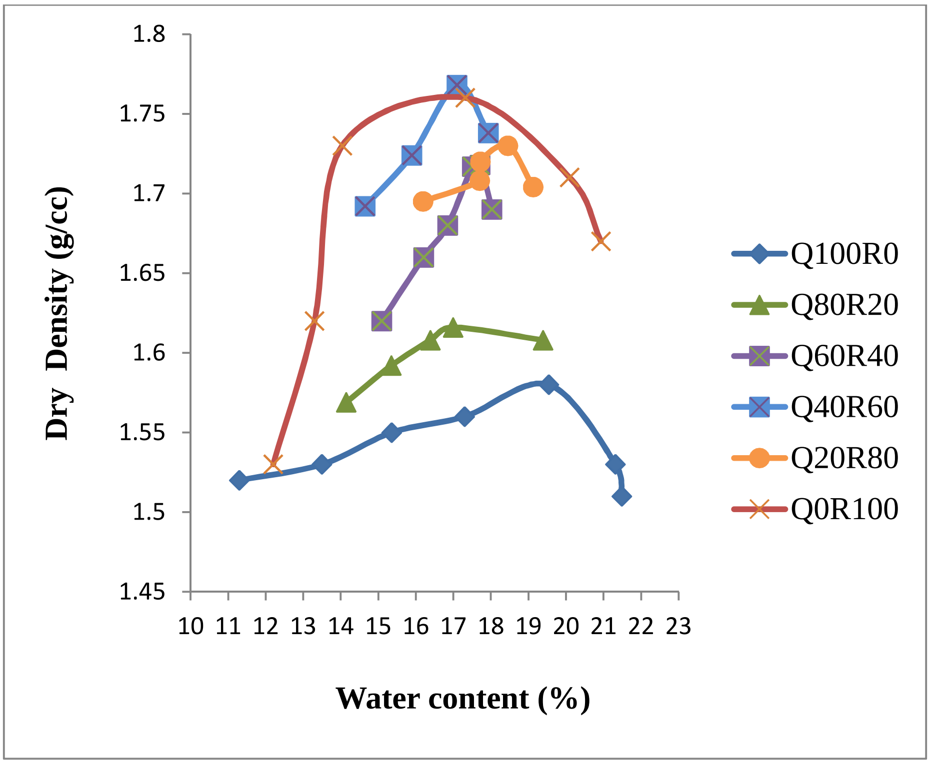

Fig. 2. Compaction curves for various proportions of red earth and quarry dust

Based on the above analysis, the dry density v/s percentage red earth graph was plotted. It was found that the dry density of $Q_{40}R_{60}$, (viz, 1.769) was greater than the dry density of quarry dust was when compacted alone, (viz, 1.76) as depicted in Fig.3. There was an increase of nearly 11.62% in the dry density. Also this dry density can be obtained by compacting the soil mix in its optimum moisture content. This is evident from Fig.3. There was a gradual increase of dry density with the decrease in the percentage of quarry dust. However, when the proportion of mix contained 20% quarry dust and 80% red earth ($Q_{20}R_{80}$), a decrease was found in the dry density. This was due to the change in the grain size. The soil was well graded until this proportion but later due to the change from well graded soil to poorly graded soil, the dry density decreased. The reason for the increase of optimum moisture content for this mixes also accounts to the same fact as seen in Fig.4.

