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Utilization of quarry dust to improve engineering properties of soils in highway construction

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Abstarct
Quarry dust is a by-product of rubble crusher units and a commonly available material due to the vast usage of crusher metal in construction industry. This product can be used to improve engineering properties of poor quality soils, in order to develop a cost effective method for highway sub grade construction. As such, research reported in this paper illustrates the effect of usage of quarry dust as an admixture to improve the engineering properties of poor quality soils with combination of cement. Poor quality soils which were rejected by the one of the main road construction projects in Sri Lanka were selected as the test samples. These poor quality soils were mixed in the laboratory with different percentages of quarry dust and 2 % of cement on the weight and left to harden for a period of seven days. Further, shear strength behavior of soil-quarry dust mixes were presented in this paper. The results of the subsequent tests revealed that even mixing with only quarry dust caused appreciable improvement in engineering characteristics of poor quality soils. It was found that this improvement can be significantly enhanced with the addition of 2 % of cement. Therefore, problems associated in the construction of highways over clayey sub grade can be reduced significantly by mixing with quarry dust and cement.

Keywords: California Bearing Ratio, compaction, quarry dust, poor quality soil

Introduction

With the developments taking place in the country, there is a scarcity of lands with good sub soil conditions. Therefore, civil engineers are compelled to build new structures and infrastructure facilities in areas where existing ground conditions are not very favorable. In Sri Lanka, numbers of new projects are proposed at locations where there are soft clays/poor quality soils with substantial thickness.

Construction on soft clay/poor quality soil leads to stability problems during the construction and long term settlements during the service due to its very low shear strength and very high compressibility. Although the heavy loads from the super structure of multistory buildings can be transferred to an underlying hard stratum through piled foundations, it is not an economical form of foundations when the roads and service lines are to be constructed. In such situations the use of shallow foundations after the improvement of the soft soil/poor quality soil layer will be a more economical option.

Different methods are available for the improvement of compressibility and shear strength characteristics of soft soil and poor quality soil. These methods can be classified primarily as densification processes and solidification processes. In addition, replacement method is also very commonly used in the developing countries.

Preloading and dynamic compaction are some of the most widely used densification processes. In the past, preloading method was the most commonly used method to improve soft soil in developing countries. The main criticism against the preloading is the rather long time period required for the process. With the development taking place in the country, necessity of quick, economical and effective methods to improve soft/poor quality soil are rising up. Therefore, it is a responsibility of geotechnical engineers and scientists to find appropriate methods to improve soft/poor quality soil.

As a result many researches have paid their attention to use waste/by-products as construction materials to improve soft soil, especially in highway construction. In this research study, applicability of quarry dust, which is a by-product of metal crusher units, to improve sub grade materials in pavement construction in highways was studied.

Quarries and aggregate crushers are basic requisites for construction industry. Rubble crushing is processed for use as construction aggregate consisting of blasting, primary and secondary crushing, screening and stockpiling operation. Quarry dust is a by-product of rubble crushing operation and is one of the newly found materials used for the ground improvement in highway construction, building industry etc, especially in developing countries. By a rough estimation about million tons of quarry dust is been generated in each year as a by-product. Gradation of this material does not satisfy the specification requirements for concrete works. This is mainly due to fine state of quarry dust resulting in large specific surface. In this background any attempt to utilize this by-product in highway construction is useful.

A review of literature indicates that, in India, quarry dust has been extensively utilized in geotechnical applications such as embankments, highway sub grades etc (Soosan et al., 2005). Further, many researches (Gidley and Sack, 1984; Kamon et al., 1989; Rao and Reddy, 1989) have utilized other industrial wastes such as fly ash, marble dust to stabilize the soft soils. There are limited information available about the utilization of industrial waste combined with cement or lime to improve the engineering characteristics of poor quality soils. The research reported in this paper, an attempt was made to improve the engineering properties of poor quality soils, which were rejected by the consultants of one of the major highway construction sites in Sri Lanka, mixing with different proportions of quarry dust and 2 % of cement.

Results obtain in this study will help to solve the problems associated with highway construction over the poor quality soils to a considerable extent and which may contribute towards the economy in construction of highways.

