# Compressive Strength of Compressed Earth Blocks Using Slaked Lime/Cement Combination as Stabilizer

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## Abstract

*This study determines the compressive strength of compressed earth blocks using a combination of slaked lime and Portland cement as stabilizer. Stabilizer: earth mix ratio of 1:10, 1:12, and 1:14 is considered in the study. Stabilizer used in this study is composed of 50% slaked lime and 50% Portland cement. Soil used for the production of blocks is taken from the quarry in Pindugangan, Iligan City. The blocks are fabricated using a locally manufactured block press. The block dimension is 100 x 150 x 300 mm (L x W x H). Compressed earth blocks were tested for compressive strength at 7$^{th}$, 14$^{th}$, and 28$^{th}$ days.*

*For 28 days of curing period, stabilizers: earth mix ratio of 1:10, 1:12, and 1:14 gives an average compressive strength of 5.75, 5.42, 5.04 MPa, respectively. The compressive strength of the different mix ratio varies slightly. Lower stabilizers-earth mix ratio develops higher compressive strength.*

Keywords: Con Earth Blocks, Stabilizers, Slaked Lime Cement

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## Introduction

Compressed earth block (CEB) is one name given to earthen bricks compressed with hand-operated or motorized hydraulic machines. Soil is found almost all over the world and can be made into building materials.

The trick for turning common soil into a suitable building material is to add a small amount of stabilizer for strength and durability, and then compact it so it will hold together. Portland cement is commonly used in compressed earth block construction though expensive, from both an environmental and monetary standpoint.

When lime is mixed with water, it forms calcium hydroxide, called slaked lime. Slaked Lime, calcium hydroxide, Ca $(OH_2)$, when wetted expands and gets hot, breaking down into a fine powder without the use of additional heat. Lime is the primary ingredient in Portland cement, however, in its unprocessed form, it requires twice as long to cure as processed cement (2 weeks wet cure, 2 weeks dry cure, and 4 more weeks max strength).

This study determines the compressive strength of compressed earth blocks using combination of slaked lime and Portland cement.

## Objective of the Study

The goal of the study is to evaluate the compressive strength of compressed earth blocks with a combination of slaked lime and Portland cement as stabilizer using the soil from the quarry in Pindugangan, Iligan City.

Specifically, the study aimed the following:

1. Determining the compressive strength of each block with varying ratios of slaked lime/cement-earth mix ratio at $7^{th}$, $14^{th}$, and $28^{th}$ day.
2. Knowing the relationship of the compressive strength of the block with its curing period.
3. Comparing the compressive strength of the blocks with three different mixtures, 1:10, 1:12, and 1:14 (stabilizer: earth). 1 part stabilizer contains 50 percent slaked lime and 50 percent Portland cement.

4. Investigate the possibility of using the soil from the quarry in Pindugangan, Iligan City as raw material for compressed earth block production.

## Review of Related Literature

### Compressed Earth Blocks

Over time, innovation in compressed earth block manufacture has included changing the original shapes. Another innovation was to create interlocking shapes that don't need to be laid in a bed or mortar. The interlocking shapes of the improved bricks can help to reduce the skill level needed for homeowners to build their own homes.

Initially, research undertaken by the Thailand Institute of Scientific and Technological Research (TISTR), Bangkok, focused on soil-cement blocks made with the CINVA-Ram manual block press (which was developed in Colombia in 1956). The demonstration houses built with these blocks were cheaper than timber houses, more durable, resistant to water, fire and termites, and aesthetically appealing. The disadvantages, however, were that the blocks were relatively heavy, and building construction required a certain amount of masonry skills. Furthermore, the mortar joints consumed a considerable amount of cement and construction time was relatively long.

Earth block material is practical, economical, and environmentally sound. Earth is man's oldest building material. Advantages of compressed earth blocks include: uniform building component sizes, use of locally available materials, and reduction of transportation.

### Stabilizer

Stabilizers such as cement, gypsum, lime and the liquid types have been used in the body or in the surface of the block. The selection of a stabilizer depends upon the soil quality and the project requirements: cement will be preferable for sandy soils and to achieve a quick a higher strength. Lime will be used for very clayey soil, but will take a longer time to harden and to give strong blocks. Slaked lime is lighter than cement having a dry density of 2.2 g/cm$^3$ while cement has a dry density of about 2.5 g/cm$^3$.

