# CEMENT DOSAGE AND COMPRESSIVE STRENGTH CORRELATION IN RAMMED EARTH WALLS: A CASE STUDY

# CORRELACIÓN ENTRE LA DOSIFICACIÓN DEL CEMENTO Y LA RESISTENCIA A LA COMPRESIÓN EN MUROS DE TIERRA APISONADA: UN ESTUDIO DE CASO

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Recibido (Received): 27 / 03 / 2023 Publicado (Published): 20/12/2023

**ABSTRACT**

This study investigated the correlation and development of a linear regression model between the variables "added cement" and "compressive strength of rammed earth walls" built with aggregates obtained from Colpa Alta, Huánuco, Peru through bivariate analysis. This analysis was motivated by the growing difficulty of the local population to build confined masonry housing due to the increase in construction material prices caused by the COVID-19 pandemic. In this scenario, rammed earth walls offer a more affordable alternative to the traditional system, although it is necessary to improve their structural capacity. 60 aggregate samples were collected in situ, following the Peruvian Technical Standard E-080. Subsequently, they were divided into four groups of 15 samples each, where 5%, 10% and 15% of the aggregate was replaced with cement. Compressive strength tests were carried out and the results were analyzed using statistical techniques. The findings revealed a significant increase in compressive strength in samples containing cement compared to conventional rammed earth blocks. It was found that there is a strong correlation between the "added cement" variable and the "compressive strength of rammed earth walls". The linear regression model quantitatively explained the influence of cement on compressive strength.

*Keywords: rammed earth walls, cement, compressive strength, correlation, linear regression*

**RESUMEN**

Este estudio investigó la correlación y el desarrollo de un modelo de regresión lineal entre las variables "cemento agregado" y "resistencia a la compresión de paredes de tierra apisonada" construidos con agregados obtenidos en Colpa Alta en Huánuco, Perú mediante análisis bivariado. Este análisis fue motivado por la creciente dificultad de la población local para construir viviendas confinadas de mampostería debido al aumento de los costos de los insumos de construcción provocados por la pandemia de COVID-19. En este escenario, los muros de tierra apisonada ofrecen una alternativa más asequible al sistema tradicional, aunque es necesario mejorar su capacidad estructural. Se recolectaron 60 muestras de agregados in situ, siguiendo la Norma Técnica Peruana E-080. Posteriormente, se dividieron en cuatro grupos de 15 muestras cada uno, donde el 5%, 10% y 15% del agregado fue reemplazado por cemento. Se efectuaron ensayos de resistencia a la compresión y los resultados se analizaron mediante técnicas estadísticas. Los hallazgos revelaron un aumento significativo en la resistencia a la compresión en muestras que contienen cemento en comparación con los bloques de tierra apisonada convencionales. Se obtuvo una alta correlación para la variable "cemento incorporado" y la "resistencia a la compresión de las paredes de tierra apisonada". El modelo de regresión lineal explicó cuantitativamente el efecto del cemento en la resistencia a la compresión.

*Palabras clave: bloques de tapial, cemento, resistencia a la compresión, correlación, regresión lineal*

## 1. INTRODUCTION

The construction of rammed earth houses or compressed earth block (BTC) involves the use of clay soil, which is compacted using wooden rammers. On this system, Roux and Espuna mention that "vestiges found in the Asian, European and American continents confirm the use of earth construction techniques for many years" [1, pp.23] And its expanded use is due to its low construction cost, because it involves the utilization of materials specific to the area and does not require skilled labor; In addition to having an excellent thermal and acoustic capacity.

Based on the most recent population survey conducted by the National Institute of Statistics and Informatics, there are 104 930 private homes with adobe or rammed earth, which represents 55.3% of the total private homes in the region [2, pp.31]. Although

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the number of homes with noble material in 2017 increased by 53.3% compared to 2007 [2, pp.26], due to the fact that families have migrated to the confined masonry system that provides greater structural safety, better finish and comfort, its implementation is expensive due to the materials required and the participation of professionals throughout the process, worsening following the COVID-19 pandemic; that is why there is still a significant number of users with preference to the BTC system. Due to this reality, there is a need to increase the compressive strength of conventional BTC, adding certain percentages of cement to the aggregate obtained from the area, to reduce structural failures in the walls built with this system for the benefit of the safety of the population.

