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Safkat Tajwar Ahmed

Mozaher Ul Kabir

Chowdhury Zubayer Bin Zahid

Tahsin Tareque
The University of Texas Rio Grande Valley

Seyedali Mirmotalebi

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Research Article

Improvement of subgrade California Bearing Ratio (CBR) using recycled concrete aggregate and fly ash

Safkat Tajwar Ahmed [a], Mozaher Ul Kabir [b], Chowdhury Zubayer Bin Zahid [c,*], Tahsin Tareque [d], Seyedali Mirmotalebi [e]

[a] Washington State Department of Transportation, Washington, USA
[b] Department of Civil and Environmental Engineering, Islamic University of Technology, Gazipur, 1704, Bangladesh
[c] Department of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia
[d] Department of Civil Engineering, University of Texas Rio Grande Valley, Edinburg, TX, USA
[e] Department of Civil, Architectural and Environmental Engineering, North Carolina Agricultural and Technical State University, Greensboro, NC, 27411, USA

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ABSTRACT

The study aims to understand the effect of different admixtures on improving the quality of flexible pavement subgrades. In this paper, recycled concrete aggregates (RCA) and Fly Ash were used as the admixtures in improving the maximum dry density (MDD), swelling potential, and California bearing ratio (CBR) of subgrade soil. The percentages of RCA and fly Ash used were 5%, 10%, and 15%. With the upscaling in fly ash dosage, the optimum moisture content and the California bearing ratio increased. However, the MDD of soil decreased for higher fly ash contents. On the contrary, the optimum moisture content (OMC) of the soil decreased and the MDD and California Bearing Ratio increased with an increase in RCA content. Both RCA and fly ash-treated soil demonstrated lower values of swelling. At 5% dosage, both RCA and fly ash admixtures were found to improve CBR. However, at higher percentages (10% and 15%) of fly ash, the CBR values decreased while in comparison, soil samples performed significantly better in the CBR test with the increasing dosage of RCA. The findings of this research can be used to examine the suitability and effects of recycled aggregate and fly ash on the performance of soil in terms of CBR, particularly when the soil is planned to be used as a subgrade in highways.

1. Introduction

The subgrade soil layer is one of the most crucial parts of the pavement that significantly affects the durability and quality of pavements. For this reason, it is crucial to use materials of the highest standard for subgrade [1] and develop alternative methods for construction on soft clay [2–4]. Despite this, most of the flexible pavements in Bangladesh are constructed on substandard subgrade soils. As a result, the thickness of the pavement needs to be very high to compensate for the low California Bearing Ratio (CBR) values of these pavements, thus increasing the overall cost of construction.

Various methods have been used to improve the CBR values of different types of pavements [5–9]. However, one of the most effective ways of improving the CBR of the subgrade is by stabilizing soil by using numerous admixture materials. Mechanical Stabilization can be done by adding high-density materials like aggregates, although materials such as lime, cement, fly ash, etc. Were used as chemical stabilizers [10]. Kesharwani et al. [11] examined the impact of 10 mm and 20 mm-sized coarse aggregates for improving the CBR of subgrade soil. It was found that soaked CBR of sub-grade is improved up to 233.17% using 20 mm coarse aggregates. Archibong et al. [12] listed mixing aggregates as an effective way of mechanical stabilization of soil and investigated the factors affecting the stabilization process using aggregates. Eren and Filiz [13] compared the effectiveness of cement, lime, and a chemical admixture named Consolid444 as soil stabilizers. Although the soil sample with 8% cement produced the maximum CBR, overall. 6% lime was found to be the most appropriate soil stabilizer based on bearing capacity and economy. In another study, enzymatic lime stabilizer was found to be highly effective in increasing the CBR of clay soil [14]. Eggshell powder was also used to increase the CBR value of soil [15], where test results indicated that the CBR value was improved by 9.52% while mixing 11% eggshell powder in soil. Coarse self-cementing fly ash was incorporated in another study to improve the CBR values [16]. The results reveal that 10% and 18% fly ash content in soil can improve soil

* Corresponding author.
E-mail address: zubayerbinzahid@iut-dhaka.edu (C.Z.B. Zahid).