When lime is mixed with water, it forms calcium hydroxide, called slaked lime.

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s)$$

**Average Stabilizer Proportion**

| | Minimum | Average | Maximum |
|---|---|---|---|
| **Cement stabilization** | 3 % | 5 % | No technical maximum |
| **Lime stabilization** | 2 % | 6 % | 10 % |

These loe percentages are part of the cost effectiveness of CEB

Basic Data on CEB

| | |
|---|---|
| Dry compressive strength at 28days (+ 10% after 1 year + 20% after 2 years) | 4 to 6 MPa =40 to 60 kg/cm$^2$ |
| Wet compressive strength at 28 days (after 3 days immersion) | 2 to 3 MPa =20 to 30 kg/cm$^2$ |
| Dry bending strength (at 28 days) | 0.5 to 1 MPa =5 to 10 kg/cm$^2$ |
| Dry shear strength (at 28 days) | 0.4 to 0.6 MPa =4 to 6 kg/cm$^2$ |
| Water absorption at 28 days (after 3 days immersion) | 8 to 12% (by weight) |
| Apparent bulk density | 1700 to 2000 kg/m$^3$ |

## Methodology

### Materials Used in the Production

Soils used in block production are taken from the quarries in Pindugangan, Iligan City. Source of slaked lime is from Maria Christina Chemical Industries, Incorporation (MCCI). Type-1 Portland cement is used in the study.

### Grain Size Analysis

Analysis on grain size distribution is performed to know the quantity of each grain size. With hand presses 10% clay is a minimum amount to make strong blocks.

### Water Content Determination

Minimal moisture content results in better strength water resistance, durability and thermal mass in the finished block.

### Compaction Test

Water content and corresponding dry density of the soil is obtained to determine the Optimum Moisture Content and Maximum Dry Density. The water content corresponding to the vertex of the curve is the optimum moisture content. Maximum dry density is the dry density/optimum moisture content of the soil.

### Data Sampling

Stabilizer used is composed of 50% slaked lime and 50% Portland cement. The amount of water needed in the mixture is based on the formula:

$$Wa = W_T \left\{ \left( \frac{1 + \frac{\omega_{omc}}{100}}{1 + \frac{\omega}{100}} \right) - 1 \right\}$$

$W_T$ is the weight of the stabilizer- earth mix

Stabilizer and earth is proportion at 1:10, 1:12, and 1:14, by weight. Each batch mix produces 9 specimens for compression test. A total of 27 specimens are obtained from this three mixes.

**Earth Block Dimension and Machine Used**

The compressed earth block dimension is 100 mm x 150 mm x 300 mm (H x W x L). This is the average size of the block. The machine used is a locally manufactured block press.

**Mixing and Casting**

The dry ingredients are mixed first, and then water is added. In using the press, it is very important to fill it with the proper amount of soil mixture. To make removing the blocks from the press easier, a kerosene / oil mixture is lightly sprayed on the inside of the press before filling.

**Curing of Blocks**

Curing for earth blocks is different with the concrete hollow blocks (CHB). As the blocks are removed from the press, they are inspected for defects and carefully stacked on a clean, flat, level surface under the shade and away from direct sunlight.

**Test for Compressive Strength**

Compression is done after the curing period of the blocks. The maximum load applied to the block before cracks in the block occur is the basis of the blocks' compressive strength. The formula is

$$f'_c = \frac{\text{Maximum Load Applied (N)}}{\text{Net Area (mm}^2)}$$

**Statistical Analysis of Data**

The Analysis of Variance describes a technique whereby the total variation is analyzed. The variance is calculated as number of degrees of freedom. The Analysis of Variance (ANOVA) was accomplished using a website in the Internet named STATLETS.