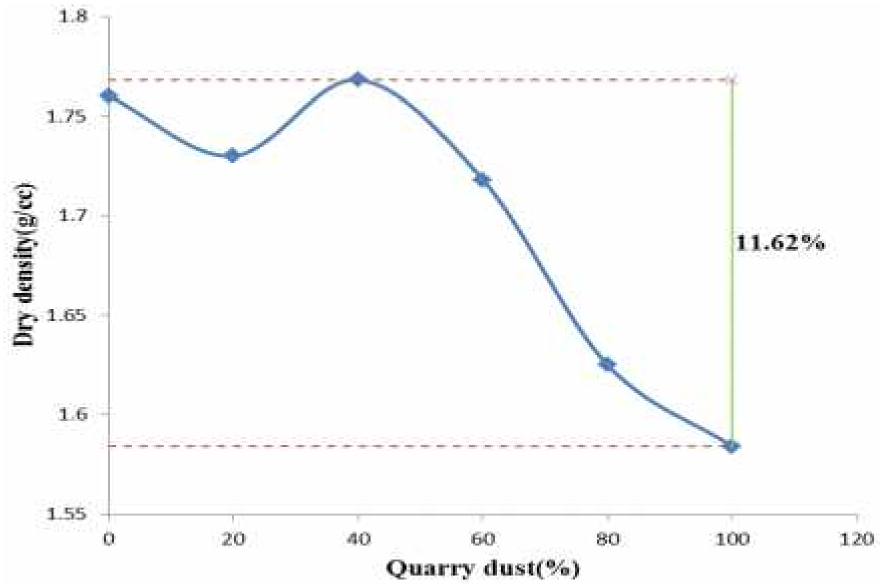

Fig. 3. Dry density versus percentage quarry dust for various mix proportions

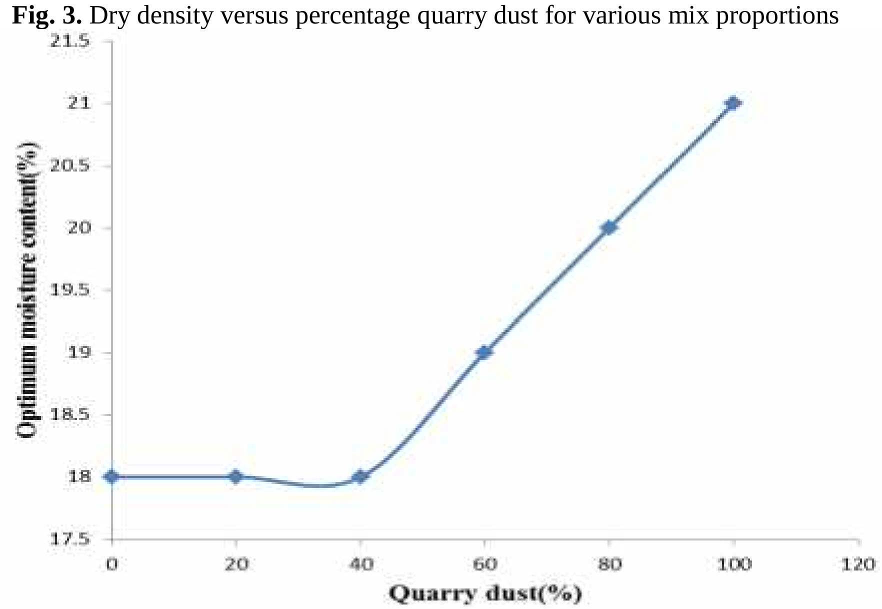

Fig.4. Optimum moisture content versus percentage quarry dust for various mix proportions

Based on the above results, the dry density versus C and Φ values were plotted and the optimum proportion of quarry dust and red earth as obtained from the compaction results was $Q_{40}R_{60}$. This value had a fairly better cohesion index and angle of internal friction.Further to obtain the trend followed by cohesion, angle of internal friction and percentage of red earth, c/c_{max} and Φ/Φ_{max} curves were also drawn. The values obtained at optimum moisture content was utilized for this purpose. This is shown in

Fig.5 and Figure 6. The c/c_{max} v/s percentage quarry dust graph showed a gradual drop with increase in quarry dust content. This was due to the fact that cohesion decreased with increase in moisture content. The Φ/Φ_{max} v/s percentage quarry dust graph did not show a definite trend with increase in moisture content due to the difference in mineralogical characteristics for different quarry dust-red earth mixes. [10]

