# PROPERTIES OF COMPRESSED AND STABILIZED EARTH BLOCKS PRODUCED WITH RECYCLED SOIL MIXES

CMMI #1537078


Nitin Kumar, Dr. Michele Barbato
Department of Civil and Environmental Engineering
University of California, Davis


EARTH USA 2019
10th International Earthbuilding Conference


This study investigates the use of recycled soil obtained by crushing earth blocks as replacement of natural soil in the production of the compressed and stabilized earth blocks (CSEBs). An experimental campaign was conducted to assess the behavior of CSEBs produced using different levels of recycled soil. The prototype CSEB (referred to as N-CSEB) was manufactured by compacting a mixture of natural soil, water, and 12% (by weight) Type-II ordinary Portland cement using a manually-operated compression machine. After determining the properties of the N-CSEBs, these blocks were crushed to obtained recycled soil by using a mechanical pulverizer machine. Recycled CSEBs (R-CSEBs) were fabricated by substituting the natural soil with 25%, 50%, 75%, and 100% (by weight) of recycled soil and by adding 12% cement. R-CSEBs were examined by measuring their compressive and flexure strength, mass loss after 12 wetting/drying cycles, dry density, and water absorption. Scanning electron microscopy images were used to study the CSEB's surface topography, and energy-dispersive X-ray spectroscopy data were used to gain quantitative information on their chemical composition. One-way analysis of variance was employed to determine the statistical significance of the obtained experimental results. The results indicate that the use of the recycled soil (crushed earth blocks) improves the mechanical properties of the CSEBs while a constant proportion of cement is added to the mix.