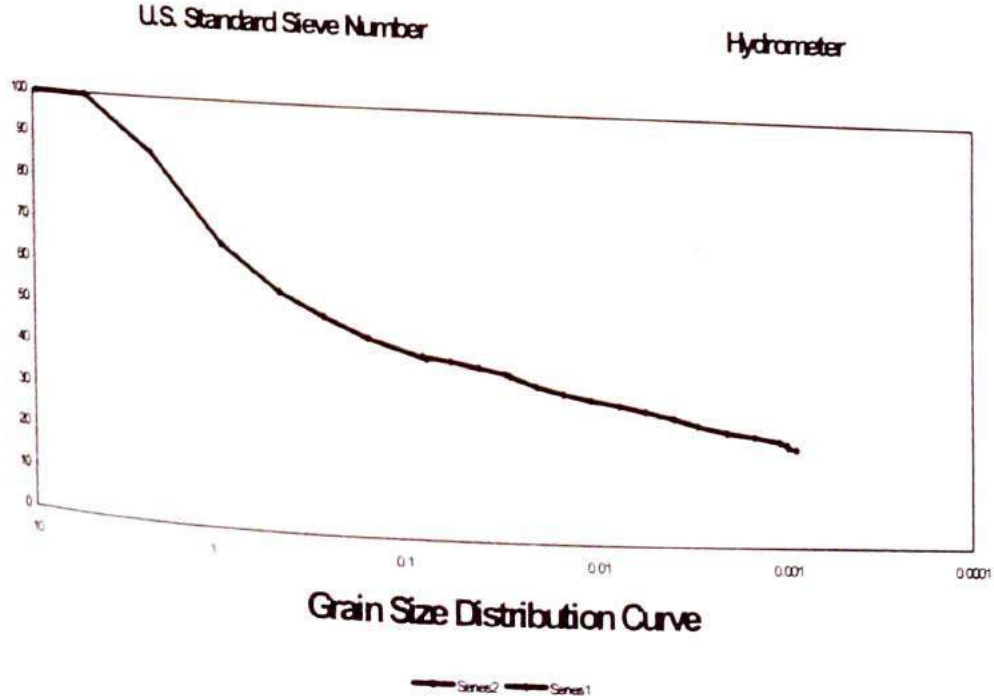
## Results and Discussion

### Grain Size Distribution

Results of grain size analysis shows that the maximum size of the soil particle has a diameter of about 9.5 mm. Sand and gravel particles are mostly of angular shape. By using the Soil Classification Chart and Plasticity Chart, and ASTM D2487-90, the soil is classified as **Clayey Sand** with the symbol **SC**. Soil contains 13.06 % of gravel, 44.75 % of sand and 42.19 % of silt and clay particles.

### Water Content Determination

Water content determinations of soils passing number 4 sieve (4.75 mm) were made before the production of the block. Soils passing the #4 sieve are used for making the blocks.




Grain Size Distribution Curve

Average Water Content, ω:

$$\omega_{average} = \frac{\sum \omega}{n}$$

$n$ is the number of trials made

The obtained average water content of the soil sample is $\omega_{average}$ **= 7.61 %**

**Compaction Test Results**

Test results show that optimum moisture content is equal to **15.24%**. Maximum dry density of the soil is equal to its dry density divided by the optimum moisture content of the soil, which is equal to **1.81 g/cm³**.

**Data Sampling**

The table shows the proportions of slaked lime, cement and water to be added for every 20 kg of soil for 1:10, 1:12 and 1:14 stabilizer/earth mix ratio.

| Lime/cement-Soil Mix Ratio | Wt. of Soil, g | Wt. of lime, g | Wt of Cement, g | Wt. Of Water added, g |
|---|---|---|---|---|
| **1:10** | 20,000 | 1000.0 | 1000.0 | 1,562.1 |
| **1:12** | 20,000 | 833.3 | 833.3 | 1,538.4 |
| **1:14** | 20,000 | 714.3 | 714.3 | 1,522.0 |

## Compressive Strength Test Results

Compressive strength of the sample was obtained when maximum applied load was divided by the actual area of the mortar cube perpendicular to the direction of the load.

Results show that the average compressive strength of the blocks increases as the curing period increases. For 1:10 mix ratio, the average compressive strength for 7th, 14th, and 28th days were 2.32, 3.83, 6.03 MPa, respectively. For 1:12 mix ratio, the average compressive strength for 7th, 14th, and 28th days were 1.74, 3.05, 5.42 MPa, respectively. For 1:14 mix ratio, the average compressive strength for 7th, 14th, and 28th days were 1.60, 3.01, 5.04 MPa, respectively.