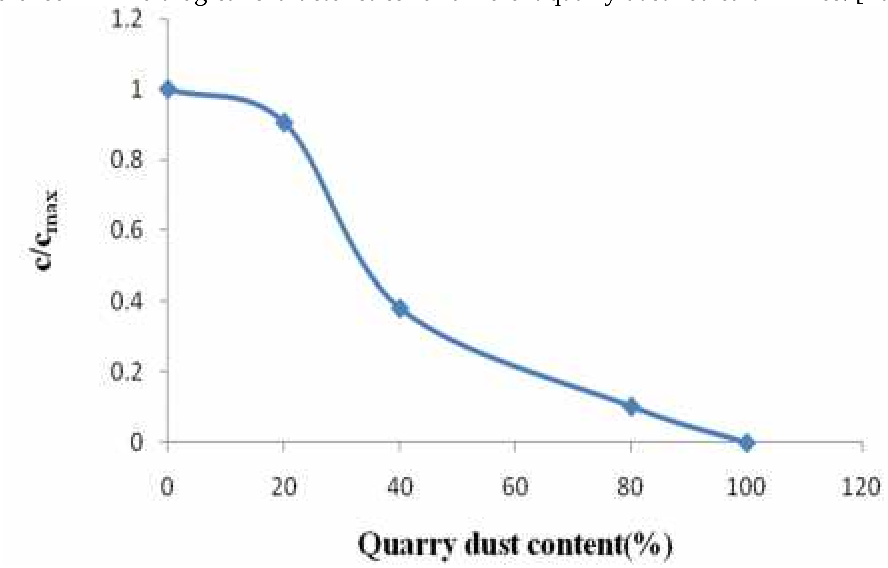

Fig. 5. c/c_{max} versus percentage quarry dust for various mix proportions

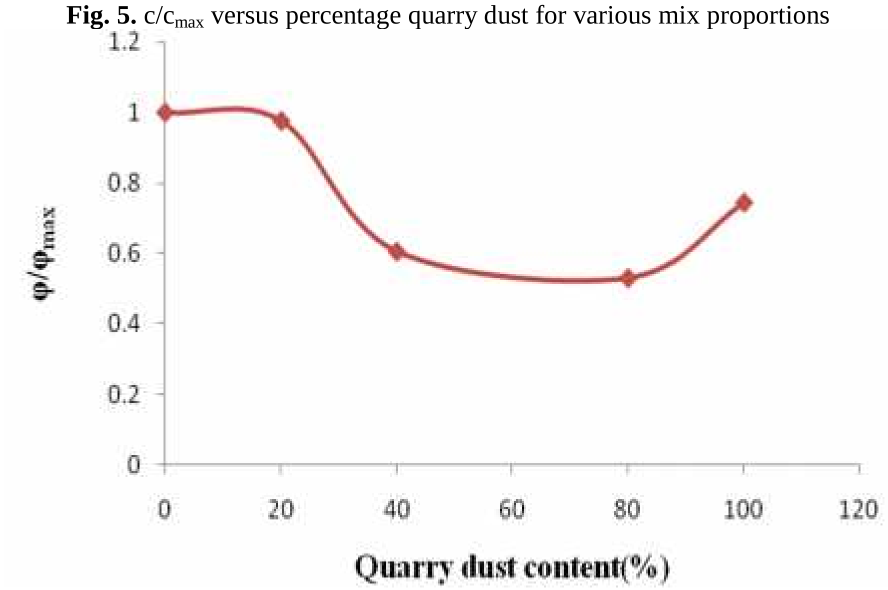

Fig. 6. Φ/Φ_{max} versus percentage quarry dust for various mix proportions

5 Conclusions

From the studies conducted, the following conclusions were derived.

- The dry density is higher for a mixture containing 60% red earth and 40% quarry dust.
- The optimum moisture content of this mix is 18%.
- The cohesion of soil decreases with increase in quarry dust content.
- The angle of internal friction increase with increase in quarry dust content.

Quarry dust, a waste material from rubble crusher units, consists of mainly sand size particles. Studies on quarry dust-red earth samples indicate that the dry density is higher for a mixture containing 60% red earth and 40% quarry dust when compared with the dry density of quarry dust alone. Furthermore, this proportion had a fairly better cohesion index and angle of internal friction. Due to this reason, this mix could be used to enhance partial replacement of red earth. When maximum dry density is obtained, the strength of soil gets increased thereby increasing its safe bearing capacity. As a result, heavy foundation is not required. Thus there is overall economy. There is also reduction in the amount of red soil to be used. Hence there is economy. It also contributes towards an environmental cause by preventing the excavation of hills for obtaining red earth.

Hence, quarry dust can be disposed of efficiently by using it in combination with red earth to strengthen the soil. This proportion can be utilized for sub base stabilization especially in case of highways.

The project can be further extended to find the number of blows which can yield the exact maximum dry density in a mini compaction apparatus. The scope also lies in usage of coir fiber to improve the shear strength characteristics of the quarry dust-red earth mixes.

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