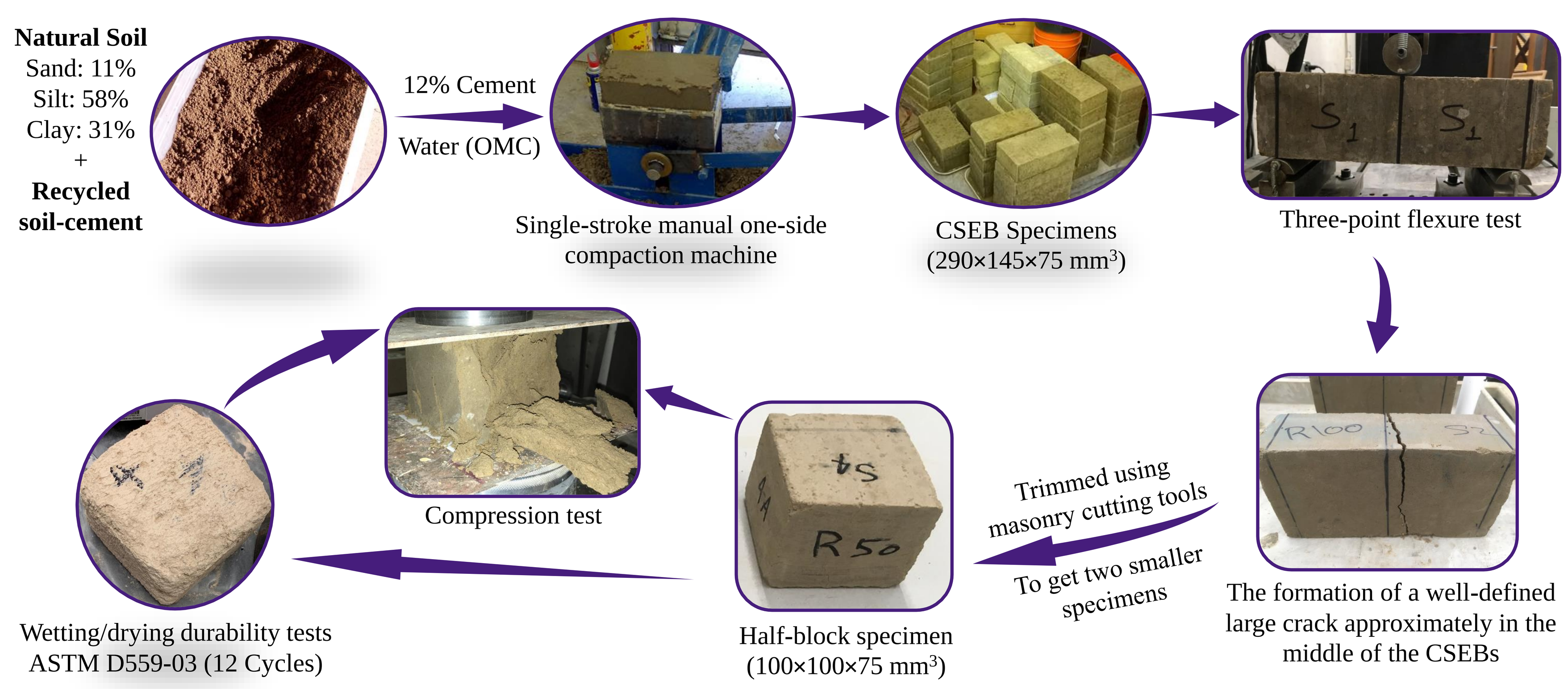

## Introduction

Compressed and stabilized earth blocks (CSEB) structural systems are becoming popular due to their low cost, low carbon footprint, use of indigenous materials, and inherent simplicity when compared to other traditional construction typologies [1-3].

- ❑ Well-built CSEB structures are typically very durable (surviving even hundreds of years [4]); However, even these structures have a finite design life.
- ❑ The construction sustainability requires a cradle-to-grave life cycle assessment that includes the environmental effects of the construction waste after demolition. In particular, it is important to identify beneficial uses for the demolished construction waste to avoid the problem of disposing the construction debris in future.

The potential of using CSEBs demolition waste for the new CSEB construction is unknown [2]. Therefore, <u>The present study investigates the recycling of CSEB demolition debris as partial or total replacement of natural soil when fabricating new CSEBs.</u>

## Materials And Methods




***Details of experimental campaign: Test matrix***

| Specimen I.D. | Number of CSEBs | Mix composition (%) Natural soil | Cement | Recycled soil-cement | Number of specimens tested in Flexure# | Compression* | Durability* |
|---|---|---|---|---|---|---|---|
| N-100 | 24 | 89.29 | 10.71 | 0.00 | 24 | 24 | 24 |
| R-25 | 6 | 66.96 | 10.71 | 22.32 | 6 | 6 | 6 |
| R-50 | 6 | 44.64 | 10.71 | 44.64 | 6 | 6 | 6 |
| R-75 | 6 | 22.32 | 10.71 | 66.96 | 6 | 6 | 6 |
| R-100 | 6 | 0.00 | 10.71 | 89.29 | 6 | 6 | 6 |

- ❑ Ordinary CSEBs (N-100) were crushed using a BICO UA V-Belt Driven pulverizer.
- ❑ One-way analysis of variance (ANOVA) was performed on the experimental results in order to determine the statistical significance of the obtained experimental data [6].
- ❑ The CSEB morphology and chemical composition was evaluated via Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS), respectively

## Results And Discussion

The experimental results are presented in the following sub-section in terms of sample means and coefficients of variation (COV) of the modulus of rupture (MOR), modulus of elasticity (MOE), wet compressive strength ($f_{bw}$), loss in mass, dry density and water absorption.

### *Mechanical Properties*

- ❑ The mean MOR, $f_{bw}$ and MOE increase for increasing amount of recycled soil-cement mix.
- ❑ The increase in mechanical properties can be attributed to the higher overall cement content of the CSEB specimens with higher recycled soil-cement mix content.
- ❑ All the CSEB specimens satisfy the strength requirements set by the NMAC 2014.
- ❑ The ANOVA results indicate that the mean values of MOR and $f_{bw}$ of N-100 are statistically different from other recycled CSEBs.

***Mechanical properties of CSEBs for different recycled soil content***

| Specimen I.D. | MOR Mean (MPa) | MOR COV (%) | $f_{bw}$ Mean (MPa) | $f_{bw}$ COV (%) | MOE Mean (MPa) | MOE COV (%) |
|---|---|---|---|---|---|---|
| N-100 | 0.46 | 23.81 | 2.08 | 12.12 | 63.70 | 28.79 |
| R-25 | 0.78 | 8.21 | 2.28 | 10.00 | 67.54 | 10.35 |
| R-50 | 0.85 | 17.78 | 2.53 | 17.28 | 77.54 | 35.15 |
| R-75 | 0.88 | 9.81 | 2.62 | 16.74 | 87.31 | 30.41 |
| R-100 | 1.06 | 21.97 | 2.72 | 12.91 | 90.22 | 22.00 |

### *Durability Properties*

- ❑ The mean values of the percentage loss in mass of CSEBs vary from 1.57% to 2.14%.
- ❑ The specimen R-75 exhibit the lowest percentage loss in mass among all specimens, and the ANOVA results indicate that it is statistically different from other specimens.