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CBR significantly. In the research of Mishra and Sachdeva [17], coarse aggregates and stone dust were added to the soil to increase the CBR value. CBR value improvement of up to 194.7% was achieved by using different combinations of stone dust and 10 mm aggregates. Hasnat et al. [18] examined the influence of various fly ash contents on the settlement, allowable bearing capacity, and consolidation time of soil. The maximum allowable bearing capacity was achieved for 5% fly ash mixed soil [19], while for 25% fly ash content, the lowest settlement and time required for consolidation were found. Zumrawi [10] investigated the effect of fly ash activated with cement in soil stabilization and found the optimum quantity of 15% fly ash content mixed with 5% cement. The improvement of unconfined compressive strength, Atterberg limits, swelling index, and CBR of fly ash stabilized soil was demonstrated in another study [20]. Henzinger and Heyer [21] improved the properties of two types of fine-grained soils by treating the soil using 0/4 mm recycled concrete aggregates (RCA). Kianimehr et al. [22] demonstrated the performance of recycled concrete aggregates in improving clay soils. The result showed that adding recycled aggregates in soil improves the unconfined compressive strength and shear strength of that clay soil. Recycled concrete aggregates were also used to treat base and sub-base layers of flexible pavement. The findings from the experiment of Maaty [23] indicated that RCA mixed with limestone aggregates can significantly improve the unconfined compressive strength of base and sub-base layers. Shourijeh et al. [24] found that RCA significantly improved the strength properties of clay soil reinforced with fiber. In a 2019 study, the unconfined compressive strength of clay soil mixtures containing fly ash and Portland cement was found to increase substantially when RCA was added to the mix [25,26]. Polypropylene fiber can also be used to improve the CBR of subgrade soil by almost 65–133% [27]. Peter et al. [28] utilized coir waste to improve the elastic modulus and CBR of soft expansive soil. They found that coir waste materials can improve the CBR of soil by almost 4.6 times. Huang et al. [29] documented the widespread use of fly ash as a precursor of geopolymers in stabilizing soil. In their review article, Wong et al. [30] discussed the advantages and disadvantages of replacing cement with geopolymers of fly ash as a soil stabilizer. Trivedi et al. [31] proposed an algorithm to predict the CBR of subgrade soil stabilized by different fly ash contents. It was found that 20% fly ash content was optimum for soil stabilization. Several past studies focused on the numerical analysis foundation [32,33], tunnel [34,35] as well as on the service life of structures [36,37].

Among all these materials and methods, recycled concrete aggregate (RCA) and fly ash hold a significant position considering their comparatively low cost and high availability. Nowadays, RCA is being used widely in a variety of construction projects. Especially in Bangladesh, the construction industry is going through a blooming phase as many old low-rise buildings are demolished and replaced by new high-rise ones [38–41]. A huge amount of concrete waste is produced every year, ensuring an abundant supply of RCA. Fly ash is another inexpensive material produced as a by-product in coal-based power plants, but an estimated amount of 52000 metric tons of fly ash is produced per year in Bangladesh [42]. Two kinds of fly ash are manufactured in Bangladesh, such as Class C and Class F. The huge quantity of concrete waste and fly ash can be a severe concern as the disposal of these materials causes significant environmental pollution. As a result, the utilization of these materials in soil improvement not only decreases construction costs but also reduces environmental pollution.

While researchers have explored the use of various materials, predominantly coarse aggregates, to enhance subgrade soil, there is a distinct need to prioritize waste byproduct materials like fly ash and Recycled Concrete Aggregate (RCA). The utilization of these materials for California Bearing Ratio (CBR) improvement not only contributes to the enhancement of subgrade soil but also presents an opportunity to mitigate disposal expenses associated with these byproducts. Previous experiments involving RCA and fly ash have been limited in scope, primarily focusing on the unconfined compressive strength of soil. Therefore, this study recognizes the existing research gap and undertakes a more comprehensive examination, addressing a range of relevant soil properties including CBR, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and swelling potential of soil.

Table 1
Physical properties of the selected subgrade soil.

