Effect of Rice Husk Ash on Mechanical Behavior of Karewa soil

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Abstract: Karewas are lacustrine soil deposits of low flat mounds or elevated plateaus. They are found abundantly throughout Jammu and Kashmir, occupying an area of more than 5000 square kilometers. Karewa soils are known for their agricultural value however, the use of Karewa soils is not limited to agriculture alone as they provide shelter for local population as well. Structures built on these soils are subjected to differential deflections, which cause distresses in Karewa soils, and cause hazardous damage to the structures. These soils exhibit low shear strength and high compressibility. They swell on wetting and shrink on drying, thus, showing undesirable engineering behavior. The present study deals with stabilization of remolded samples of Karewa soils using Rice Husk Ash (RHA). Various soil samples were collected from different locations of the Pampore area in the Kashmir valley. Soil tests like gradation, consistency limits, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) tests were performed. The mechanical properties of Karewa soil were improved using RHA in percentages of 5%, 7.5%, 10%, 12.5%, and 15% by dry weight of soil. The results obtained show that increase in RHA content increased the Optimum Moisture Content (OMC), and decreased the Maximum Dry Unit weight (MDU) of the soil. It was also seen that increase in RHA content reduced the plasticity, increased the volume stability, increased the UCS, and CBR of the soil. The optimum value of RHA was observed at 10%, beyond which the strength decreased.

Keywords: Mechanical properties, Karewa soil, Rice husk ash, Soil stabilization

1. Introduction

Karewas are fresh-water lacustrine soil deposits, found as low flat mounds, or elevated plateaus in the Kashmir valley [1]. The word ‘Karewa’ is derived from a Kashmiri dialect, ‘Wudars’ meaning plateaus [2]. The Kashmir basin, which was once a lake, is surrounded by the great Himalayan mountain range in the north-east and Pir-Panjal range in the south-west. The sediments deposited in the lake are about 1300m thick, known as quaternary sediments of the Karewa group [3]. These deposits are largely fluvio-lacustrine, glacio-fluvio-lacustrine, and aeolian in origin [4]. The lake deposits of mud, called ‘Karewas’, are believed to have originated in two different periods of history, forming a younger and an older series of Karewa soils [5].

The Karewa group of sediments is mostly composed of sand, silt, clay, shale, mud, lignite, gravel, and loessic sediment [6]. Karewa soils usually show undesirable engineering properties [7]. They display low shear strength, which is decreased on wetting, and other physical disturbances [8]. These soils can be plastic and compressible, swell when wetted, and shrink when dried. Karewa soils creep with time under a constant load, particularly when the shear stresses get closer to its shear strength, making it vulnerable to sliding [9]. They develop large lateral pressures and give low values of resilient modulus. During winters, Karewa soils absorb water, become swelled and soft, decreasing its load bearing capacity. In dry seasons, these soils shrink, due to the evaporation of their water content and become harder [7]. Due to the problems associated with Karewa soils, their properties need to be improved by stabilizing the soil mass.

Since Karewa soils are present in the form of elevated plateaus or flat top mounds, they are susceptible to slope failures and landslides [10]. The Kashmir valley receives abundant snowfall during winters, and plenty of rainfall in spring. This leads to increase in the shear stresses and decrease in the shear strength of the soil, resulting in slope failures of the soil mass [11]. Landslides occur at an average shear stress far smaller than the peak strength, due to the mechanism of progressive failure. The mechanism of progressive failure is normally associated with non-uniform stress distribution along the failure surface, and the strain softening characteristics of the soil. During the past few years, the frequency of slope failures has increased considerably in comparison to other natural calamities [12]. Landslides are a potentially damaging natural disaster [13, 14]. Thus, Karewa soils need to be strengthened, and stabilizing them, using waste material like rice husk ash (RHA) is a feasible choice [15].

Rice husks are the hard-protective coverings of rice grains, produced during the winnowing of the rice paddy [16, 17]. The husk is a waste material, and is generally disposed of, either by dumping or burning in the boiler for processing paddy [18]. Combustion of rice husk produces ash, which is about 20% of its weight [16]. This ash, commonly known as RHA, contains silica as its basic constituent, whose quality (percent of amorphous and un-burned carbon) depends on the type of burning process [19]. Research has shown that RHA contains about 90% silica, [20, 21] which is the highest concentration of all plant residues [22]. Based on this, RHA has found utility in improving the properties of soil, either when added alone or when mixed with a hydraulic activator such as cement or lime [23-25]. The properties of RHA mainly depend on whether the husks have undergone complete destructive distillation or have only been partially burned [26]. Houstin [20] classified RHA into the following classes:
(1) High-carbon (char) ash,
(2) Low-carbon (grey) ash, and
(3) Carbon-free (pink or white) ash.

RHA possesses a high content of amorphous silica, which makes it pozzolanic in nature [16]. The annual rice paddy production of India is approximately 100 million tons, which generates more than 4 million tons of RHA [27]. Owing to its high 'fineness' value, it can be a good material for sealing fine cracks in civil structures, where it can penetrate deeper than the conventional 'cement-sand' mixture [28].

2. Materials and Testing Program

2.1 Materials

In this study, the following materials were used and tested in the laboratory using the standard code guidelines.