Materials and Methods

Quarry dust samples were collected from three different rubble crusher units (Location 1, 2 and 3) near to the faculty premises. Particle size distribution of quarry dust samples from different locations are presented in Figure 1. It can be seen from the figure that quarry dust mainly consists of sand size particles; fine sand ranging from 23.3 to 26.9 %; medium sand ranging from 31.0 to 41.4 %; coarse sand ranging from 15.4 to 23.6 %. Even though the samples are collected from different locations and different quarries, variation in particle size distribution is marginal. Since the lowest gravel percentage is obtained from the rubble crusher unit at Location 2, which was selected for collecting quarry dust materials for this research study. Physical properties of the selected quarry dust sample are illustrated in Table 1.

Poor quality soil samples which were rejected by the consultants of one of the main road construction projects in Sri Lanka, were selected for this research study. Particle size distribution and physical properties of the selected soil sample are depicted in Figure 1 and Table 1 respectively along with the data of quarry dust. The soils possess relatively high liquid limit and relatively high plasticity index, which does not satisfy the Road Development Authority (RDA) highway pavement construction specifications. Further, particle size distribution of soil sample possesses a large percentage of silt and clay. According to the Unified Soil Classification System (USCS) this soil can be classified as High Plasticity Silt (MH).

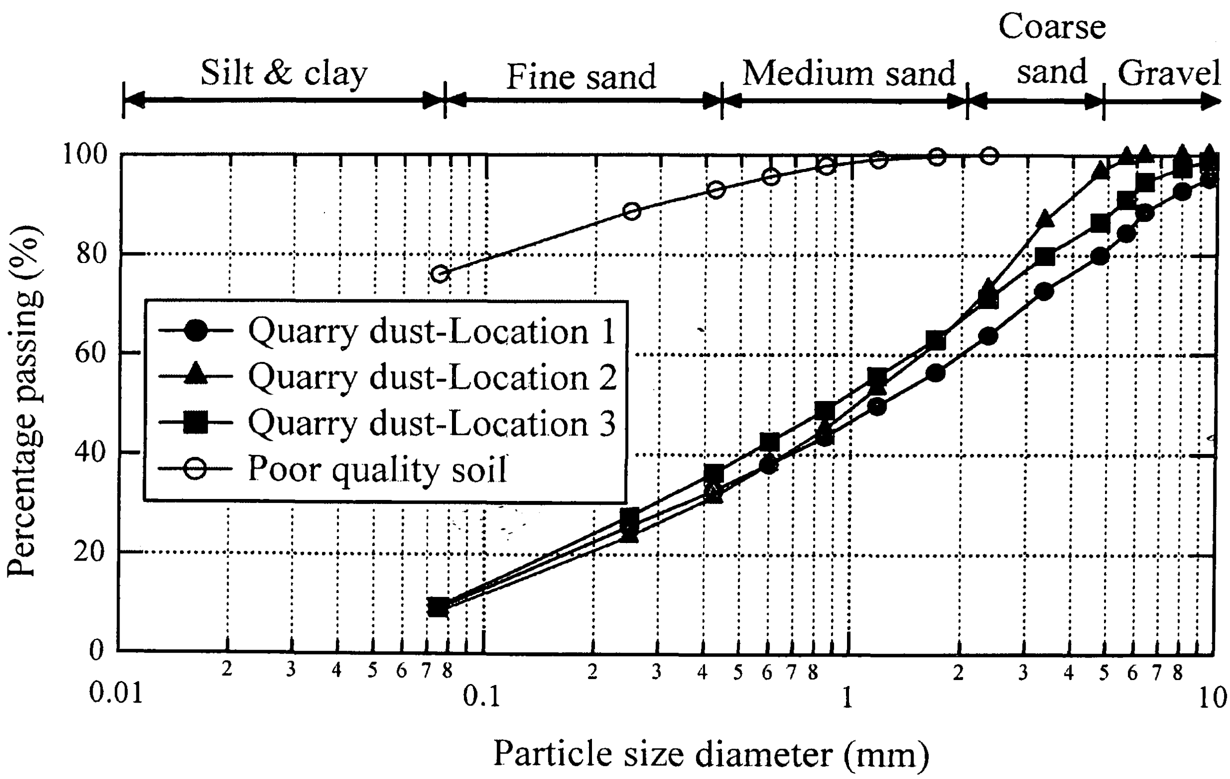

Figure 1 - Particle size distribution of quarry dust and poor quality soil

Table 1 – Physical properties of quarry dust and poor quality soil

Properties	Quarry dust	Soil
Soil classification according to USCS	SM	MH
Specific gravity	2.64	2.49
Maximum dry density(kg/m^3)	2102	1244
Optimum moisture content (%)	10	35
Unsoaked CBR value (%)	61.18	11.67
4 day soaked CBR value (%)	48.00	2.90
Liquid Limit (LL) (%)	27.00	73.50
Plastic Limit (PL) (%)	Non-plastic	38.20
Plasticity Index (PI) (%)	0	35