Parameter	Value
Moisture Content	4.72%
Specific Gravity	2.66
Uniformity Coefficient (C_u)	3.69
Coefficient of Curvature (C_c)	1.35
MDD	1.711 gm/cc
OMC	17.75%

Table 2
Grain size distribution of soil.

Sieve Size (mm)	% of soil Passing
9.5	100
4.75	98.10
2.36	93.70
1.18	84.11
0.6	72.50
0.3	32.00
0.15	12.60
0.075	7.00

1.1. California Bearing Ratio

The California Division of Highways developed the California Bearing Ratio test for the assessment of subgrade materials for flexible pavements [43]. It is a penetration test in which the ratio of the penetration resistance of a particular soil sample to that of a standard crushed stone is calculated. The result is expressed as a percentage as per the equation (1).

$$CBR = \frac{Load\ carried\ by\ specimen}{Standard\ load\ carried\ by\ crushed\ stone} \times 100 \tag{1}$$

For design purposes, the CBR value of the subgrade can be obtained by testing soil samples in saturated conditions. In this research, only the soaked CBR tests were carried out.

1.2. MDD and OMC

For pavement construction, soil with the maximum dry density (MDD) is preferred, and to find the MDD, dry density is calculated for a set of moisture content values, and a dry density vs. moisture content curve is plotted. The theoretical MDD and the corresponding OMC of the soil sample can be acquired at the highest point of this curve.

2. Soil sample and materials

This section discusses the sample collection site, the properties of the soil sample, and the materials used for improving the CBR of soil.

2.1. Soil sample

The Dhaka-Chittagong national highway was selected as the subgrade soil sample collection site. For conducting the tests, the 'OSJI-JV' head office Meghna laboratory and all equipment setup were used. After soil collection, the moisture content and specific gravity of the soil were measured. The ASTM D2216-04 and the ASTM D854-00 standard test methods were followed for the moisture content and specific gravity tests, respectively. Table 1 shows the physical properties of the soil. The result from the dry sieve analysis (ASTM D422-04) of the soil sample is presented in Table 2.

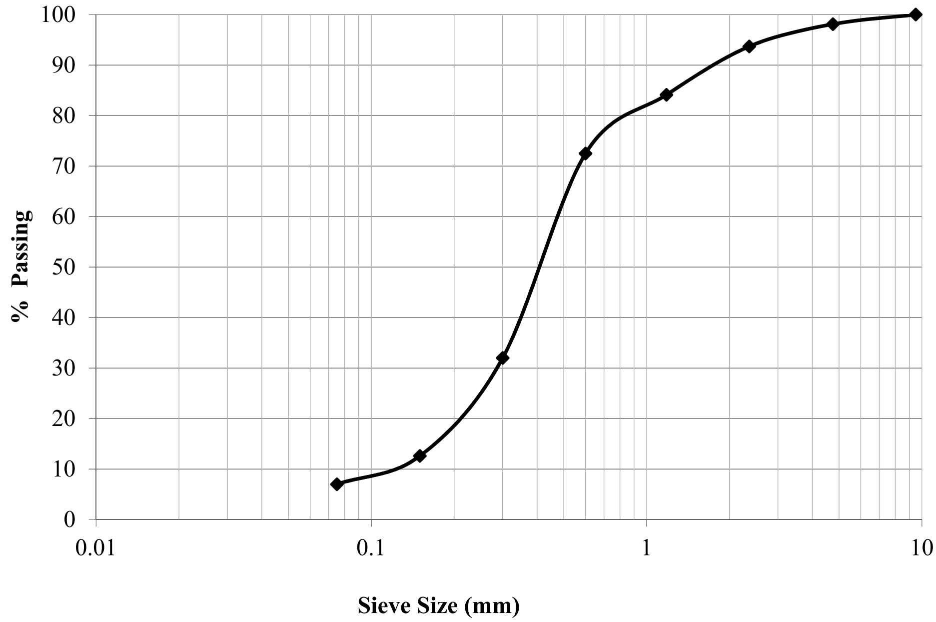

Fig. 1. Particle size distribution curve of soil.