## 2. BACKGROUND

A comprehensive review of the relevant scientific literature, related to the scope of our research, was conducted with the aim of obtaining a solid theoretical context and understanding the experimental background prior to conducting the field tests. One of these references was that of Samaniego and Sarmiento [3] who clarified to what extent the additives used to modify the mechanical properties of concrete alter the compressive strength and density of cement-stabilized rammed walls. Research requires an experimental quantitative approach. The values of the results obtained from the test of the compressive strength of the rammed earth gave as a standard of 10.71 kg / cm²; In addition, in the methodology of replacing the earth with cement in 6%, 8% and 10% a resistance of 7.2 kg / cm², 10.73 kg / cm² and 13.47 kg / cm² was obtained respectively. It is concluded that mixture No. 12, composed of 10% cement and even air, has the best compressive strength of 29.48 kg/cm²; This obtained 22% more resistance when contrasting with the stabilized rammed earth with 10% cement and an increase of 175% compared to the standard tapial.

On the other hand, Garcia [4] focused on testing the compressive strength of unburned masonry by replacing 3%, 6%, 9% and 12% of the soil with grade I Portland cement and lime. The result obtained from the compressive strength of standard adobes is on average 11.3 kg/cm², and when compared to test samples containing 9% lime and 12% cement, the results are 63 kg/cm² and 73.47 kg/cm² respectively; Therefore, it is concluded that the addition of cement and lime presents higher performance compared to conventional adobe.

Another important research work for data processing was that of Chávez and Medina [5] whose objective was to produce blocks of compacted earth mixed with cement to be used in the construction of houses in rural areas in the province of San Martín. The results show that the design compressive strength of a stable compacted lump containing 10% cement is 39.02 kg/cm² at 7 days and 76.96 kg/cm² at 14 and 21 days. In addition, increases of 52.66%, 154.83% and 252.20% were evidenced in 7 days, 14 days and 21 days respectively compared to standard BTC. Because of this, it is concluded that the addition of cement to BTC increases its strength.

### 2.1 TAPIAL

The Peruvian Technical Standard E.080 [6, pp. 5] defines rammed earth as a "construction technique that uses wet earth poured into firm molds (boards), to be compacted by layers using wooden mallets or rammers".

### 2.2 RAMMED EARTH AND FORMWORK UNIT

Peruvian Technical Standard E.080 [6, pp. 18] stipulates that rammed earth units must have specific dimensions: a minimum width of 0.40 m, a maximum height of 0.60 m, a maximum length of 1.50 m, and the wood used for formwork must have a minimum thickness of 20 mm.

### 2.3 AGGREGATE

In the present work it has been called as an aggregate to the earth used in the construction of BTC, the Peruvian Technical Standard E.080 [6, pp.5] defines the earth as "construction material composed of four basic components: clay, silt, fine sand and coarse sand".

### 2.4 PORTLAND CEMENT TYPE 1

The main components of this type of cement are tricalcium silicate, Ca 3 SiO5, beta dicalcium silicate, Ca 3 SiO 4, and lime (CaO, 60%) and alumina (Al2O3) and Portland Clinker. In addition, his theories of structure, constitution and the process of formation are diverse [7]. According to Sánchez, this type of cement is used in different works in general since no peculiar properties are requested to this type of cement [8, pp. 49].

## 3. METHODOLOGY

### 3.1 AGGREGATE EXTRACTION

The optimal location for obtaining aggregates for the manufacture of BTC in the region of Colpa Alta, Huánuco, was identified. It was considered important that the soil used meets the evaluation criteria corresponding to the presence of clay, to ensure its suitability in the construction of rammed earth walls stipulated in NTP E0.80 [6].

According to [6, pp.19], the first test performed was the "Clay Ribbon" in which a 12mm diameter cylinder was molded with a wet mud sample, and then flattened with fingers., forming a 4mm thick tape. If you hang it as much as possible between 20cm and 25 cm long, the soil has a high clay content.

The second test applied was the "Dry Resistance" test where with the minimum amount of water, four pellets were formed: Then these dried for 48 hours, protecting them from moisture and water in general. Once dry they were pressed with the fingers, in our case none broke or cracked, so the aggregate could be used as a building material. If this had not happened, the test would have to be performed again, if they still do not pass the test, the quarry is discarded.

The third test was "Moisture content" where a fist-sized aggregate ball was formed, compressing it strongly; It was then released to a firm surface of1.10m high. The earth ball broke into more than 5 pieces, so the amount of moisture was indicated. [6, p. 20]

### 3.2 SOIL MECHANICS TESTS

The granulometric analysis test was conducted to assess the percentage of clay, silt, and gravel content in the extracted aggregate, following the guidelines of NTP-400.012 [9] The plasticity index (PI) was also determined, whose definition according to NTP 339.129 [10, pp. 4] is the range of soil moisture content in which soil behaves plasticly; to determine this value, the liquid limit and the plastic limit were previously calculated in order to make an arithmetic subtraction of the values in the same order mentioned. The Liquid Limit symbolizes the soil moisture content percentage at the transition from its liquid to plastic states, determined by the Casagrande test. Conversely, the Plastic Limit denotes the moisture content percentage at the boundary between the plastic and semisolid states. To calculate LP, approximately 20 grams of the material prepared for the LL calculation are kneaded. This material is then allowed to lose moisture until cylinders with a diameter of 3.2 mm form. The process involves gradually reducing the diameter until the cylinder starts to crack or crumble, indicating the need to measure the material's weight to assess moisture content. This procedure is repeated with another soil sample, and the average moisture content from both tests is calculated to determine the LP.