2.1.1 Karewa soil

The disturbed soil samples were collected from the Pampore Karewas of the Pulwama district, which falls along the national highway NH-1A, at a depth of 1.5 m below the ground level. Sufficient care has been taken to ensure that the samples obtained are homogenous. The soil samples were air dried and passed through 4.75mm sieve. The physical properties of the Karewa soil are given in Table 1.

2.1.2 Rice husk ash (RHA)

A solid agricultural waste Rice Husk Ash (RHA) was selected in order to study its impact on the indices and engineering characteristics of the Karewa soil. The RHA obtained from the Shalimar area of Srinagar, was burned properly before being used. The physico-chemical composition of the RHA used is listed in Table 2. The silica content of RHA is 89.5%, which provides good pozzolanic action when mixed with the soil [29].

Table 1 Physical properties of Karewa soil

Property	Value
Natural water Content, w_n (%)	23
Specific gravity, G	2.61
Clay (%)	9
Silt (%)	88
Sand (%)	3
Gravel (%)	0
Liquid Limit, LL (%)	35
Plastic Limit, PL (%)	29
Shrinkage Limit, SL (%)	16
Plasticity index, $PI = (LL - PL)$ (%)	6
Plasticity index, A-line, $PI_A = 0.73(LL\text{-}20)$ (%)	11
Plasticity index, U-line, $PI_U = 0.9(LL\text{-}8)$ (%)	24
Clay mineral	Kaolinite
Classification	MI
Unconfined compressive strength, q_u (kPa)	162
Optimum moisture content, (%)	19
Maximum dry unit weight, (kN/m^3)	16.3
Un-soaked CBR, (%)	7.8
Soaked CBR, (%)	3.3

2.2 Testing Program

The soil samples were subjected to different soil tests including gradation, specific gravity, consistency limits, and light compaction tests using the relevant standard procedures [30, 31]. Unconfined compressive strength [32] and California bearing ratio tests [33] were conducted to establish the strength parameters. Test specimens were prepared by adding RHA to Karewa soil in the ratio of 5%, 7.5%, 10%, 12.5%, and 15% respectively by dry weight of soil at 0.95γ_{dmax} and optimum moisture content. The treated soil specimens were subjected to consistency limits, unconfined compressive strength, and California bearing ratio tests using the standard code procedures.

Table 2 Physicochemical composition of RHA

Chemical composition (%)	Value
Silicon dioxide (SiO_2)	89.5
Calcium oxide (CaO)	0.11
Magnesium oxide (MgO)	1.70
Sodium oxide (Na_2O)	0.57
Potassium oxide (K_2O)	2.01
Ferric oxide (Fe_2O_3)	0.76
Aluminum oxide (Al_2O_3)	1.39
Manganese oxide (MnO_2)	0.07
Loss on ignition	3.59

3. Results and Discussions

3.1 Physical and Engineering properties of untreated Karewa soil

The soil samples collected were brownish in color, having a specific gravity of 2.61 [34]. The particle size distribution curve of the Karewa soil is shown in Figure-1 [35]. The gradation curve reveals that the soil contains a maximum silt content of 88% and a clay content of 9%. The gradation curve represents the distribution of particles of different sizes in the soil mass. The particle size analysis is used in the classification of coarse grain soil [36]. It provides the index of the strength and load bearing capacity of the soils [37]. It is required for the design of drainage filters, suitability of backfill material and the susceptibility of a soil to frost action. Generally, a well graded soil has higher strength compared to a uniformly or poorly graded soil [38].