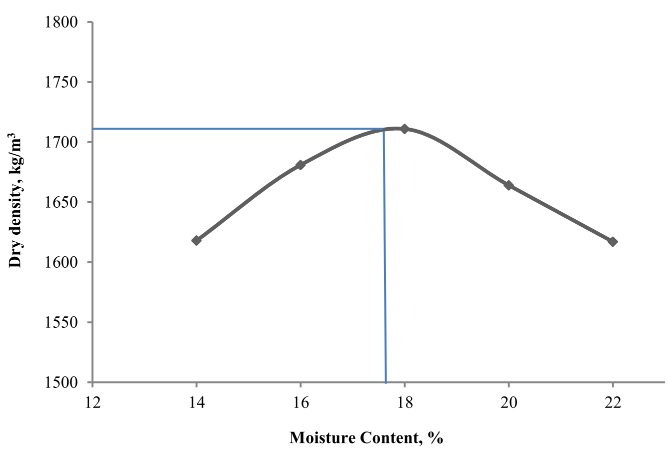

Fig. 2. Dry Density vs. Moisture Content.

Table 3
Gradation of recycled aggregates.

Sieve Size (mm)	Cumulative % Passing
25	100
19	93.6
9.5	73.5
4.75	23.7
2.36	6.9

The particle size distribution curve for the selected soil is presented in Fig. 1.

The soil was compacted, and a modified Proctor test (ASTM D1557-04) was conducted to find the MDD and OMC. The dry density vs moisture content graph is shown in Fig. 2.

2.2. Recycled concrete aggregate

The recycled concrete aggregates were collected from the waste of an old, demolished building in Hazaribag, Dhaka. After collecting, the aggregates were crushed in two steps using a pneumatic hammer and a rotating crusher to achieve suitable gradation. ASTM C136-06 standard method was used for the sieve analysis, the gradation of which is presented in Table 3.

Fig. 3 shows the grading curve of RCA after crushing.

The oven-dry density was found to be 3.04 gm/cm^3 and the water absorption was 2.43% for the aggregates.

2.3. Fly ash

Local class F fly ash was used for soil stabilization in this study. The properties of fly ash (ASTM C618) are mentioned in Table 4.

2.4. Ratio of soil and admixtures

The materials used as admixtures are recycled concrete aggregates and fly ash. The test samples were made by mixing 5%, 10%, and 15% of these materials by weight with the collected soil. The names and the material proportions of the specimens are shown in Table 5.

3. Test procedure

The ASTM D1883-07 standard specification was followed for performing the CBR tests.

1. Subgrade soil was collected from the selected site. The soil was dried in the Sun and then prepared using a rubber hammer. An ASTM #4 sieve was used to screen the soil.
2. The specimens were subjected to compaction to a density of 95%–100% by using a rammer with 10, 30, and 65 blows. Each sample weighed about 7 kg and was divided into 5 equal layers. The 4.5 kg rammer (150 mm diameter) was used to give a blow on each layer of the samples.
3. Molds were prepared for MDD checking. The MDD and corresponding OMC were calculated by performing a modified proctor test.
4. The CBR specimens were soaked for four days in a soaking tank. Then the percentage swell was measured from swell readings. After soaking, the molds were dried for 15 min.
5. Penetration Test: The specimens were attached to the CBR machine after removing from the molds. In the penetration test, a circular plunger with a diameter of 50 mm was employed, and the penetration rate was set at 1.25 mm/min. The necessary forces for