The IP value in ranges of IP>20, 20≥IP≥7, 7>IP>0 and IP=0 indicates the presence of very clay soils, clay soils, little clay soils and clay-free soils, respectively.

### 3.3 HANDLING AND PROCESSING OF SAMPLES

After the soil mechanics tests, 4 groups of 15 samples were formed each, making up a total of 60 soil samples. One of the groups was left unchanged; to the other three, 5%, 10% and 15% of Port Cement were added to the type I, respectively.

Then the compressed samples were elaborated, according to NTP E.080 [6, p.15], in molds of 0.1 x 0.1 x 0.15 m to which it was compacted by applying 10 blows with a mallet of 5 Kg.

The compressed samples were reserved for 28 days in an area away from moisture and fresh, so that they have a slow drying in order to prevent cracking. [6, p. 18]

### 3.4 COMPRESSIVE STRENGTH TEST

Breaking stress tests were conducted by applying axial loads or compressive forces to previously prepared and mixed cubes at a set speed, aiming to measure the compressive strength of the soil block until failure was induced. The sample resistance was determined by dividing the peak force attained in the test, as specified by NTP-339.034, by the specimen's cross-sectional area. [11].

Keep in mind that in [6, p.15] explains that the average of the four best samples of 6 cubes must be greater than or equal to the last resistance observed.

### 3.5 DATA ANALYSIS AND PROCESSING

After collecting the data from applying the test [11] using laboratory records, the data were processed using Excel spreadsheets, calculating the compressive strength of the samples. The statistical evaluation of the data of the studied samples was carried out using the statistical program SPSS V.26, with which the measures of central tendency of each group of samples were determined. First, we assessed that the data samples proceed from a Gaussian distribution using the Shapiro-Wilk test since no more than 50 samples were analyzed and the Student's parametric t test to compare the sample measurements.

## 4. ANALYSIS OF RESULTS

In the TABLE I, the compressive strengths obtained from the standard samples are presented, which is formed only by the aggregate.

TABLE I
Compressive strength of conventional rammed earth blocks

| Conventional rammed earth blocks or standard (sample) | Compression force (Kg) | Area ($cm^2$) | Compressive strength ($Kg/cm^2$) |
|---|---|---|---|
| 1 | 2046 | 102.01 | 20.06 |
| 2 | 2056 | 100.00 | 20.56 |
| 3 | 2038 | 104.04 | 19.59 |
| 4 | 2239 | 100.00 | 22.39 |
| 5 | 2137 | 98.01 | 21.80 |
| 6 | 2120 | 100.00 | 21.20 |
| 7 | 2048 | 98.01 | 20.90 |
| 8 | 2069 | 96.04 | 21.54 |
| 9 | 2139 | 100.00 | 21.39 |
| 10 | 2024 | 102.01 | 19.84 |
| 11 | 1970 | 102.01 | 19.31 |
| 12 | 2146 | 100.00 | 21.46 |
| 13 | 2026 | 102.01 | 19.86 |
| 14 | 2126 | 100.00 | 21.26 |
| 15 | 1988 | 100.00 | 19.88 |

Note: Calculation of the compressive strength after division of the compressive force obtained from the test by the cross-sectional area of the sample.

Considering TABLE I, Fig. 1 was elaborated, which shows the behavior of the compressive strength of the blocks. In addition, TABLE II shows the measures of central tendency of the data collected.

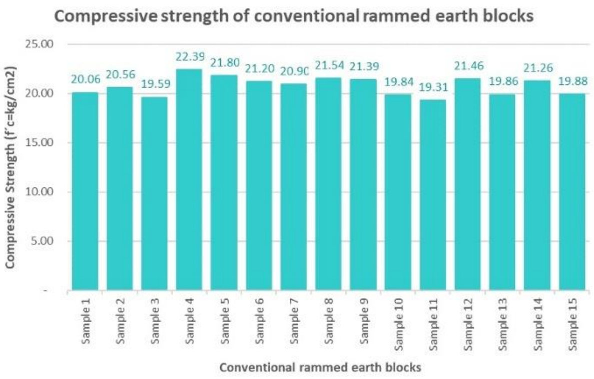


Fig. 1. Graph of the compressive strength of conventional rammed earth blocks [12]

TABLE II
Central tendency measures of compressive strength data from conventional rammed earth blocks

| Sample number | Valid | 15 |
|---|---|---|
| | Lost | 0 |
| Stocking | | 20.7360 |
| Fashion | | 19.31[to] |

Note: Average and mode of 15 valid data.

