A Study on the Effect of Replacing Coarse Grains in Sub-Base Materials with Concrete Residues on their California Bearing Ratio

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ABSTRACT

California Bearing Ratio (CBR) values are critical to the properties of granular subgrade materials and play a significant role in determining the design variables of several flexible pavement design methods. Concrete waste is considered an environmental problem in many regions of Iraq. Therefore, its removal is of significant environmental value when used to improve the properties of certain materials, such as the granular sub-base examined in this study. This research examined the impact of substituting particles measuring 19 mm to 12 mm in granular sub-base materials, class C and D, with crushed concrete waste at replacement rates of 25%, 50%, 75%, and 100% while preserving their gradation characteristics, on the CBR value. The CBR examination results showed that the most significant improvement in the CBR value was observed at a 100% replacement ratio, attaining 55.84% and 57.22% at a 1 mm penetration for the unsoaked C and D samples, respectively, and 63.32% and 48.11% for the soaked condition at a 1 mm penetration for the C and D samples, respectively. The increase in CBR was correlated with an increase in Optimum Moisture Content (OMC) and a decrease in maximum dry unit weight (γdry max), demonstrating that the percentage increase in CBR is non-linear. An increase in CBR may be helpful in the foundation base for many projects.

Keywords-California Bearing Ratio (CBR); granular sub-base material; crushed concrete waste; improving

I. INTRODUCTION

The inability of certain materials to satisfy standard specifications is prompting researchers to seek solutions. The recycling of demolition and construction waste serves a dual purpose: it can be disposed in an environmentally friendly manner, while improving the properties of certain materials. Subgrade is a basic material for road construction and a filtration layer for foundations and other works. It can have drawbacks, including not meeting certain standard specification limits, such as the CBR, while meeting other limits. These materials cannot be used due to a lack of economic alternatives, so they are treated with construction debris recycling. This process can then be considered economical as there is no waste of materials that have not met CBR values, and it helps to maintain an environment free of concrete construction debris. The CBR value of the soil showed significant improvement after mixing with fine concrete particles generated during the crushing of concrete waste [1]. The use of residual materials from the demolition of buildings in Mosul, Iraq, along with clayey soils increased the CBR values, with improvement values reaching 49.7% [2]. The utilization of Recycled Concrete Aggregate (RCA) with fly ash significantly affected the dry density, CBR, and swelling potential of the subgrade soil [3]. Adding recycled aggregate to the soil had a positive effect on increasing CBR values [4-8]. Dune sand can also be used as a soil enhancer, being combined with other additives to stabilize expansive soils [9]. Replacement of materials greater than 4.75 mm in Class B subgrade with crushed stone at rates of 20%, 40%, and 60% resulted in increased CBR values of 39%, 45%, and 58%, respectively, along with increased γdry max and OMC [10]. Phosphate limestone (type 1) and limestone (type 2) wastes have been used for road base construction, with CBR values for type 1 and type 2 wastes of 10.5% and 18.7%, respectively [11]. The addition of RCA to Natural Aggregate (NA) at ratios of 25, 50, and 75 to produce granular road materials affected the CBR values [12]. The CBR of mixed construction waste used in base or subbase layers decreases as the percentage of waste in the mix increases [13]. Stabilizing natural soil with Waste Marble Dust (WMD) and Corncob Ash (CCA) increased CBR values from 1.68% to 15.53% and unconfined compressive strength from 41.33 to 174.68 kN/m² [14]. When 5, 10, 15, 20, and 30% crushed concrete was mixed with soft soil samples, the undrained shear strength of the soft soil went up by 40 to 145%. At the same time, it became less compressible, as indicated by a 25%-47% decrease in the Compression Index as sulfate levels and soil alkalinity increased [15]. The addition of steel slag to the soil sample at concentrations between 0% and 20% resulted in an increase in CBR values from 4.5% to 16% [16]. The incorporation of 12% concrete demolition waste into the soil increased the CBR from 4.27% to 24.14% [17]. Adding Sawdust Ash (SDA) and Sugarcane Bagasse Ash (SCBA) to cement with stabilized lateritic soil increased the CBR values by up to 175% [18]. The addition of 2.5% Sugarcane Bagasse Ash (SBA) and 5% lime as chemical stabilizers to a clay soil subbase resulted in an increase in CBR of approximately 69% [19]. Mixing SCBA and SDA with soil and Ordinary Portland Cement (OPC) led to increased CBR values, which were higher with cement content up to 7%, reaching a peak of 175.7%, followed by a decrease to 102.6% at 9% cement content [20]. A significant increase in the CBR of compacted fine clay was observed following the use of air-burned tire ash [21]. The CBR increased by 4.7% when 1% High-Density Polyethylene (HDPE) polymer was added to gypsum soil (under wet conditions). CBR increased by 55.8% and 148.8% when 3% and 6% HDPE polymer were added, respectively [22]. The improvement of granular sub-base material may be related to its cost effectiveness and efficiency. Incorporating materials to increase the value of CBR may be more economically and environmentally sustainable when combined with concrete waste. It may be necessary to replace some or the whole material with a grain size of 19-12.5 mm with recycled concrete materials to compensate for the CBR deficiency of the granular sub-base material while maintaining the gradations specified in the required standards. When less than 12.5 mm fine materials are present and granular sub-base material is not available, recycled concrete materials may be used with the fine ones to produce a granular sub-base material that meets standard specifications, such as those, but not limited to, of Iraqi specifications.