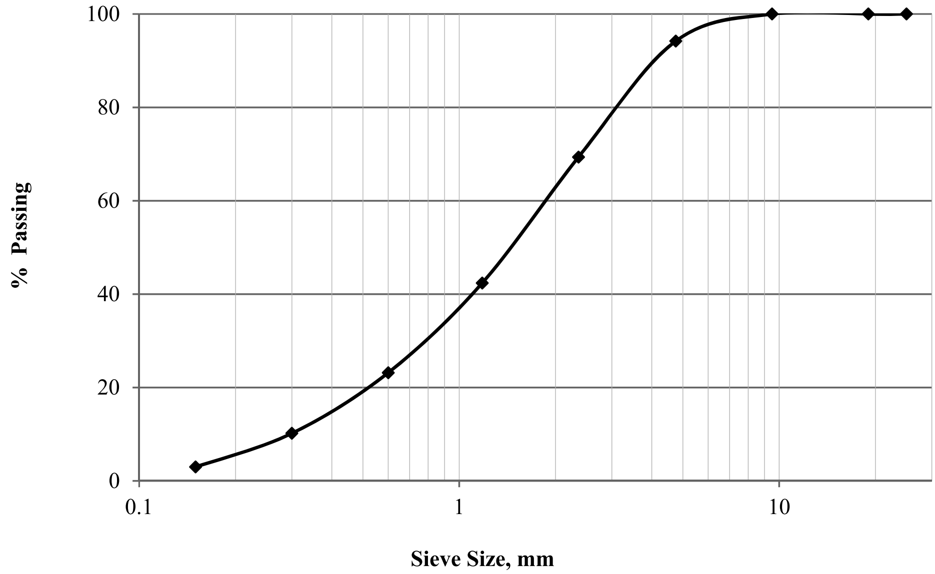

Fig. 3. Particle size distribution curve for RCA

Table 4
Chemical composition and Properties of Fly ash.

Oxides	Percentages (%)	Properties	Value
SiO_2	54.3	Specific Gravity	1.88
Al_2O_3	35.7	Moisture Content	0.9 %
Fe_2O_3	2.8	Percent retained on 45 μm	13%
TiO_2	3.4	Loss on ignition	8.5%
Mn_3O_4	0.12		
CaO	0.58		
K_2O	0.65		
Na_2O	0.07		
MgO	0.19		
P_2O_5	0.45		
SO_3	0.15		

Table 5
Proportion of soil and materials.

Designation	Proportion of soil and admixtures
S-0	Subgrade Soil 100%
SRA-5	Subgrade Soil 95% + Recycled Aggregates 5%
SRA-10	Subgrade Soil 90% + Recycled Aggregates 10%
SRA-15	Subgrade Soil 85% + Recycled Aggregates 15%
SFA-5	Subgrade Soil 95% + Fly Ash 5%
SFA-10	Subgrade Soil 90% + Fly Ash 10%
SFA-15	Subgrade Soil 85% + Fly Ash 15%

penetrating the samples were determined, and subsequently, the ratios of these forces to the forces required for the same penetrations in standard rock were calculated. Specifically, for penetrations of 2.54 mm and 5.08 mm, the California Bearing Ratio (CBR) ratios were computed, providing insights into the relative strength and bearing capacity of the tested samples compared to standard rock. The CBR at 5.08 mm was found higher than the ratio at 2.5 mm in repeated tests, thus the ratio at 5.08 mm was selected.

4. Results

In this research, at first, the physical properties of untreated clay soil and the selected admixtures (RCA, FA) were determined. Afterwards, the admixtures were mixed with the soil in different proportions and tested for determining the CBR, MDD, OMC, and swelling potential.

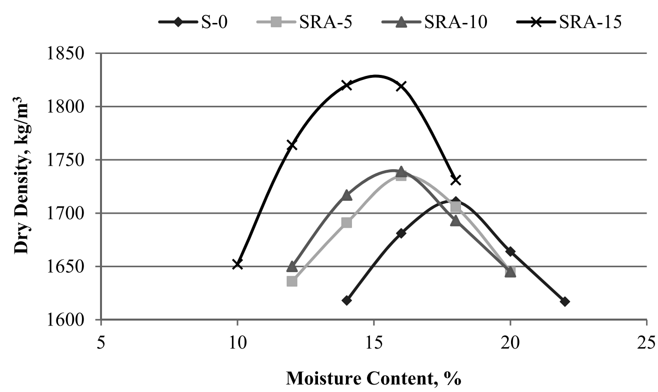

Fig. 4. MDD & OMC for different RCA contents.