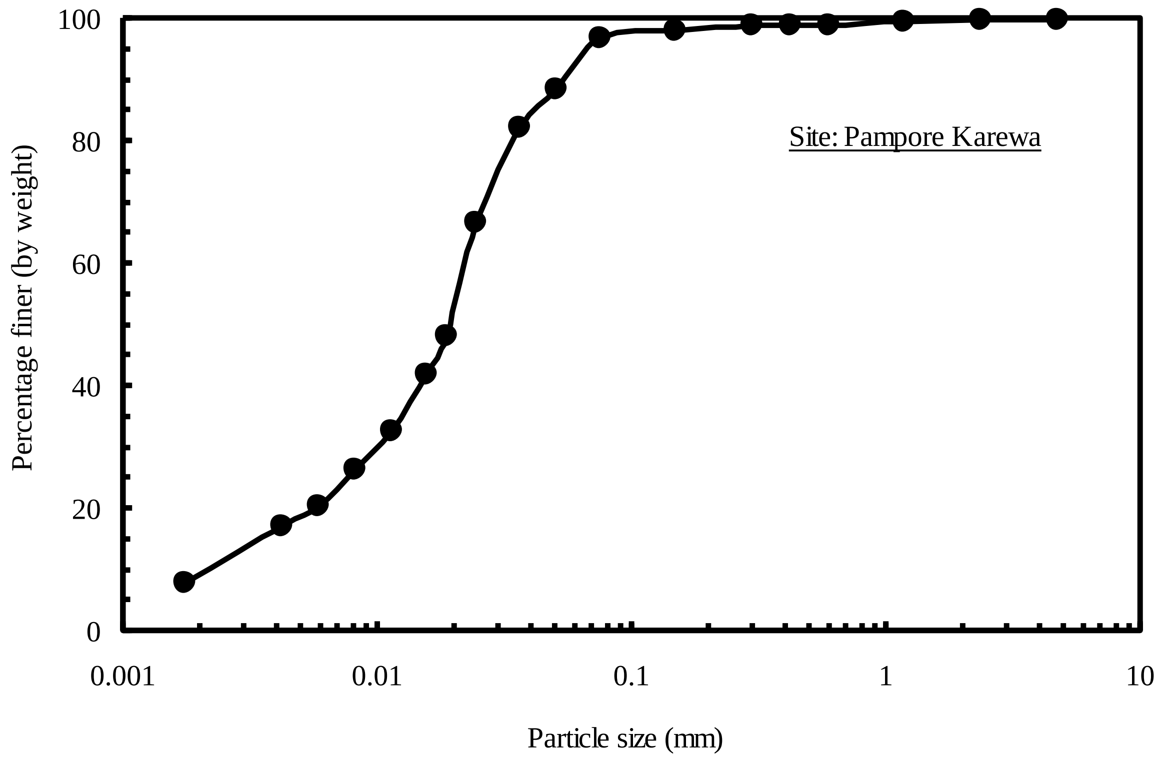

Fig. 1 Particle size distribution curve of Karewa soil

Atterberg limits- the liquid limit, plastic limit, and the shrinkage limit are widely used in soil mechanics [39]. The values of the liquid limit and the plastic limit give us a basic measure of fine grained soils, besides being essential in the classification of soils [40]. They give us an overall idea of the engineering properties of soils. Consistency limit tests were conducted using the relevant standard testing procedures [41]. The liquid limit and the plasticity index of soil is 35% and 6% respectively. Based on the test results, Karewa soil is classified as clayey silt of medium plasticity as per Indian system of soil classification (ISC) system [30]. The flow curves of the soil are shown in Figure-2. The compaction curves of the Karewa soil were obtained using the standard Proctor compaction test method (Figure-3) [42]. The maximum dry unit weight is 16.3kN/m^3, and the optimum moisture content is 19%.