II. MATERIALS AND PROPERTIES

This study examines a variety of materials beginning with two samples of granular sub-base material, class C and D, sourced from a natural quarry within the city limits of Baghdad, Iraq. These two classes (C and D) were selected based on their extensive extraction in the region and their usage in building foundations and soil replacement. However, these samples frequently exhibit CBR values that deviate from standard specifications, leading to their rejection. This rejection can result in significant project delays and financial losses if the deviant samples are not appropriately treated. The second material consists of crushed concrete from demolished aged structures. The preparation of crushed concrete includes the crushing and screening of waste concrete, selecting material that passes through a 19 mm sieve and is retained on a 12.5 mm sieve. Figure 1 presents the concrete waste before and after the crushing process.

Fig. 1. Concrete waste before and after the crushing process.

Table I presents the sieve analysis of the materials employed in this study. It is evident that each specimen displays a maximum particle size of less than 19 mm. In accordance with the specification of ASTM D1883 [23], the gradation of the samples remained unchanged for the CBR test preparation. Samples C and D were used as reference samples for comparison when preparing the material for the CBR examination. In sample C, the gravels between the sieves (19 mm-12.5 mm) were substituted with crushed concrete at weight percentages of 25%, 50%, 75%, and 100%, resulting in samples C25, C50, C75, and C100, respectively, constituting the first group. The sample second group, D25, D50, D75, and D100, was prepared using sample D, while the substitution process did not impact the gradation of either sample. This is because the crushed concrete used complies with the specifications of 12.5 mm-19 mm, as specified by ASTM D422, 2014 [24].

TABLE I. SIEVE ANALYSIS RESULTS

Sieve opening (mm)	Percentage, %		
	Natural granular sub-base material		Crushed concrete
	Sample C	Sample D	
25	100	100	100
19	100	100	100
12.5	83	93	0
9.5	68	80	0
4.75	50	68	0
2.36	32	39	0
0.30	19	25	0
0.075	8	9	0

According to ASTM D1883, the compression test of all specimens is required to determine the γdry max and OMC for the CBR test. Table II and Figures 2 and 3 present the outcomes of the compression tests conducted on samples, on the basis of ASTM D1557 (using modified effort of 56,000 ft-lbf/ft³ or 2,700 kN-m/m³) [25]. The findings of the density test show that the values of γdry max and OMC for the two original samples (C and D) changed after the replacement. Specifically, the γdry max value exhibited a decline in proportion to the increase in the replacement ratio. Conversely, OMC exhibited an increase with the rise in replacement percentage, attributable to the substituted material's comparatively lower density and higher porosity, relative to the original material. This observation aligns with the findings in [3], where alterations in OMC and maximum dry density values were reported, upon incorporating concrete waste and fly ash. However, authors in [10] argued that substituting sub-base material (exceeding 4.75 mm) with crushed stone enhances the γdry max.