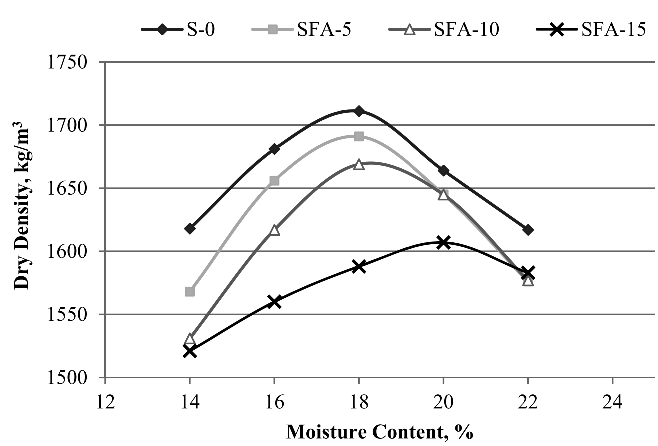

Fig. 5. MDD & OMC for different fly ash contents.

While conducting all the laboratory tests, this study adhered to the established ASTM standards and met all the standard testing requirements as mentioned in Chapter 2 and 3. The test results in terms of swelling, MDD, OMC, and CBR for each specimen are presented in this chapter.

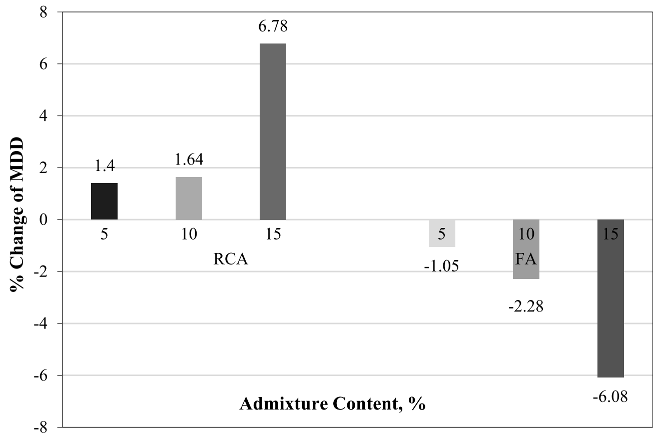

Fig. 6. Percent change in MDD.

Table 6
Swelling Index for all the specimens.

Specimen Name	Height of Specimen (mm)	Swell (mm)	% Swell
S-0	115.6	0.35	0.303
SRA-5		0.28	0.242
SRA-10		0.27	0.236
SRA-15		0.25	0.216
SFA-5		0.26	0.225
SFA-10		0.26	0.225
SFA-15		0.24	0.208

4.1. Maximum dry density and optimum moisture content

The MDD of the 100% soil sample was 1711 kg/m3 and the OMC was 17.2%. After mixing 5%, 10%, and 15% recycled concrete aggregates by weight, the MDD values of the samples were found to be 1735, 1739 and 1827 kg/m3, respectively. The corresponding optimum moisture contents for these MDD values were 15.6, 15.2, and 14.8 %, respectively. It is evident that by increasing the RCA content in subgrade soil, the MDD increases and the OMC decreases. Fig. 4 shows the MDD vs. OMC curves for different soil and RCA mixed samples.

Fig. 5 shows the MDD vs. OMC curves for different soil and fly ash mixed samples. At fly ash contents of 5%, 10%, and 15%, the Maximum Dry Density (MDD) values for the mixtures were determined to be 1693 kg/m^3, 1672 kg/m^3, and 1607 kg/m^3, respectively. Concurrently, the corresponding Optimum Moisture Content (OMC) values were measured as 17.7%, 18.0%, and 19.7%, respectively. The MDD values follow a decreasing trend while the OMC values increase with the increment in fly ash content.

Fig. 6 shows the percent change of maximum dry density for all the mixed samples. The MDD increased by a highest value of 6.78% compared to soil with no admixtures when 15% RCA was mixed. For all the samples containing fly ash (FA), the MDD values decreased.

4.2. Swelling

After 4 days of soaking, the swelling value for soil with no admixtures was found to be 0.3%. In the case of soil with RCA, the minimum swelling index was found to be 0.216% for 15% recycled concrete aggregate content. For fly ash-treated soil, the swelling index was reduced to a minimum value of 0.208%. The result of the swelling test is shown in Table 6.