Compressive strengths of lower lime/cement-soil mix ratio vary only with slight difference. These blocks can be used in any non-load bearing structure.

## Analysis of Variance for Compressive Strength Data

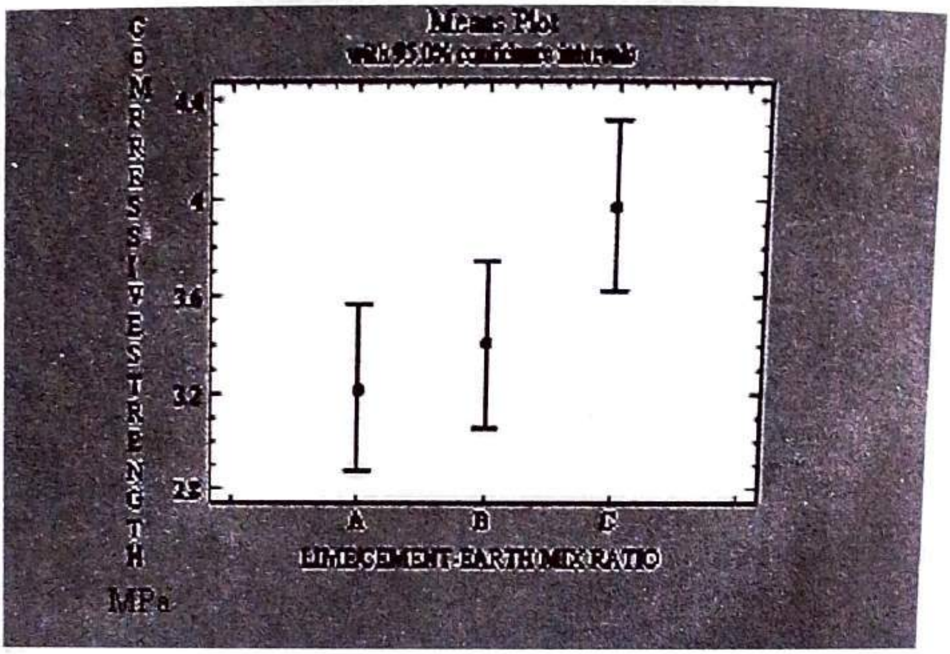
Result shows that the following factors, factor A- Stabilizer/Earth mix ratio and factor B- Curing period have a P-value 0.0125 and 0.0001below 0.05, thus, statically significant at the 95% confidence interval. The null hypothesis is rejected. Varying mix ratio of Lime/cement-soil when applied in CEB does affect its compressive strength. Interaction is barely insignificant at the 0.05 level, but the P-value of 0.9517 is not statically significant at the 95% confidence interval. This means that there is no interaction between lime/cement-earth mix ratio and curing period.

**Analysis of Variance for Compressive Strength**

| Source of Variance | Sum of Squares | Degrees of | Mean Square | F-Ratio | P-Value |
|---|---|---|---|---|---|
| Lime/Cement Mix, A | 2.67160 | 2 | 1.3808 | 5.64 | 0.0125 |
| Curing Period, B | 56.37 | 2 | 28.185 | 115.11 | 0.0001 |
| Interaction | 0.165015 | 4 | 0.0412537 | 0.17 | 0.9517 |
| Error | 4.40747 | 18 | 0.244859 | | |
| Total | 63.7041 | 26 | | | |