Experimental Investigation on Soil-Quarry Dust Mixtures

Different percentages of quarry dust varying between 0 to 100 % in steps of 20 % on dry weight were mixed with poor quality soil using a mechanical mixer. Sample prepared by mixing four parts of soil (80 %) with one part of quarry dust (20 %) on dry weight is designated as S-20 In similar lines, in samples S-40, S-60 and S-80, quarry dust content was 40, 60 and 80 % respectively on total dry weight of the mixture. Unimproved soil is represented as S-0 where as quarry dust alone is designated as S-100

Particle size distributions of soil-quarry dust combinations are presented in Figure 2. It can be seen that percentage of sand content gradually increases with the addition of quarry dust. Conversely, it can be noted that percentage of silt and clay content decreases with the increase of percentage of quarry dust. The physical properties of the soil-quarry dust combinations are illustrated in Table 2.

It is well known that liquid limit of a particular soil is determined using Atterberg limit apparatus which is commonly named as Casagrande's method. However, difficulties are encountered in cutting a groove in order to determine the liquid limit of soil-quarry dust mixtures when the percentage of quarry dust increases (Sheerwood and Ryley, 1970; Soosan et al., 2005). In order to overcome these problems, Sheerwood and Ryley (1970) proposed to use Cone Penetrometer to determine liquid limit. As such, in this research study, liquid limit of soil-quarry dust mixture were determined using Cone Penetrometer method according to BS 1377-Part 2.

Compaction tests were conducted for all soil-quarry dust mixtures using the Standard Proctor Compaction test. The California Bearing Ratio (CBR) tests under both unsoaked and 4 day soaked condition were conducted based on the results of Standard Proctor Compaction test for all soil-quarry dust mixtures. Further, direct shear test on samples compacted at optimum moisture content were conducted in order to investigate the shear strength characteristics of soil-quarry dust mixtures (Wijesooriya et al., 2008)