4.3. CBR

From the CBR penetration test, the corresponding forces per unit area required to go through the soil specimens by 0.64, 1.27, 1.91, 2.54, 3.18, 3.81, 4.45, 5.08, and 7.62 mm were recorded. The forces were achieved from the dial gauge readings of the CBR machine by multiplying them with a conversion factor. Load versus penetration curves were obtained for all the specimens.

The load versus penetration curves for soil specimens with 0%, 5%, 10%, and 15% RCA contents are shown in Fig. 7.

Fig. 8 shows the load versus penetration curves for fly ash-treated subgrade soil specimens. CBR values improve as the amount of RCA in soil increases. For fly ash-treated soil, the CBR value goes up with the increment in fly ash up to 5% fly ash. After that, the value drops with the increment of fly ash content.

For the instances when the starting portion of the curve was found to be concave upwards, the adjustments were done by shifting the origin and thus, the corrected load values were obtained. The CBR values for all the specimens are shown in Table 7.

Fig. 9 shows the trend of CBR improvement for different amounts of both RCA and fly ash mixed soil.

5. Conclusion

The experimental research was performed to examine the effects of RCA and fly ash on CBR, MDD, and swelling potential of subgrade soil.

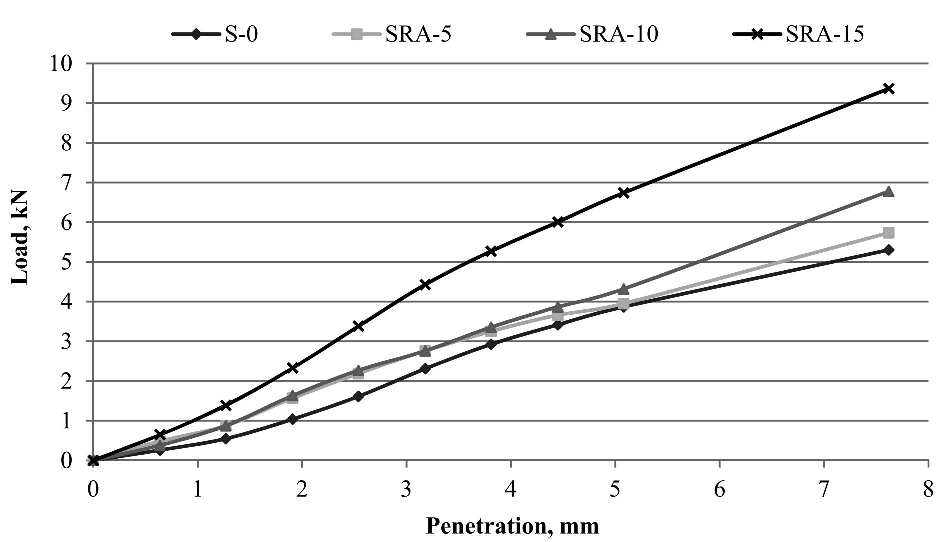

Fig. 7. Plot of Load vs. Penetration for soil-RCA mix.

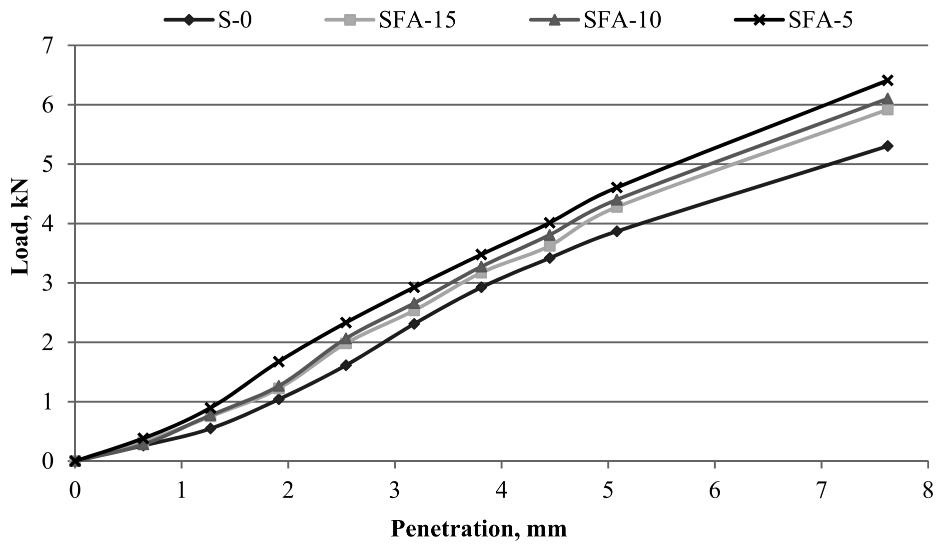

Fig. 8. Plot of Load vs. Penetration for soil-fly ash mix.