### Mean Compressive Strength vs. Lime/Cement-Earth Mix

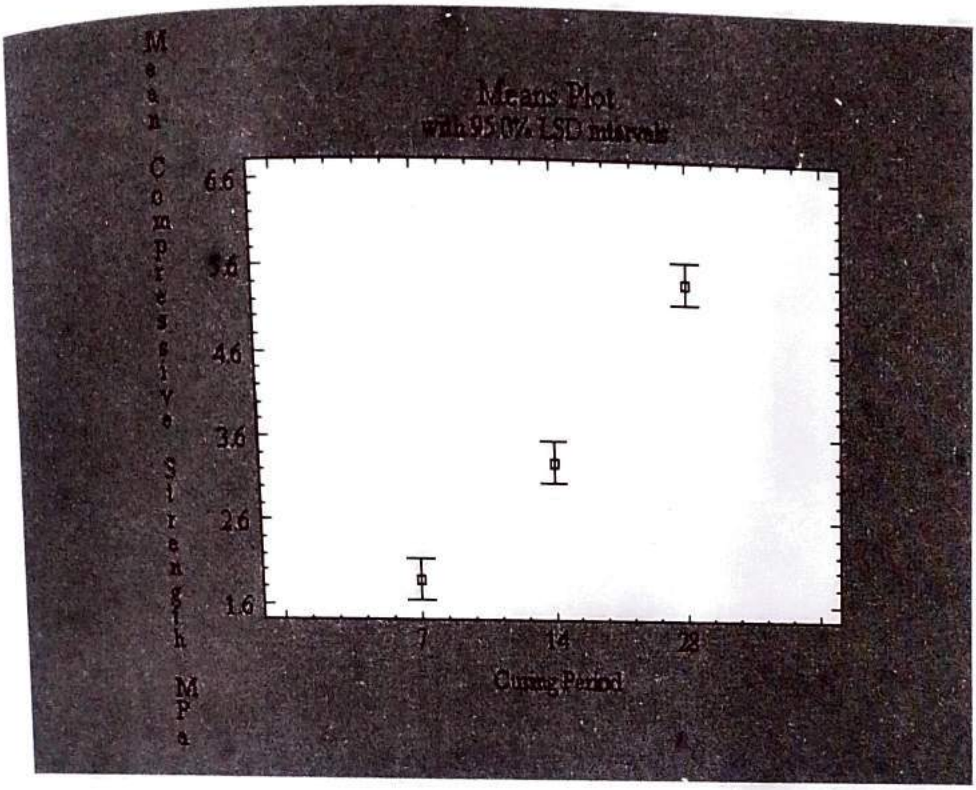
The result of varying stabilizer-earth mix ratio affects the compressive strength of the blocks as shown Figure 4.2. The compressive strength of the block is directly proportional to lime/cement-soil mix ratio. For lime/cement-earth mix ratio category in the x-axis, A, B and C corresponds to 1:14, 1:12, and 1:10 mix.




Compressive Strength vs. Lime/Cement-Earth Mix

### Mean Compressive Strength vs. Curing Period

Figure shows the mean for each level of curing period and the interval around each mean. As the curing period increases, their corresponding compressive strength also increases.




Mean Compressive Strength vs. Curing Period

## 4.1 Interaction Plots of Factors A and B

There is only a small interaction between compressive strength and curing period. If there were absolutely no interaction, these lines would be parallel. The more different the shapes of the lines in the interaction plots, the more effective is their interaction.