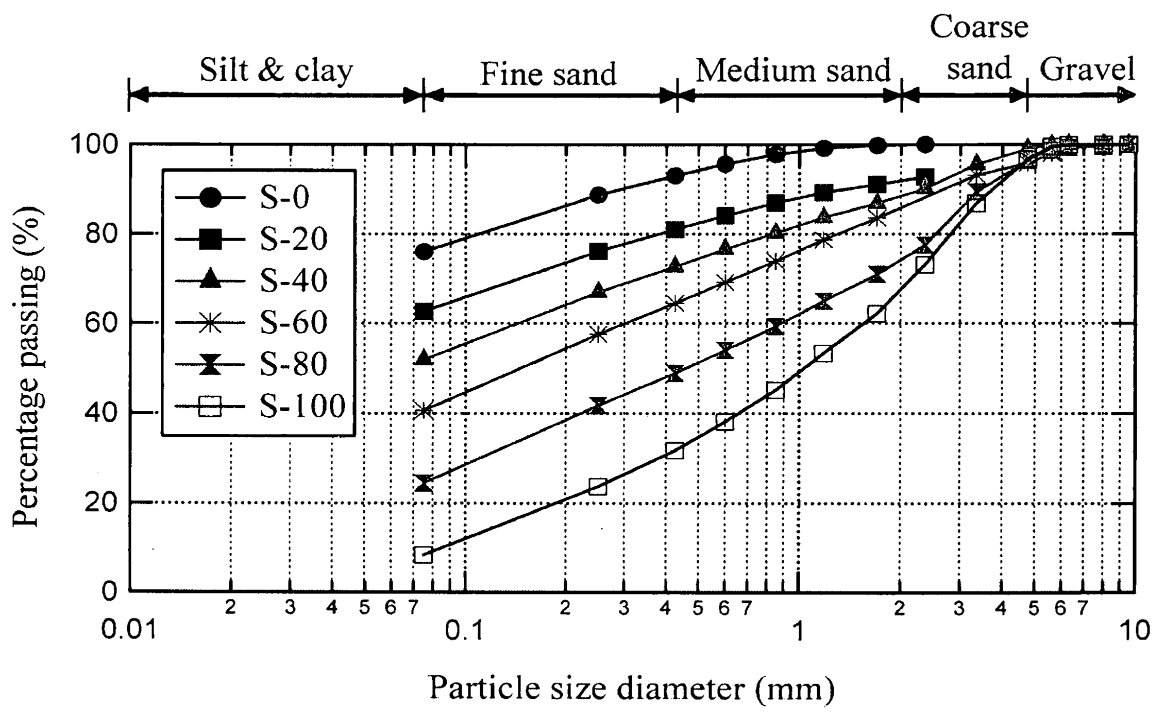

Figure 2 - Particle size distribution of soil-quarry dust mixtures

Table 2 - Physical properties of soil-quarry dust mixtures

	Liquid Limit (%)	Plastic Limit (%)	Maximum dry density (kg/m^3)	Optimum moisture content (%)	4 day soaked CBR value (%)	Unsoaked CBR value (%)
S-0	73	38	1244	35	2.90	11.67
S-20	67	Non-plastic	1414	27	3.00	11.25
S-40	54	Non-plastic	1529	22	3.67	16.10
S-60	43	Non-plastic	1767	15	5.57	23.20
S-80	32	Non-plastic	1939	13	13.80	33.35
S-100	27	Non-plastic	2102	10	48.00	61.18

Experimental Investigation on Soil-Quarry Dust-Cement Mixtures

In order to further improve the engineering characteristics of poor quality soil, cement was added to the soil–quarry dust mixture. Kulathilaka et al. (2001) has been found that, engineering properties of peat can be sufficiently improved with mixing 5 % of cement. Based on this fact, 5 % of cement on dry weight was mixed with S-40 sample which was taken as the trial sample.

Three soil-quarry dust-cement samples were prepared, in order to find the CBR at unsoaked, 4 day soaked and 7 day soaked conditions. Results of this pilot test are presented in Table 3. It is a well known factor that concrete achieves its full unconfined compressive strength within 28 days and 70 % of the unconfined compressive strength within 7 days. Further, due to the long testing period of durability test (28 days), many highway agencies currently use 7 day unconfined compressive strength values for cement treated soils (Zhang and Tao, 2008). Therefore, in addition to the conventional 4 day soaked CBR value, 7 day soaked CBR value was determined for soil-quarry dust-cement mixture as shown in Table 3.

It can be seen that CBR values have been increased significantly with the addition of 5 % of cement. A noticeable increase in 7 day soaked CBR value can be observed over the 4 day soaked CBR value due to the hardening effect of the cement. Therefore, it was decided to check only the 7 day soaked CBR value instead of conventional 4 day soaked CBR value for the cement treated soil-quarry dust mixtures.

Due to the significant improvement of CBR value with mixing 5 % of cement on soil- quarry dust mixture, it was decided to reduce the cement percentage, in order to reduce the cost. As show in the Table 3, there was no improvement with the addition of 0.5 % of cement. Therefore, 2 % of cement was added to soil-quarry dust mixture in order to achieve a substantial improvement in CBR value. Zhang and Tao (2008) also indicated that in order to achieve a substantial improvement in unconfined compressive strength in cement treated soil, cement percentage should be greater than 2.5 %. Therefore, the selected cement percentage in this research is almost comparable with the literature.

Table 3 - CBR values of soil-quarry dust-cement mixtures

Quarry dust percentage (%)	Cement percentage (%)	CBR value		
		Unsoaked	4 day soaked	7 day soaked
40	5.0	24.00	76.70	173.20
40	0.5	5.68	-	4.76
40	2.0	13.22	-	73.57

Results and Discussion

Liquid Limit

Variation of liquid limit with the addition of quarry dust is presented in Figure 3. It can be seen that liquid limit of soil-quarry dust mixtures linearly decreases with the increase of quarry dust percentage. About 45 % reduction in liquid limit with respect to unimproved soil can be observed with the addition of 60 % of quarry dust. This indicates that cohesive nature caused by the absorbed water surrounding the clay particles reduces with the addition of quarry dust. Another notable feature is that all combinations of soil-quarry dust mixtures show non-plastic behaviour, i.e. plasticity index of all combinations of soil-quarry dust mixture equal to zero.