***Wetting and drying durability test results***

| Specimen I.D. | Loss in mass Mean (%) | Loss in mass COV (%) | Change in dry density Mean (%) | Change in dry density COV (%) | Change in water absorption Mean (%) | Change in water absorption COV (%) |
|---|---|---|---|---|---|---|
| N-100 | 2.09 | 17.34 | -1.80 | 85.15 | 8.93 | 85.15 |
| R-25 | 2.14 | 16.22 | -2.20 | 34.26 | 9.26 | 38.88 |
| R-50 | 1.99 | 14.05 | -2.05 | 40.29 | 10.07 | 18.46 |
| R-75 | 1.57 | 17.46 | -2.71 | 45.48 | 9.30 | 38.60 |
| R-100 | 1.92 | 23.02 | -3.75 | 46.82 | 7.55 | 31.05 |

- ❑ A decrease in dry density and increase in water absorption is observed for all the specimens.
- ❑ ANOVA results indicate that only the mean values of the dry density and water absorption for the R-100 specimen are statistically different from other specimens.

**Compressive Strength after Durability Investigation**

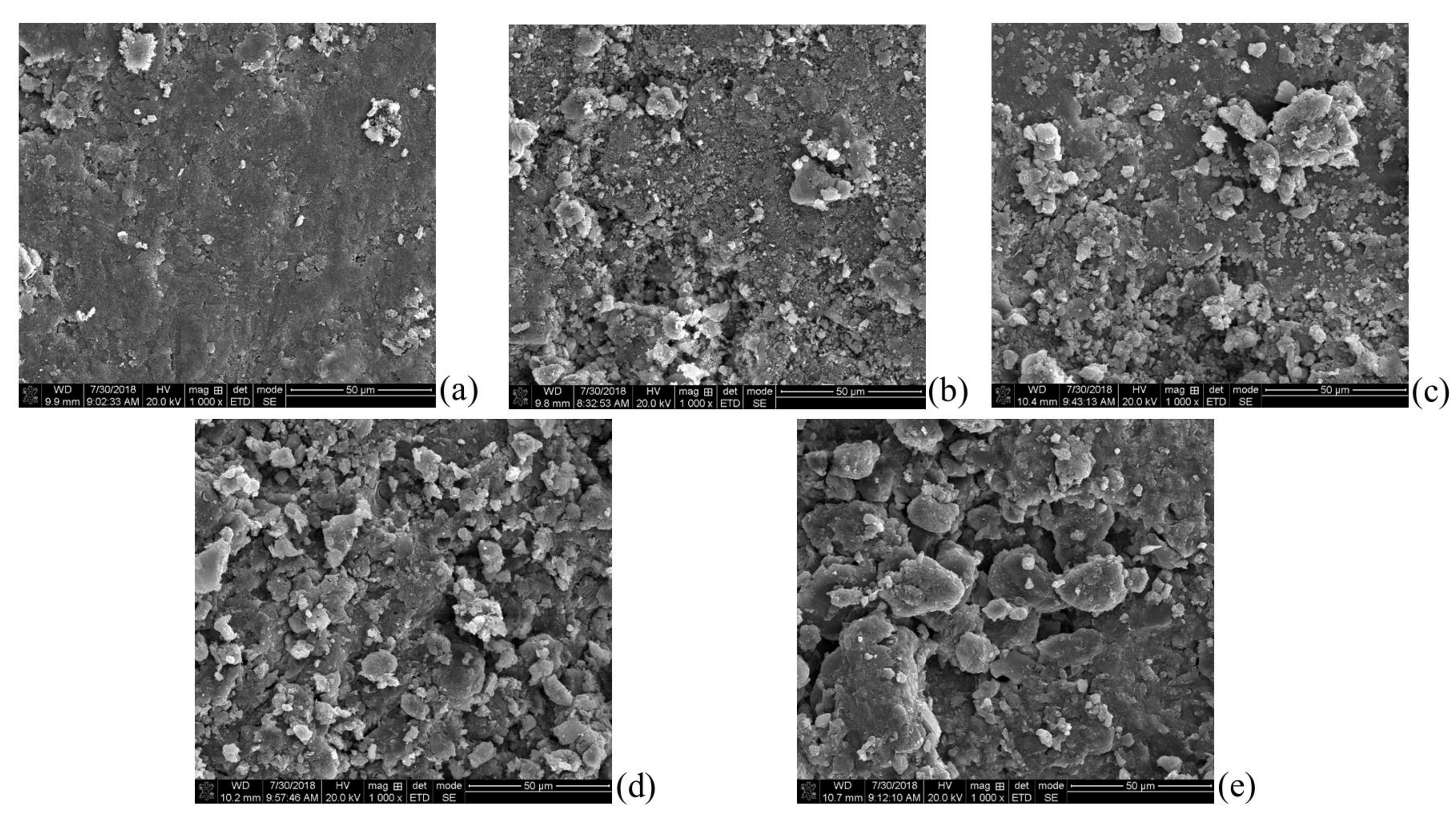
- ❑ All CSEB specimens exhibit an increase in $f_{bw}$ and MOE after durability tests.
- ❑ The mean values of $f_{bw}$ after the durability tests are 3.09% to 7.47% higher when compared to their original blocks; whereas, the mean values of MOE are 2.46% to 10.74% higher.
- ❑ ANOVA results indicate that the differences in the mean values of $f_{bw}$ and MOE before and after the durability test is statistically insignificant for all CSEB specimens.