Table 7
CBR results for soil samples.

Specimen Name	Corrected CBR %
S-0	20.35
SRA-5	20.6
SRA-10	22.33
SRA-15	33.75
SFA-5	24.32
SFA-10	22.82
SFA-15	21.34

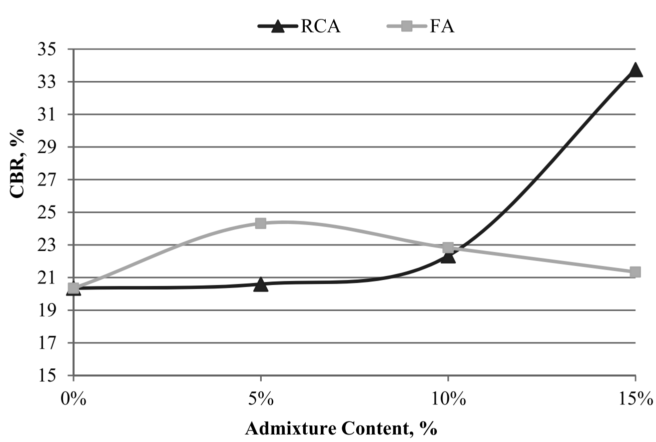

Fig. 9. CBR improvement with different RCA and fly ash content.

5%, 10%, and 15% of these materials were mixed in the dry soil. After going through all the tests, it was found that CBR values for soil with different materials are significantly greater than that of normal soil samples. For RCA mixed soil specimens, the CBR value continues to rise with the increase in RCA content (maximum 33.75% for 15% RCA). On the other hand, the maximum CBR for fly ash-treated soil was found for 5% fly ash content (24.32%), but after that, the values gradually decreased. However, all the CBR values were greater than that of the initial untreated soil. Swelling of soil also reduced with the increase in both RCA and fly ash content, while the minimum swelling (0.208%) was recorded in the case of 15% fly ash mixed soil. In the Modified Proctor Test, RCA and fly ash mixed soil samples exhibited opposite trends. As the RCA content increased, there was a corresponding rise in the MDD. In contrast, an increase in fly ash dosage resulted in a decrease in the MDD.

In most developing countries like Bangladesh, there is a gradual increase in the cost of construction materials. Consequently, it is crucial to utilize waste and byproduct materials such as recycled concrete aggregates and fly ash to improve the soil. Every year, a substantial amount of concrete waste is produced from the demolition of structures. Fly ash is also produced in huge quantities as a byproduct in coal power plants. Improving the California Bearing Ratio (CBR) of the subgrade soil through stabilization using the mentioned materials offers the potential for significant cost savings in pavement construction. With improved soil stability, the required thickness of the road structure can be reduced. This reduction in thickness leads to a more economical construction of pavements. The use of stabilization materials aims to strengthen the subgrade, ensuring better load-bearing capacity and overall structural performance. Ultimately, this approach contributes to cost-effective pavement construction by optimizing material usage and improving the efficiency of the road structure.

For future studies, it is recommended to conduct a thorough assessment of trace element contamination associated with the use of RCA and fly ash as soil admixtures, addressing specific heavy metals, residual cement, and potential environmental implications.

CRediT authorship contribution statement

Safkat Tajwar Ahmed: Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mozaher Ul Kabir:** Writing – review & editing, Validation, Supervision, Project administration. **Chowdhury Zubayer Bin Zahid:** Writing – review & editing, Visualization, Validation, Methodology. **Tahsin Tareque:** Writing – review & editing, Visualization, Validation, Supervision. **Seyedali Mirmotalebi:** Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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