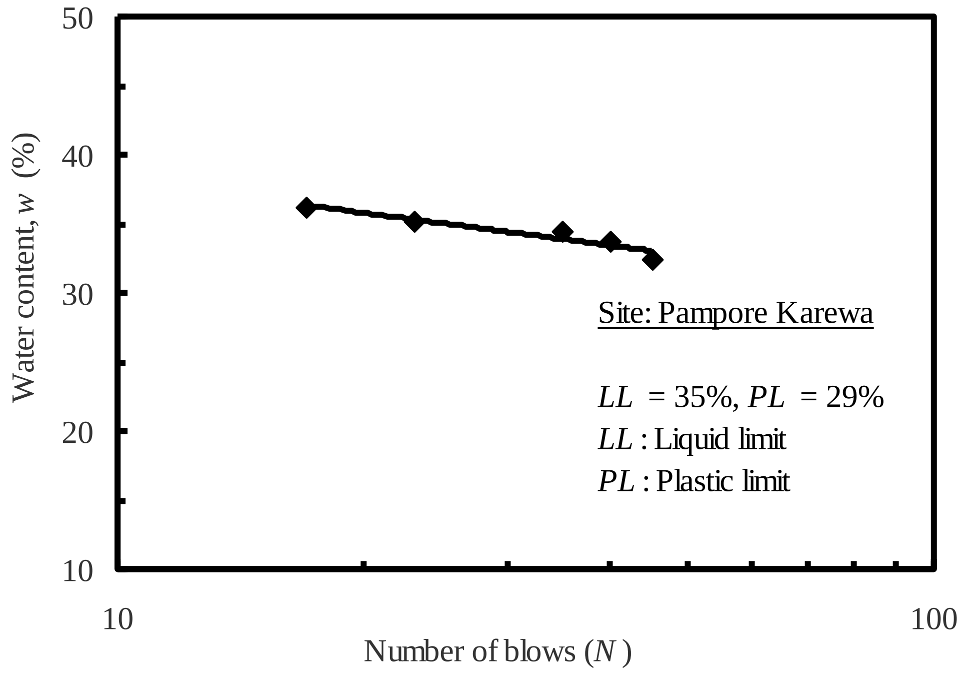

Fig. 2 Flow curve of untreated Karewa soil

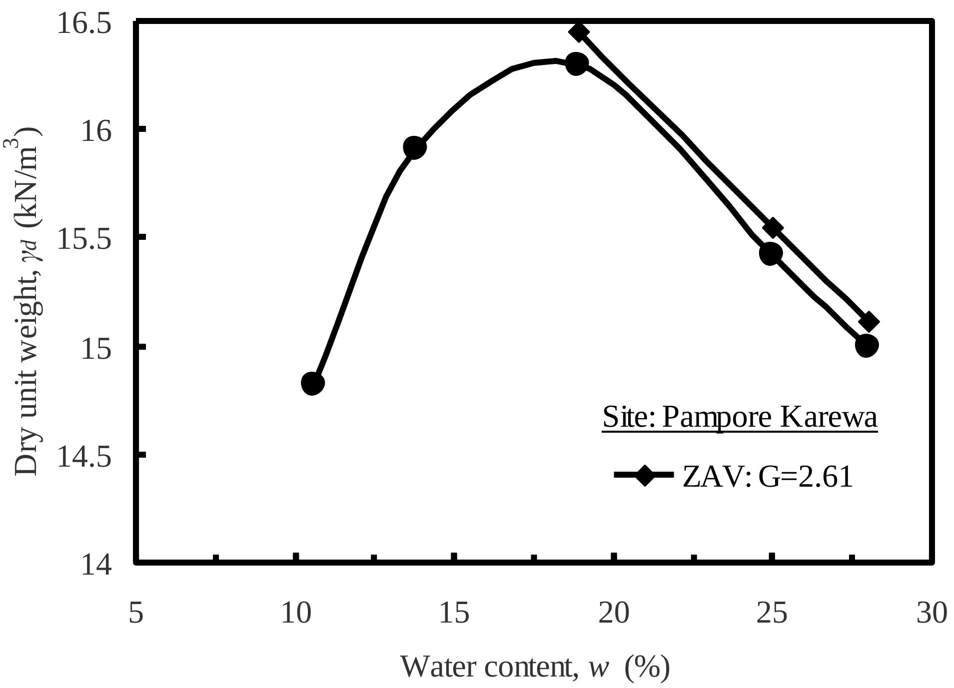

Fig. 3 Compaction curve of untreated Karewa soil

The unconfined compression strength (UCS) and the California Bearing Ratio (CBR) tests were conducted on the Karewa soil using the standard code procedures. Figure-4 shows, that the soil possesses an unconfined compressive strength of 162kPa. The CBR of the soil for un-soaked and soaked conditions is 7.8% and 3.3% respectively (Figure-5). The soaked CBR of the soil is less than that of the un-soaked condition. This is because the surface tension forces, which were offering additional resistance to penetration under un-soaked condition, are destroyed [43].

3.2 Physical and Engineering properties of RHA stabilized Karewa soil

3.2.1 Effect of RHA on index properties of Karewa soil

In this study, Karewa soil was stabilized using RHA in varying percentages of 5%, 7.5%, 10%, 12.5%, and 15% (by dry weight of soil). The variation of the consistency limits of RHA content is shown in Figure-6. From Figure-6, it is seen that the liquid limit and the plastic limit of the treated soil specimens increased with increase in rice husk ash. The increase in the plastic limit is more pronounced than the liquid limit, which decreases the plasticity index of the soil. The plasticity index decreases from