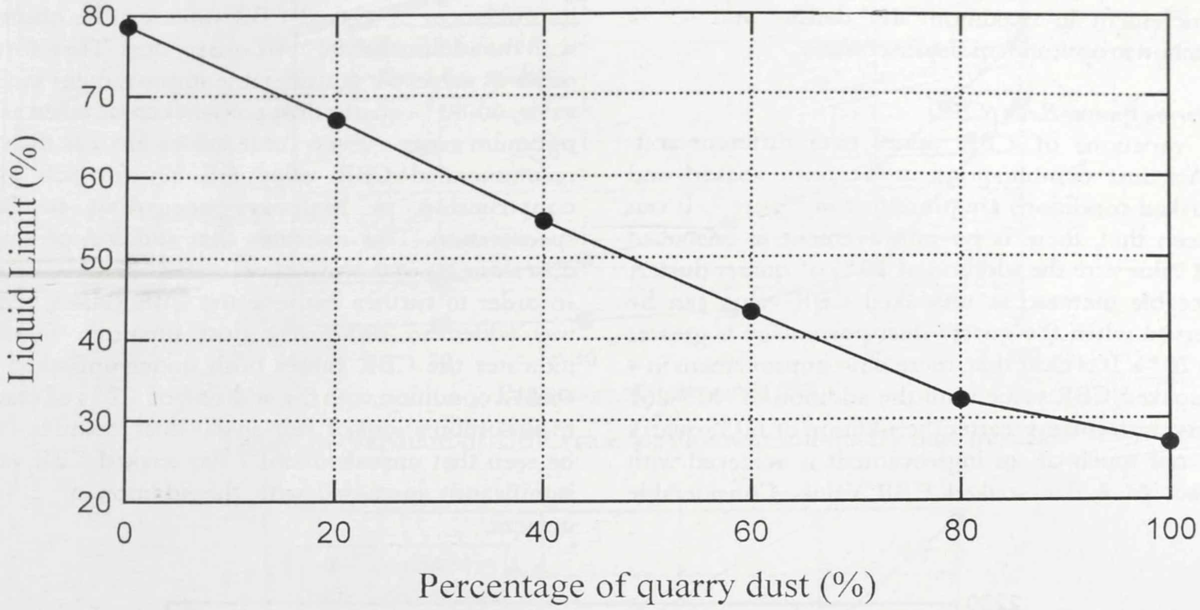

Figure 3 – Variation of liquid limit of soils with the addition of quarry dust

Shear Strength Characteristics

Figure 4 illustrates the variation of internal friction angle and cohesion of soil-quarry dust mixtures with respect to percentage of quarry dust. It can be noted that addition of quarry dust to soil reduces the cohesion whereas increases the friction angle. A significant variation in shear strength characteristics can be observed when the quarry dust percentage varies from 20 to 60 %. Conversely, no significant variation can be achieved when the quarry dust percentage is greater than 60 %. These results clearly indicated that addition of quarry dust is more effective when quarry dust percentage is 20-60 % with respect to shear strength characteristics.