TABLE II. RESULTS OF COMPACTION TEST ON SAMPLES

Sub-base sample	γdry max (g/cm^3)	OMC (%)
Sample C	2.160	5.5
Sample C25	2.130	6.0
Sample C50	2.108	7.1
Sample C75	2.047	8.3
Sample C100	2.022	9.3
Sample D	2.128	6.8
Sample D25	2.100	7.5
Sample D50	2.052	8.3
Sample D75	2.035	9.2
Sample D100	2.005	10.2

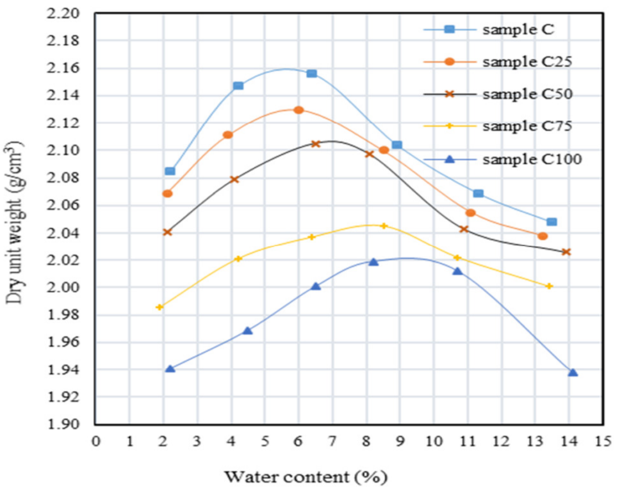

Fig. 2. Dry unit weight variation of sub-base samples of group C with various amounts of replacement in various water contents.

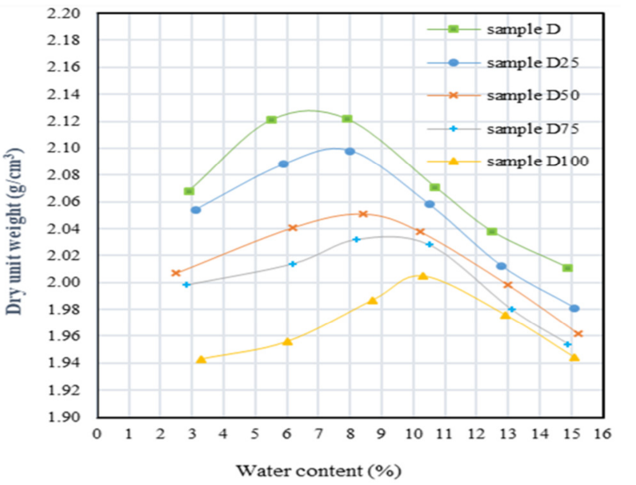

Fig. 3. Dry unit weight variation of sub-base samples of group D with various amounts of replacement in various water contents.

III. TESTING APPARATUS AND EXPERIMENTAL PROCEDURES

A. Apparatus

The preparation of the CBR equipment was completed with all the necessary accessories/equipment, and it satisfies the requirements of ASTM D1883 for sample testing.

B. Experimental Procedures

The following steps are outlined in the experimental protocols:

- Preparing the specimens: As specified in the study, the original pavement base material specimens for testing (specimens C and D) and four models in which the pavement materials of each original specimen are replaced with crushed concrete are created. Consequently, ten samples will undergo practical testing.
- The specimens are then compacted according to the OMC and γdry max values determined from the compaction test by ASTM D1557 (employing a modified effort of 56,000 ft-lbf/ft³ or 2,700 kN-m/m³) using a CBR mold. Surcharge weights of 4.54 kilograms (10 pounds) are utilized.
- For each specimen, one instance has been created that has undergone water soaking, and another which has not. Consequently, ten samples underwent the CBR test without soaking, while ten additional samples were subjected to the CBR test following a four-day soaking period.

IV. RESULTS AND DISCUSSION

The program entails conducting a CBR test on the original samples (C and D) and using the test values as reference points to assess them against the values obtained from testing the samples produced during the replacement process. Figures 4 and 5 present the laboratory results for load penetration for samples from group C, and Figures 6 and 7 from group D under unsoaked and soaked conditions, respectively.