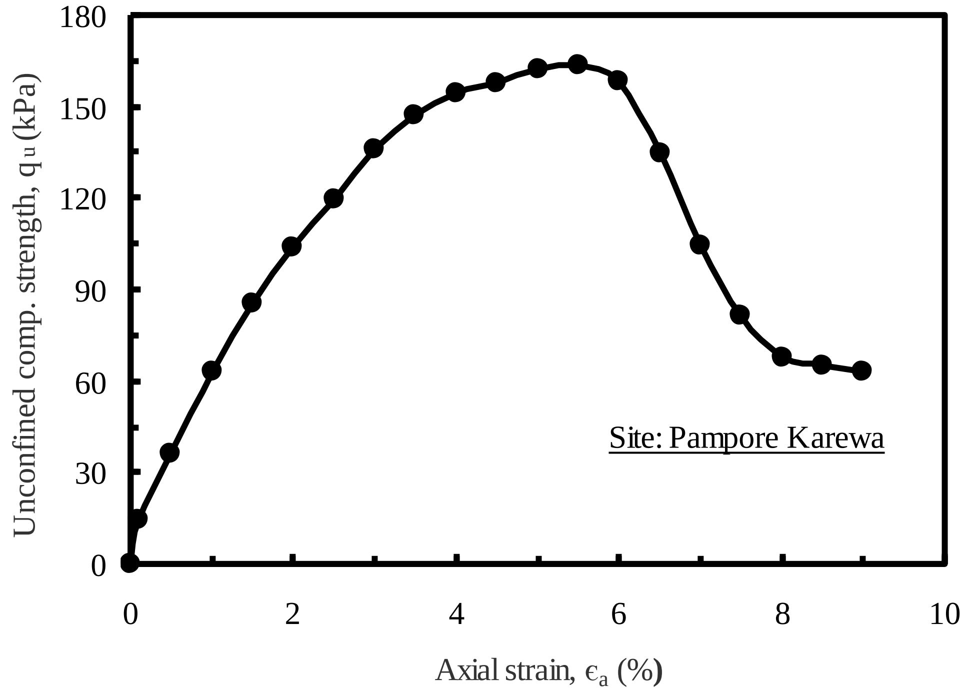

Fig. 4 Stress strain curves of untreated Karewa soil

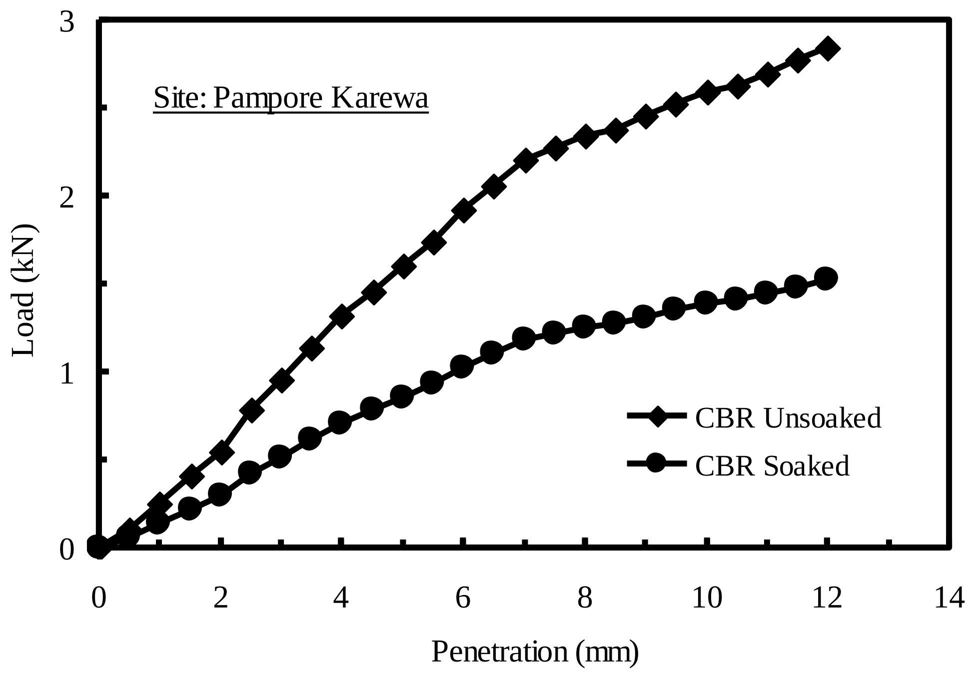

Fig. 5 Load penetration curve of Karewa soil

a value of 6% to 5.5%, thereby increasing the workability of soil [44]. However, no optimum value was seen, and the behavior remained unchanged until a final increment of 15% of RHA was added to the soil.

The increase in the liquid limit is attributed to the fact that more water is required for RHA-treated soil to make it fluid, due to the pozzolanic characteristics of RHA [45]. Rice husk ash is fine grained compared to Karewa soil, which causes an increase in the liquid limit. The increase in the plastic limit implies that the treated soil requires more water to change its plastic state to a semisolid state [46]. Sarkar [47] reported an increase in the liquid limit from 46% to 56%, the plastic limit from 22% to 36%, and a decrease in plasticity index from 24% to 20% on addition of RHA. Akinyele [48] also found an increase in the liquid limit and the plastic limit, and a decrease in the plasticity index of soil, when mixed with RHA.

3.2.2 Effect of RHA on compaction characteristics

Density is an important parameter that determines the load, which a structural fill will apply to itself and its foundation. Density influences the permeability, stiffness, and strength of the fill, thus affecting the settlement and ultimate stability of the soil [37]. Compaction increases the density of a soil by packing the soil particles close to each other due to expulsion of air from the voids [49]. The standard Procter compaction test was conducted to determine the effect of RHA on the Optimum Moisture