***Compression test results of CSEBs after the durability test***

| Specimen I.D. | $f_{bw}$ Mean (MPa) | $f_{bw}$ COV (%) | MOE Mean (MPa) | MOE COV (%) |
|---|---|---|---|---|
| N-100 | 2.23 | 15.84 | 68.88 | 25.33 |
| R-25 | 2.36 | 23.60 | 74.79 | 24.59 |
| R-50 | 2.59 | 18.40 | 79.45 | 22.62 |
| R-75 | 2.76 | 13.42 | 90.21 | 18.85 |
| R-100 | 2.87 | 14.22 | 92.83 | 20.32 |

### *Morphology*

- ❑ Specimen N-100's micrograph mostly shows compacted fine particles and with a few grain-like particles.
- ❑ The size and amount of particles increase for increasing recycled soil-cement content.



***SEM micrographs of CSEBs at 50 $\mu m$: (a) N-100; (b) R-25; (c) R-50; (d) R-75; and (c) R-100***

### *Chemical composition*

- ❑ The chemical composition of CSEBs is similar to that of the natural soil.
- ❑ The Ca content increases progressively with increasing amounts of soil-cement mix, which may be attributed to the increasing cement content.

***EDS microanalysis results (% mass of chemical elements) of natural soil and CSEBs***

| Specimen I.D. | O | Si | Ca | Al | Fe | K | Mg | S | P |
|---|---|---|---|---|---|---|---|---|---|
| Natural soil | 50.49 | 32.47 | 0.76 | 8.45 | 3.66 | 2.71 | 1.05 | 0.01 | 0.24 |
| N-100 | 48.53 | 28.89 | 6.76 | 7.68 | 3.91 | 2.47 | 1.07 | 0.28 | 0.24 |
| R-25 | 48.04 | 28.09 | 8.19 | 7.49 | 4.24 | 2.47 | 1.07 | 0.29 | 0.24 |
| R-50 | 47.77 | 27.50 | 9.71 | 7.38 | 4.05 | 2.37 | 1.06 | 0.38 | 0.14 |
| R-75 | 47.29 | 26.72 | 11.28 | 6.97 | 4.13 | 2.28 | 1.07 | 0.43 | 0.17 |
| R-100 | 46.93 | 25.94 | 12.85 | 7.07 | 3.83 | 2.11 | 1.07 | 0.47 | 0.18 |

## Conclusions

1. The compressive strength of recycled CSEBs increases with increasing recycled soil-cement mix content when a constant proportion of cement is added to the mix.
2. Recycled CSEBs satisfy the strength requirements set by the NMAC 2014.
3. The CSEB specimen R-75 exhibit the lowest percentage loss in mass among all the specimens considered in this study when subjected to a durability test.
4. CSEBs experience a decrease in dry density and an increase in water absorption when subjected to wetting and drying cycles.
5. The scanning electron microscopy micrographs show that the average particle size in CSEBs increase for increasing recycled soil-cement mix content.

## Acknowledgments


Partial support for this research by the Louisiana Board of Regents through the EDA Program and the National Science Foundation through award CMMI #1537078 is gratefully acknowledged.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Nitin Kumar, PhD Student | Department of Civil & Environmental Engineering, University of California Davis, 1124 Crocker Ln, 2209 Academic Surge, California 95616; Email: ntnkumar@ucdavis.edu
Dr. Michele Barbato, Professor | Department of Civil & Environmental Engineering, University of California Davis, One Shields Avenue, 3149 Ghausi Hall, Davis, California 95616; Email: mbarbato@ucdavis.edu