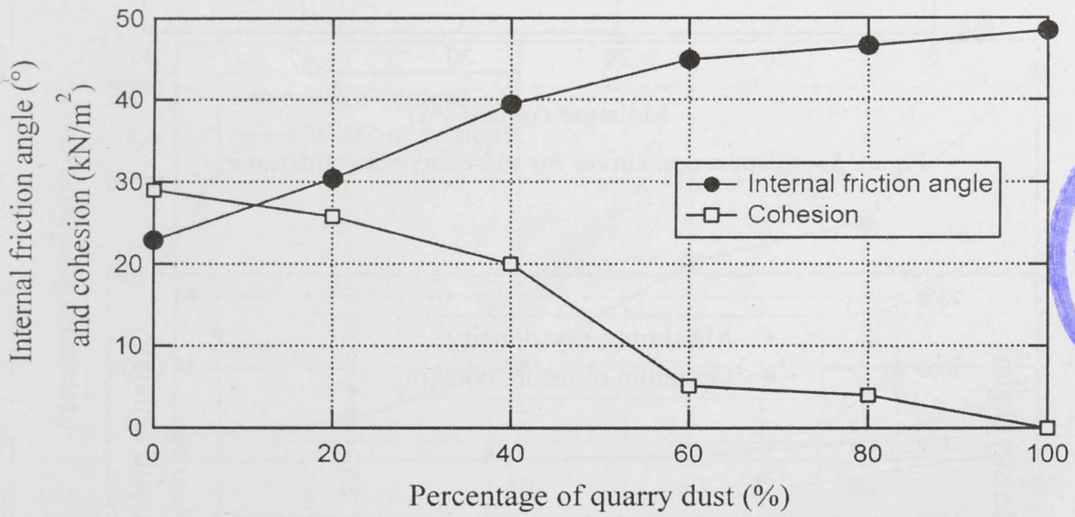

Figure 4 – Variation angle of internal friction and cohesion with the addition of quarry dust

Compaction Characteristics

Standard Proctor Compaction curves for soil-quarry dust mixtures are presented in Figure 5. It can be seen that unimproved soil gives an almost flat curve. Conversely, quarry dust shows the highest value of maximum dry density and the lowest value of optimum moisture content compared to unimproved soil. This is mainly because of the coarser of solid particles and high specific gravity of quarry dust.

The compaction curve of unimproved soil (S-0) which is relatively flat shows more and more pronounced peak with the addition of quarry dust. The variations of maximum dry density and optimum moisture content over the percentage of quarry dust are presented in Figure 6.

It can be noted that addition of any amount of quarry dust to soil increases maximum dry density and decreases optimum moisture content considerably. Results indicated that percentage increment in maximum dry density and percentage reduction in optimum moisture content are significant when addition of quarry dust percentage vary from 40 to 60 %. It is a notable feature that maximum dry density can be improved to 1600 kg/m^3 which is the RDA requirement for sub grade construction in highways with the addition of 47 % of quarry dust. This is a 23

% increment in maximum dry density and 43 % reduction in optimum moisture content.

California Bearing Ratio (CBR)

The variations of CBR values over different soil-quarry dust combinations under both soaked and unsoaked conditions are presented in Figure 7. It can be seen that, there is no improvement in unsoaked CBR value with the addition of 20 % of quarry dust. A noticeable increase in unsoaked CBR value can be observed when the quarry dust percentage is greater than 20 %. It is clear that, there is no improvement in 4 day soaked CBR value until the addition of 40 % of quarry dust. But even after the addition of 60 % quarry dust not much of an improvement is achieved with respect to 4 day soaked CBR value. Considerable improvement in soaked CBR value can be observed with the addition of 80 % of quarry dust. Therefore, in order to achieve a considerable improvement in CBR value, 60-80 % quarry dust content can be taken as the optimum range. Even these values are less than the recommended CBR value (15 %) for sub grade construction in highways according to RDA specification. This indicates that addition of quarry dust alone is not that effective.

In order to further improve the CBR values, cement was added to soil-quarry dust mixtures. Figure 8 indicates the CBR values both under unsoaked and soaked condition with the addition of 2 % of cement to all combinations of soil-quarry dust mixtures. It can be seen that unsoaked and 7 day soaked CBR values significantly increased with the addition of 2 % of cement.