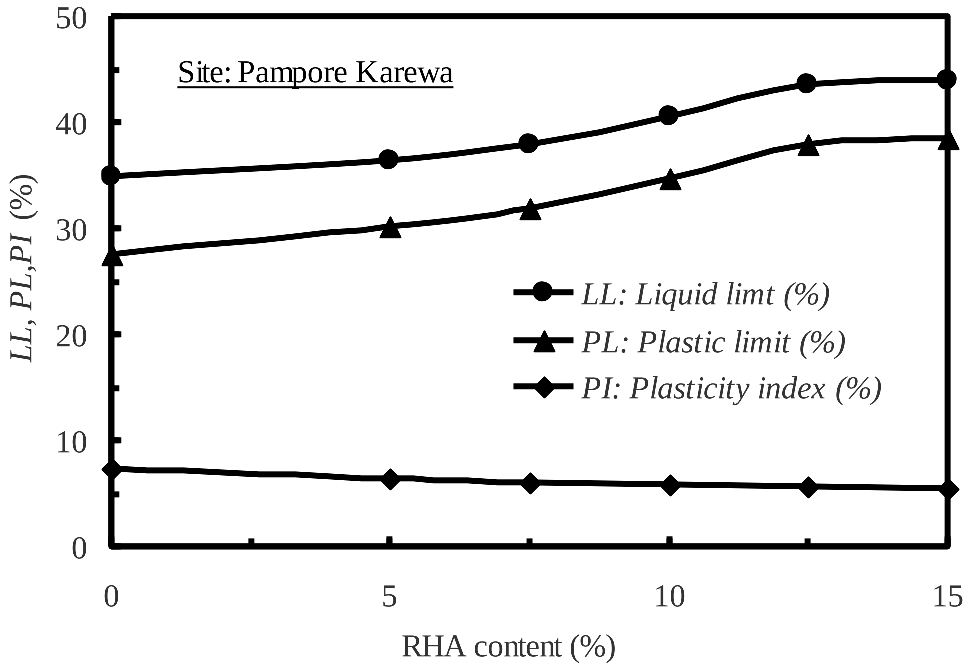

Fig. 6 Variation of consistency limits with rice husk ash (RHA) for Karewa soil

Content (OMC) and the Maximum Dry Unit weight (MDU) of the soil. The compaction curves obtained are shown in Figure-7. The OMC increased and the MDU decreased with an increase in RHA content of the treated soil specimens (Figure-8), which agrees with the findings of Osula [50], and Ola [51]. The increase in OMC may be attributed to decrease in the quantity of free silt and the clay fraction, along with the formation of coarser materials having larger surface areas in the presence of water. This further implies that more water is needed to compact the soil-RHA mixtures [52]. Hossain [53] related increase in OMC to increase in the pozzolanic reaction between RHA and soil particles. The reduction in MDU is due to the replacement of soil by RHA in the mixture, which has a relatively low specific gravity compared to that of the soil [18. 54 and 55]. It may also be attributed to the coating of the soil by RHA, which results in large particles with larger voids and less density [56, 57].

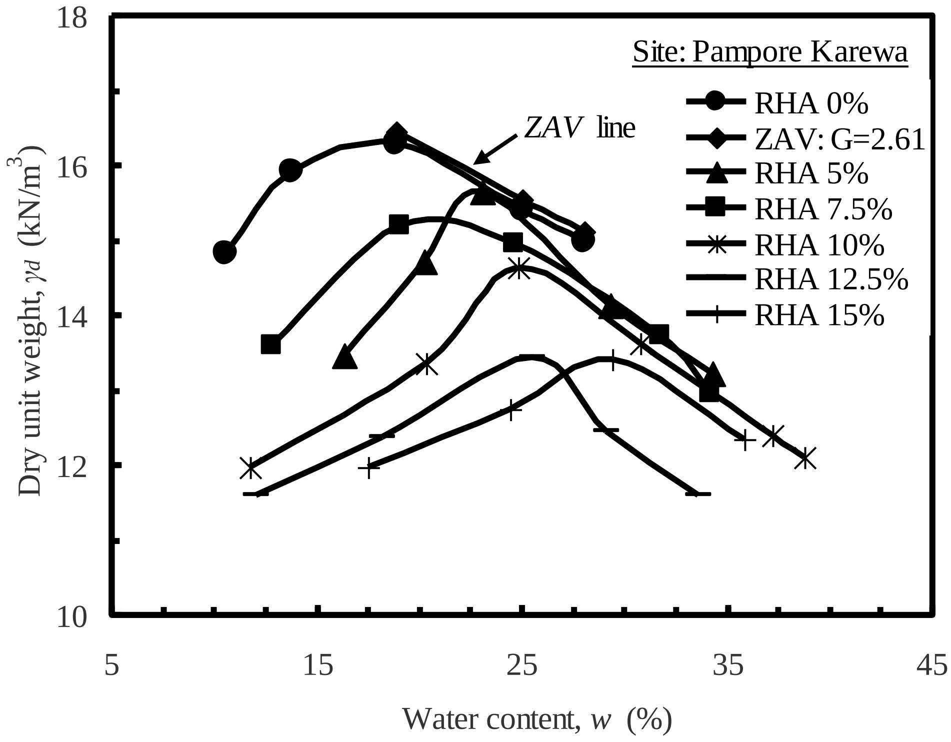

Fig. 7 Compaction curves for RHA treated Karewa soil

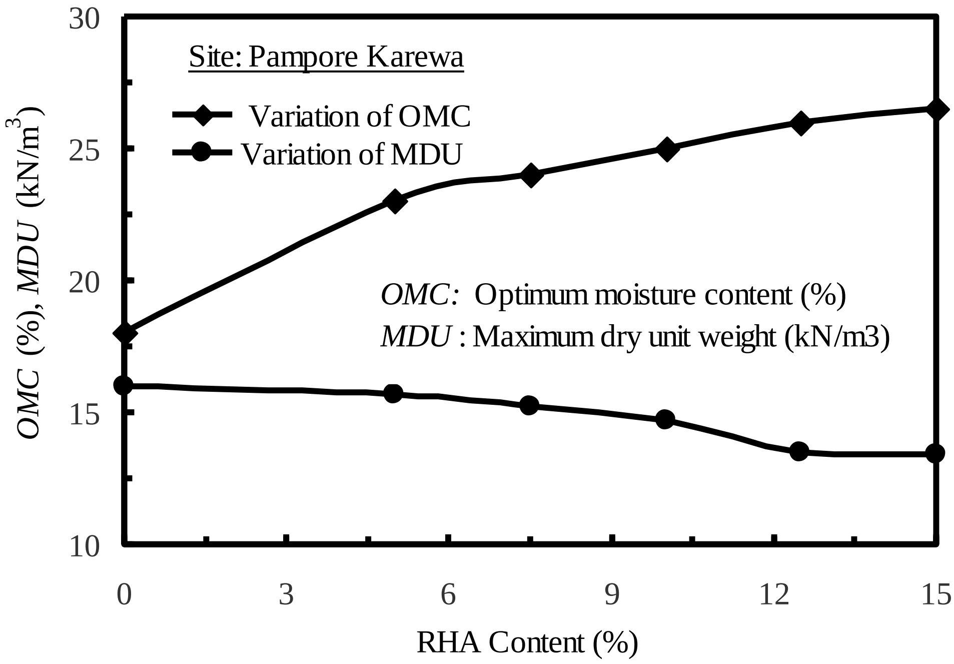

Fig. 8 Variation of Optimum Moisture Content (OMC) and Maximum Dry Unit weight (MDU) with rice husk ash (RHA) for Karewa soil