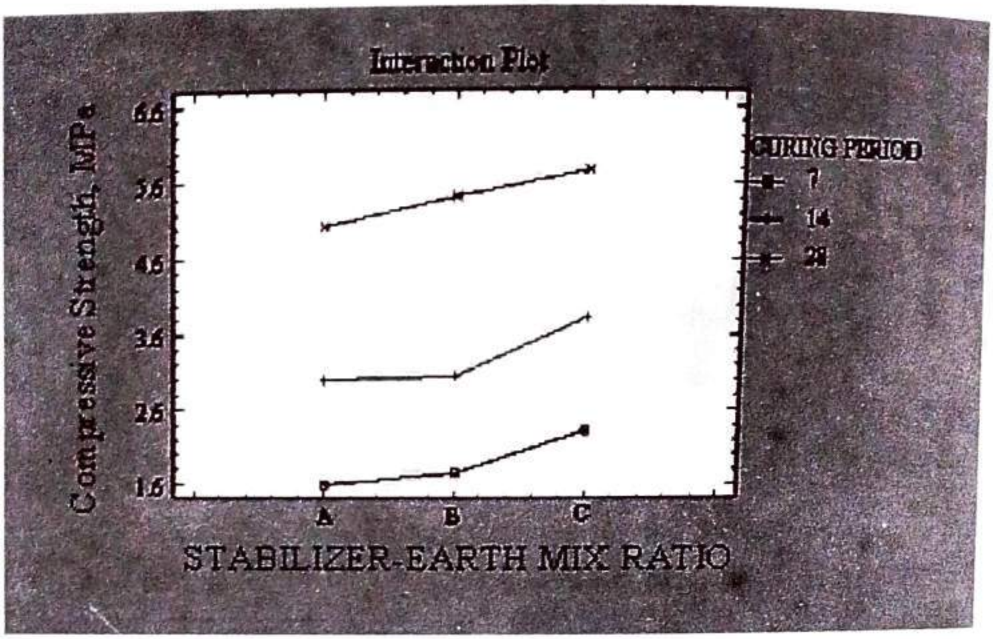



**Figure 4.4** Interaction Plots of Factors A and B

## Conclusions and Recommendations

### Conclusions

The obtained compressive strength of the blocks vary respectively with respect to the varying mix ratios of lime/cement-soil and its curing period. Compressive strength of the blocks is directly proportional to the lime/cement-soil mix ratio and curing period. It has been observed that compressive strength of the blocks is slightly affected by the two factors. As the curing period increases, average compressive strength also increases. For 1:10 mix ratio, the average compressive strength for 7$^{th}$, 14$^{th}$, and 28$^{th}$ days were 2.32, 3.83, and 5.75 MPa respectively. For 1:12 mix ratio, the average compressive strength for 7$^{th}$, 14$^{th}$, and 28$^{th}$ days were 1.74, 3.05, and 5.42 MPa respectively. For 1:14 mix ratio, the average compressive strength for 7$^{th}$, 14$^{th}$, and 28$^{th}$ days were 1.60, 3.01, and 5.04 MPa respectively. For the 28$^{th}$ days of curing period, the average compressive strength of 1:10, 1:12, and 1:14 mix ratio were 5.75, 5.42, and 5.04 MPa respectively. Compressive strengths of lower lime/cement-soil mix ratio vary only with slight difference. These blocks can be used in any non-load bearing structure.

## Recommendations

For succeeding studies, the following modifications are recommended:

1. When mixing the dry components, add first the slaked lime to the soil, moisten and keep covered for a period of time to give more time for the lime to stabilize the soil. Mix cement after the given period before making blocks.
2. A comparison of the curing period of the blocks with varying mix ratio of stabilizers.
3. In addition, it is recommended to vary the quantity of slaked lime, Portland cement and soil, by volume.

## Appendix

## ASTM PROCEDURES USED IN THE EXPERIMENT

### ASTM D698 Standard Test Method for Compaction Test

**Apparatuses:**

Standard compaction mold
Standard compaction hammer
Balance
Oven

**Procedure:**

1. Obtain a sample and break it down to smaller than 4.75 mm (No. 4 sieve).
2. Add water to bring the sample to within about 5% of the estimated optimum water content. Mix thoroughly.
3. Find the mass of the mold without the collar.
4. Compact the soil in the mold (with the collar) in three layers, using standard compactive effort.
5. Remove the collar and trim the compacted mixture to even with the top of mold using the straightedge.
6. Measure the mass of the mold and the soil.

7. Extract the soil from the mold, split it, and obtain a sample to test for water content.
8. Place this sample in a beaker, obtain the mass of the sample with the container, and place it in the oven to dry.
9. Break the soil down until it passes a 4.75 mm (No. 4) sieve.
10 Add water to increase the water content by about 2%, and repeat steps 4 through 10.
11. Continue until the mass of the mold and the soil decrease from the previous trial.

**ASTM D422-63 Standard test Method for Particle Analysis of Soils**
**Materials and Equipment:**

Set of sieves with Pan and Cover
Mortar and Pestle
Balance sensitive to 0.1 g
Thin-bristle brush

**Procedure:**

1. Obtain exactly 500 g of oven-dry soil
2. Take a sample of 250 g to be wash through #200 sieve discarding that passing.
3. Oven-dry the residue and weigh before running it to a stack of sieves varying from larger sizes to smaller sizes from top down.
4. Compute the percent retained on each sieve by dividing the weight retained on each sieve by original sample weight.
5. Compute the percent passing by starting with 100% and subtracting the percent retained on each sieve as a cumulative procedure.

Make a plot of grain size versus percent finer.

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