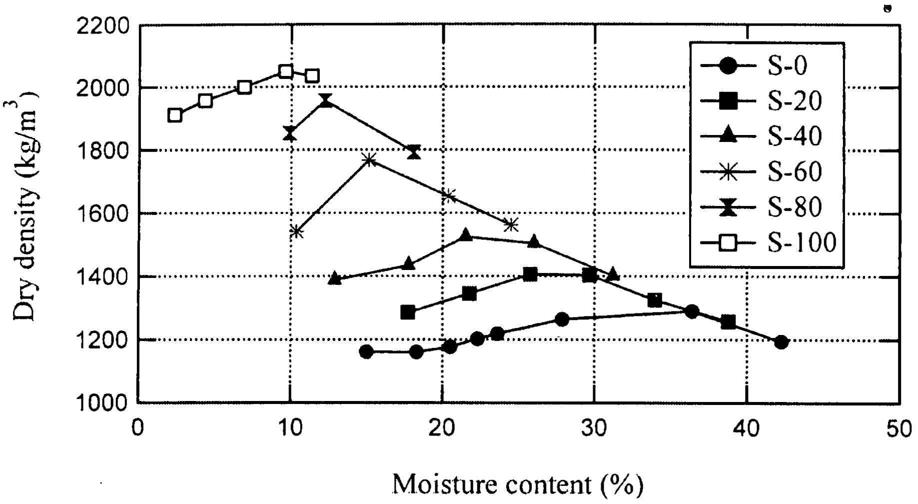

Figure 5 – Compaction curves for soil-quarry dust mixtures

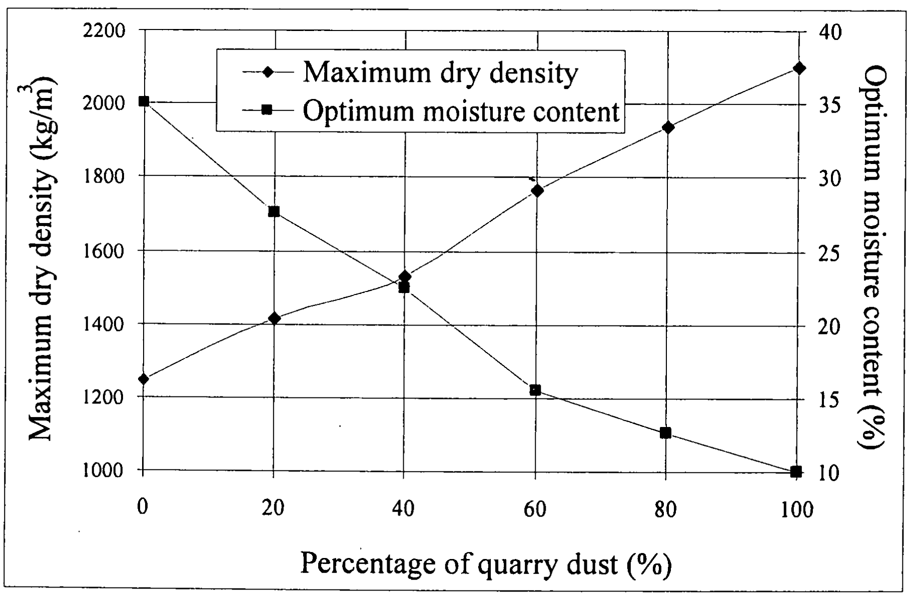

Figure 6 – Variation of maximum dry density and optimum moisture content of soil-quarry dust mixture over percentage of quarry dust

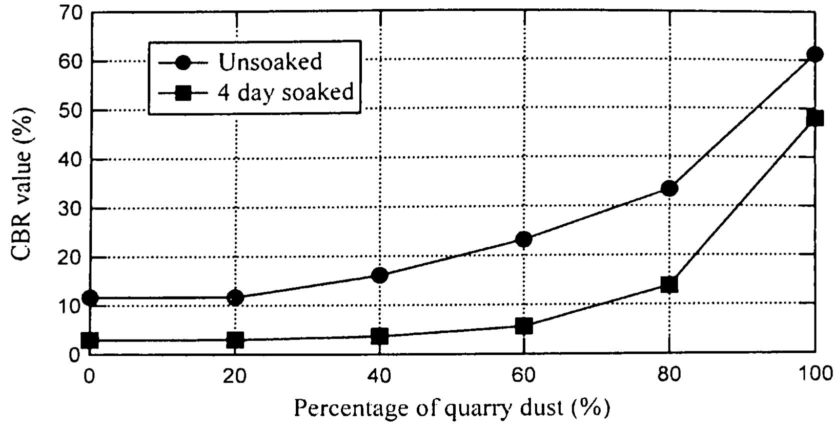

Figure 7 – Variation of CBR value for different soil-quarry dust mixtures

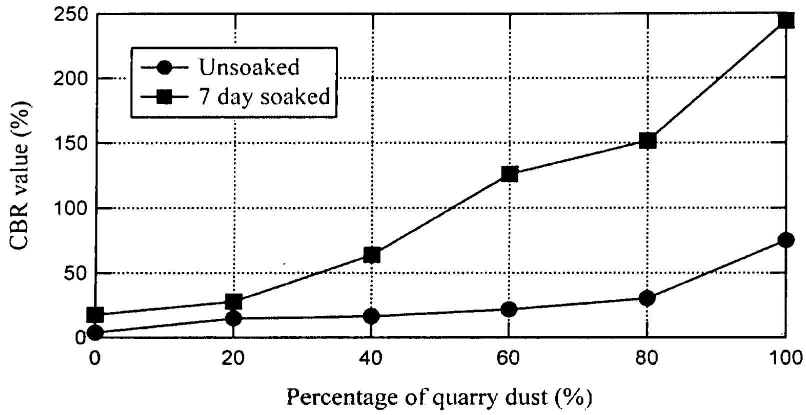

Figure 8 – Variation of CBR value for different soil-quarry dust mixtures with the addition of 2 % of cement