3.2.3 Effect of RHA on strength characteristics

Strength characteristics are important parameters in determining the suitability of a soil in engineering applications [58]. In this study, unconfined compression strength (UCS) and California bearing ratio (CBR) tests were conducted on RHA-treated Karewa soil. The unconfined compression test is a very simple and quick test that can determine the strength of cohesive soils [38]. The treated soil specimens were prepared, compacted at $0.95\gamma_{dmax,}$ and the optimum moisture content under standard testing procedures. The stress strain behavior of RHA-treated Karewa soil is shown in Figure-9. The maximum value of Unconfined Compressive Strength (UCS) of 222kPa is obtained at an optimum value of 10% RHA, beyond which the strength decreases (Figure-10). Various researchers have reported an optimum content of RHA in the range of 10%-15% [59]. The increase in UCS is attributed to the formation of cementitious compounds between the CaOH present in the soil and RHA, and the pozzolans present in the RHA [55]. The decrease in UCS values, after the addition of 10% RHA, may be due to excess RHA being added to the soil and therefore, developing weak bonds between the soil and the cementitious compounds formed [60].

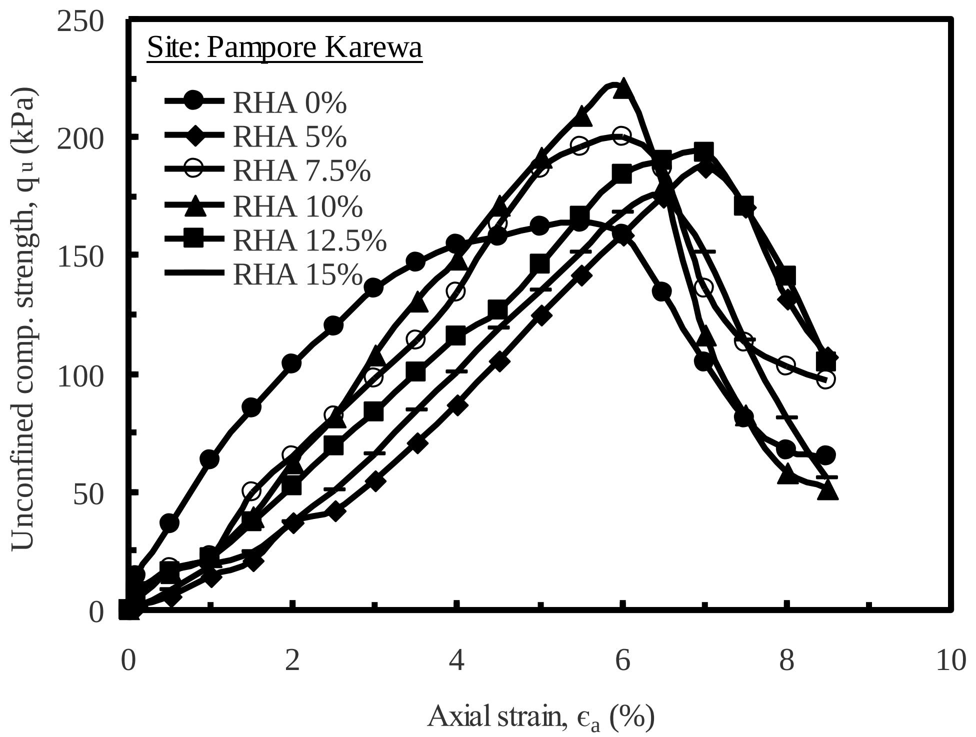

Fig. 9 Stress strain behavior of RHA treated Karewa soil

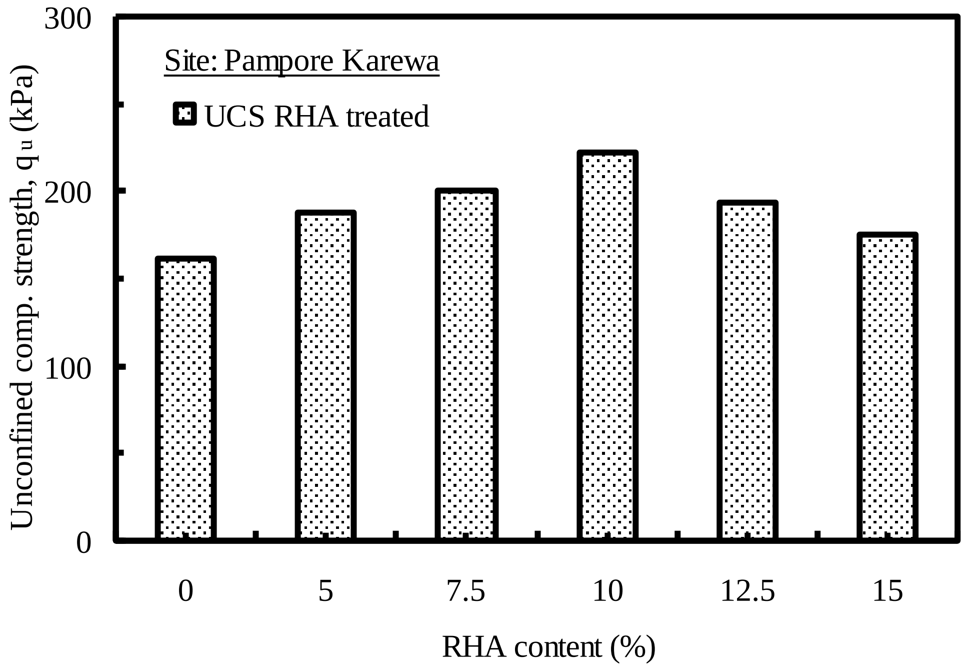

Fig. 10 Variation of Unconfined Compressive Strength (UCS) with change in rice husk ash (RHA) for Karewa soil

The California Bearing Ratio (CBR) test is a penetration test of the sub-grade, used in the design of pavement thickness [61]. The CBR values give us a measure of quality of the pavement materials [62]. The CBR tests were conducted for both un-soaked and soaked conditions using the standard testing procedure. The addition of RHA to Karewa soil increased its CBR