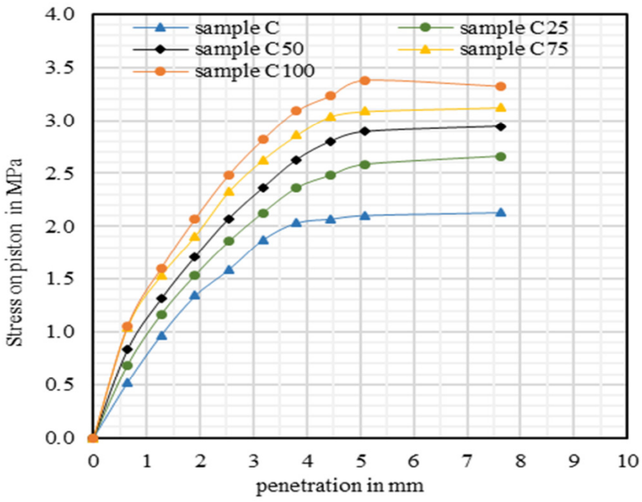

Fig. 4. Load-penetration curves for samples C, C25, C50, C75, and C100 for unsoaked condition.

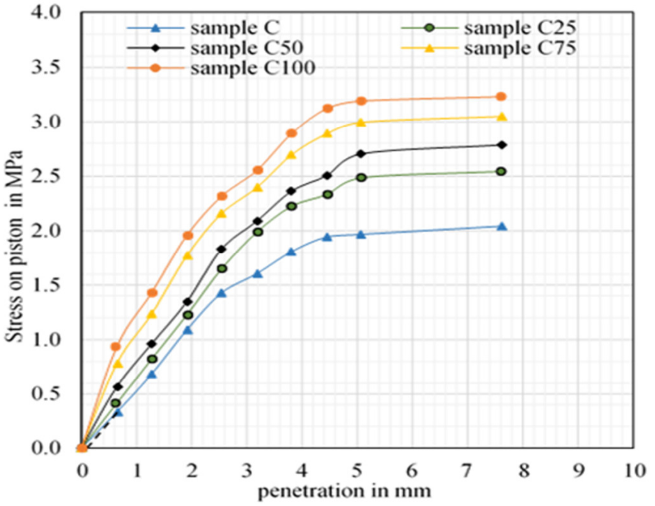

Fig. 5. Load-penetration curves for samples C, C25, C50, C75, and C100 for soaked condition.

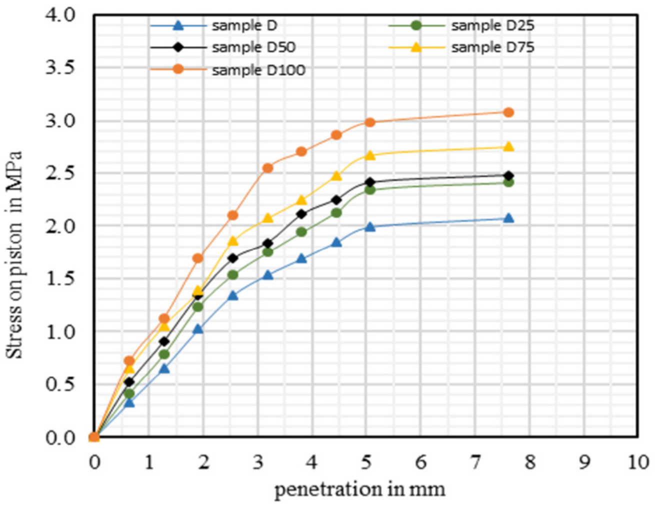

Fig. 6. Load-penetration curves for samples D, D25, D50, D75, and D100 for unsoaked condition.

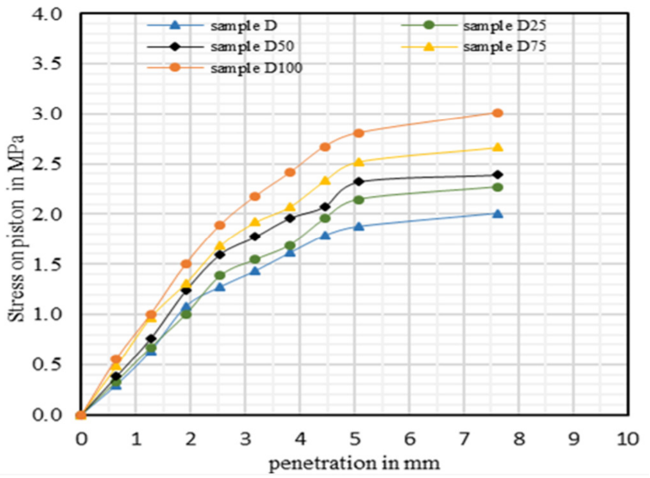

Fig. 7. Load-penetration curves for samples D, D25, D50, D75, and D100 for soaked condition.