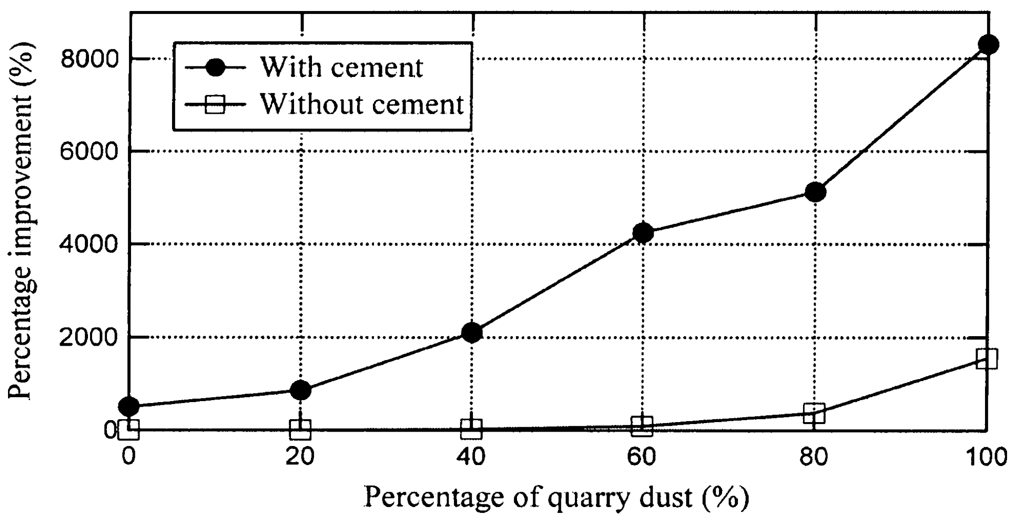

Figure 9 – Comparison of improvements achieved in CBR values with the addition of cement

The effect of mixing cement with soil-quarry dust mixture on soaked CBR values are illustrated in Figure 9. A noticeable improvement in CBR values can be observed when 2 % of cement mixing with 20-60 % of soil-quarry dust combinations. No significant improvement in CBR values is observed, when the quarry dust content is between 60-80 %. Therefore, 20-60 % of quarry dust content with 2 % cement can be taken as the optimum range, in order to achieve a substantial improvement in engineering properties of poor quality soil.

Conclusions

Improvement of poor quality soils mixing with industrial waste like quarry dust is one of the major challenges faced by Sri Lankan civil engineers. Quarry dust, a by-product of rubble crusher units, consists of mainly sand size particles with high specific gravity and high dry density.

The improvement by mixing with different percentage of quarry dust and 2 % of cement were tried under laboratory conditions and improvements achieved in engineering properties were evaluated. Engineering properties of poor quality soils were improved substantially by the addition of quarry dust. Improvements are manifested in the form of reduction of liquid limit, reduction of plasticity index, increase of internal friction angle and reduction of cohesion.

Addition of quarry dust into poor quality soil is seemed to cause significant improvement in maximum dry density and reduction in optimum moisture content. It was found that highway sub grade construction requirements stated by RDA specification can be achieved with respect to maximum dry density with the addition of 47% of quarry dust into poor quality soil.

The research presented in this paper found that CBR values steadily increased with increase in percentage of quarry dust. Considerable improvement in 4 day soaked CBR value was obtained with the addition of 80 % of quarry dust. Even this value is less than the recommended soaked CBR value (15 %) for highway construction. Further, usage of 80 % of quarry dust cannot be recommended based on the cost factor. Therefore, it was concluded that addition of quarry dust alone to improve the engineering properties of poor quality soil is not much effective.

In order to further improve the CBR values, 2 % of cement was recommended to mixing with soil-quarry dust mixture. It was revealed that 20-60 % quarry dust content with 2 % cement can be taken as the optimum range, in order to achieve a substantial improvement in engineering properties of poor quality soil. Hence it can be concluded that use of quarry dust for geotechnical applications is economically beneficial and environmental friendly.

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