from 7.8% to 13.7% for the un-soaked condition, and from 3.3% to 6.1% for the soaked condition respectively. However, the optimum value was found at an RHA content of 10%, beyond which the CBR results showed a decreasing trend (Figure-11). The excess RHA occupies space within the specimen and reduces the clay and silt content in soil and hence, reduces the bond/cohesion in the soil-RHA mixture [63].Gupta reported an optimum RHA content of 10%, and with further addition of RHA to 15% in the soil, no improvement in the value of CBR was seen [64].

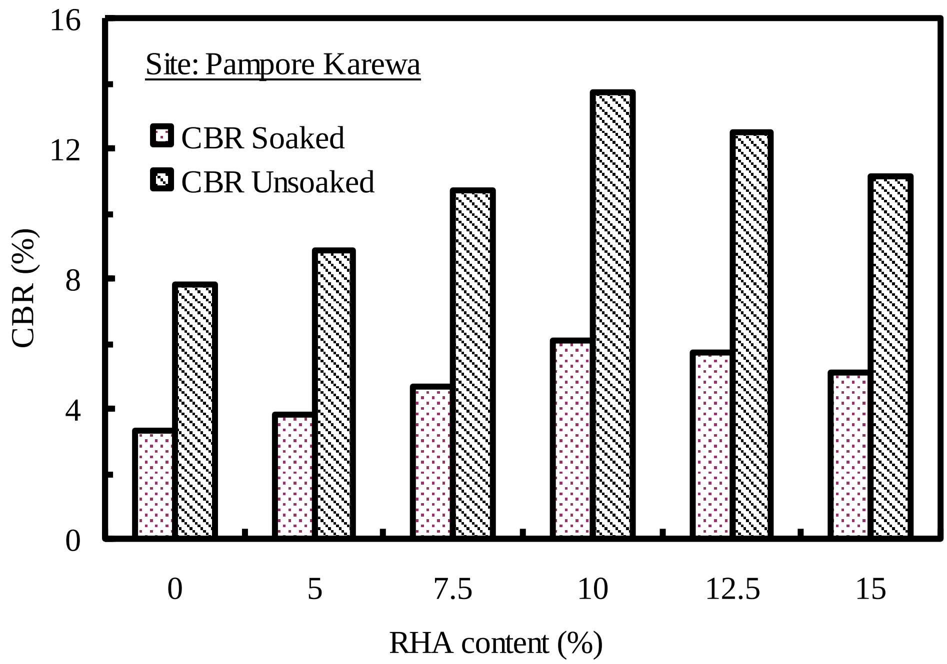

Fig. 11 Variation of California bearing ratio (CBR) with change in rice husk ash (RHA)

Conclusions

The key conclusions drawn from this study can be summarized as:

1. The addition of rice husk ash to the Karewa soil improved the engineering properties of the soil.
2. The liquid limit and the plastic limit of the soil increased with an increase in RHA content, thereby, decreasing the plasticity index of the soil. The decrease in the plasticity index indicates an improvement in the soil properties, making it more workable.
3. The optimum moisture content of soil increased, and the maximum dry unit weight decreased with an increase in RHA content. The decrease in MDU is beneficial in soil retaining structures, as it reduces lateral earth pressures. Increase in OMC suggests soils are still workable and non sticky. They can be well-compacted at higher water contents than the OMC of untreated soils.
4. The unconfined compressive strength of the soil increased with the addition of RHA.The optimum value of RHA was found to be 10%, beyond which the compressive strength of soil decreased.
5. The CBR of the soil increased with an increase in RHA content. However, beyond 10% the RHA content of the soil CBR values showed a decreasing trend.

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