The substitution process enhanced the resistance to soil penetration. The CBR values for all samples are illustrated in Table III.

TABLE III. RESULTS OF BEARING RATIO OF SAMPLES

Sample	**Condition**	**CBR (%)**			
		For 0.1 in.	Improvement rate (%)	For 0.2 in.	Improvement rate (%)
C	Unsoaked	23.1	---	20.4	---
C25		26.9	16.45	25.1	23.04
C50		30.0	29.87	28.1	37.75
C75		33.3	44.16	30.0	47.06
C100		36.0	55.84	32.8	60.78
C	Soaked	20.7		19.1	
C25		23.9	15.46	24.1	26.18
C50		26.5	28.02	26.3	37.70
C75		30.9	49.28	29.1	52.36
C100		33.6	62.32	31.0	62.30
D	Unsoaked	19.4	---	19.3	---
D25		22.2	14.43	22.7	17.62
D50		24.4	25.77	23.4	21.24
D75		26.5	36.60	25.9	34.20
D100		30.5	57.22	29.0	50.26
D	Soaked	18.5	---	18.2	---
D25		20.1	8.65	20.8	14.29
D50		23.2	25.41	22.5	23.63
D75		24.1	30.27	24.5	34.62
D100		27.4	48.11	27.3	50.00

Authors in [1-5] and [12] found that CBR values increased with higher replacement levels, correspondingly to the results of the present research. However, this study was unique in replacing the coarse materials (12.5 mm -19 mm) in the sub-base with crushed concrete without integrating them into the mix in order to maintain the gradation of samples C and B, which is critical for meeting the standard gradation specifications. The CBR test results for the 0.1-inch penetration of the samples exhibited a correlation between the replacement ratio and the CBR values, displayed in Figure 8, and the rate of improvement, depicted in Figure 9.

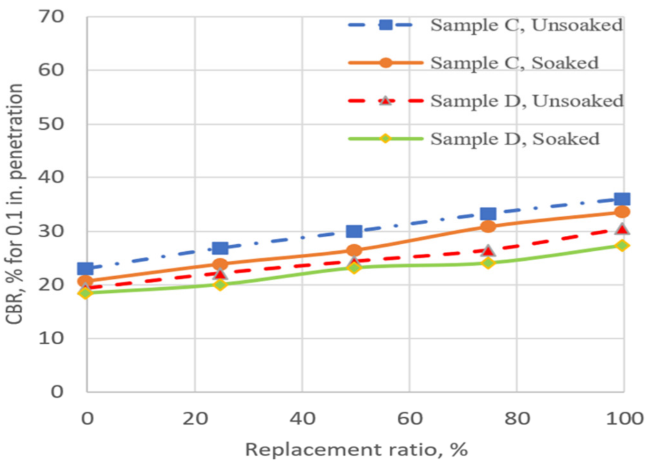

Fig. 8. Relation between replacement ratio and CBR value.

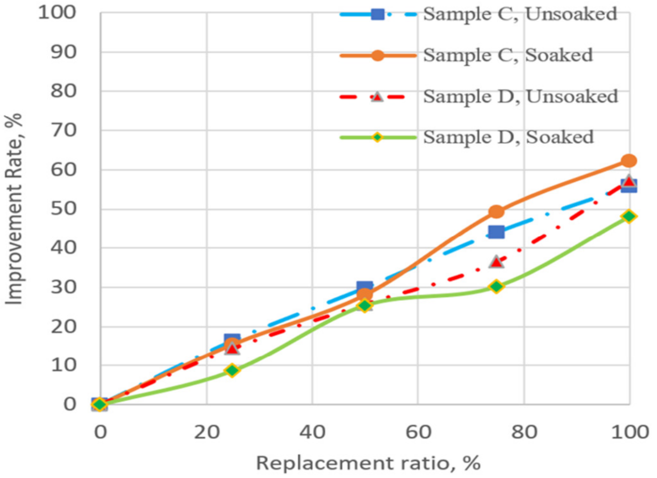

Fig. 9. Relation between replacement ratio and improvement rate.

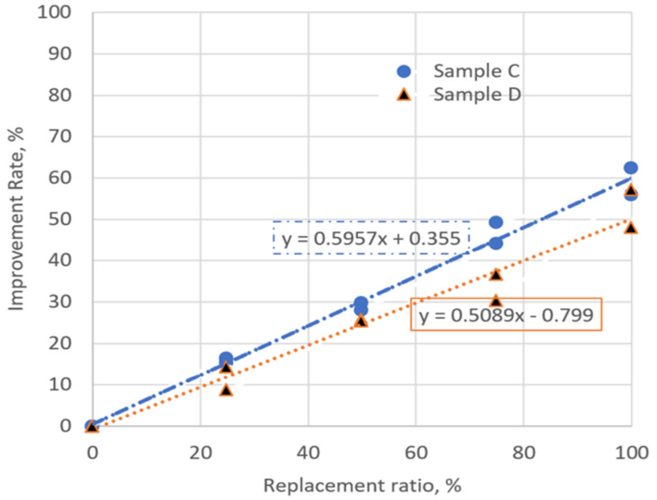

Fig. 10. Relation between replacement ratio and improvement rate for samples C and D in unsoaked and soaked conditions.

These relationships are critical in evaluating the effects of the replacement process since they highlight the values that can be achieved in practical, real-world applications. When selecting a particular material to improve the CBR value of the base material, the relationships illustrated in Figures 7 and 8 must be obtained to evaluate the replacement treatment while maintaining the gradation of the original sample. The improvement ratios for each sample can be aggregated for both non-soaked and soaked conditions to calculate an average improvement ratio, as shown in Figure 10. This provides an equation to estimate the replacement ratios corresponding to the required improvement ratios.

V. CONCLUSIONS

Based on this study's results, the following conclusions can be drawn:

- The Optimum Moisture Content (OMC) increased with higher replacement ratios for samples C and D. When the replacement ratio reached 100%, the OMC increased by 69.1% for sample C and 50% for sample D.
- The maximum dry unit weight (γdry max) decreased as the replacement ratio increased for samples C and D. When the replacement ratio reached 100%, the maximum dry density was reduced by 6.4% for sample C and 5.78% for sample D.
- The increase in OMC values and the decrease in γdry max do not affect the material's compliance with standard specifications, such as those in Iraq, since the success thresholds do not define these values.
- California Bearing Ratio (CBR) values at 0.1 mm penetration increased non-linearly with an increasing concrete replacement ratio as follows: In the uncured condition, sample C exhibited improvement ratios of 16.45%, 29.87%, 44.16%, and 55.84% at replacement ratios of 25%, 50%, 75%, and 100%, respectively. For sample C, the improvement ratio increased by 15.46%, 28.02%, 49.28%, and 62.32% at replacement ratios of 25%, 50%, 75%, and 100%, respectively. In the soaked condition at 0.1 mm penetration, sample C showed improvement ratios of 14.43%, 25.77%, 36.00%, and 57.22% at 25%, 50%, 75%, and 100% replacement, respectively. For sample D, the improvement ratio increased by 8.65%, 25.41%, 30.27%, and 48.11% at 25%, 50%, 75%, and 100% replacement, respectively. The increase in CBR values is attributed to the use of a material with sharper angles than the original substance.
- The convergence of improvement ratio values in CBR measurements for samples with identical replacement ratios is demonstrated.
- It is important to perform a CBR test prior to any replacement or addition process to validate its practical feasibility in achieving favorable CBR values relative to those of the original models. This is achieved by conducting a correlation analysis between the replacement and improvement ratios and by meticulously examining the economic ramifications of the process.
- The usage of concrete waste to enhance the CBR values of a given area has a positive effect on the environment by facilitating the disposal of construction debris.
- The influence of the compressive strength of concrete residue on enhancing CBR values can be examined in future research.

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