The mean for the analyzed data of the compressive strength of conventional rammed earth blocks at 28 days is 20.74 kg/cm$^2$.

From the altered samples, in which 5%, 10% and 15% of cement were added, the data of compressive strength were obtained, which on average were f'c=25.27 Kg/cm$^2$, f'c=30.75 Kg/cm$^2$ and f'c=39.43 Kg/cm$^2$, respectively. To this end, the average of these was determined, whose values are shown in TABLE III together with the compression resistance of the unaltered samples.

TABLE III
Compressive strength of cement earth blocks from 5% to 15% with respect to the dry weight of the mixture

| Sample | Compressive strength of standard samples (Kg/cm$^2$) | Compressive strength of blocks with 5% cement addition (Kg/cm$^2$) | Compressive strength of blocks con 10% cement addition (Kg/cm$^2$) | Compressive strength of blocks with 15% cement addition (Kg/cm$^2$) |
|---|---|---|---|---|
| 1 | 20.06 | 25,18 | 31,53 | 39,32 |
| 2 | 20.56 | 24,58 | 29,33 | 37,36 |
| 3 | 19.59 | 24,88 | 30,44 | 37,45 |
| 4 | 22.39 | 24,90 | 31,07 | 39,72 |
| 5 | 21.80 | 24,93 | 30,41 | 38,51 |
| 6 | 21.20 | 25,26 | 31,39 | 39,18 |
| 7 | 20.90 | 24,01 | 31,01 | 38,24 |
| 8 | 21.54 | 24,63 | 29,60 | 42,09 |
| 9 | 21.39 | 26,43 | 30,94 | 39,69 |
| 10 | 19.84 | 24,23 | 30,62 | 40,58 |
| 11 | 19.31 | 26,55 | 29,87 | 39,07 |
| 12 | 21.46 | 26,74 | 31,52 | 40,00 |
| 13 | 19.86 | 25,24 | 30,85 | 41,44 |
| 14 | 21.26 | 25,47 | 32,30 | 39,02 |
| 15 | 19.88 | 25,96 | 30,34 | 39,83 |

Note: The compressive strengths of the standard samples and the compressive strengths of the samples with 5%, 10% and 15% Portland cement type I are displayed.

Considering TABLE III, Fig. 2 showing the behavior of the compressive strength of the blocks compared to the averages of the resistances of the blocks with addition of cement of 5%, 10% and 15%.

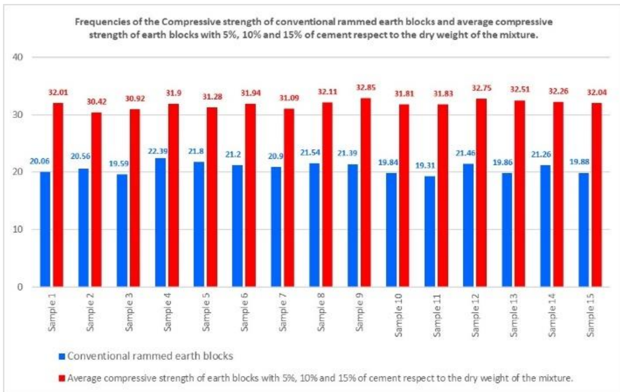


Fig. 2. Frequency graph of conventional rammed earth blocks' compressive strength versus earth blocks with 5%, 10%, and 15% cement by dry weight [12]

In the figure above you can see a marked improvement in the compressive strength of the samples with cement content compared to the results obtained from the standard samples. The first step in determining whether cement is influenced by aggregates extracted from Colpa Alta is to verify whether the compressive strength values for the datasets meet the normality hypothesis for data distribution using the Shapiro-Wilk test. (n<50 samples).

TABLE IV
Compressive strength normality test

| | Shapiro-Wilk | | |
|---|---|---|---|
| | Statistical | Gl | Gis. |
| Compressive strength of conventional rammed earth blocks | 0.942 | 15 | 0.412 |
| Compressive strength of rammed earth blocks with 5% by weight of cement | 0.940 | 15 | 0.387 |
| Compressive strength of rammed earth blocks with 10% by weight of cement | 0.982 | 15 | 0.982 |
| Compressive strength of rammed earth blocks with 15% by weight of cement | 0.967 | 15 | 0.805 |

Note: Applied to conventional rammed earth blocks and average compressive strength for rammed earth blocks with 5%, 10% and 15% by weight of Portland cement type.

After applying the Shapiro-Wilk as indicated by the TABLE IV, a p-Value = 0.412 was obtained for the compressive strength of the conventional rammed earth blocks, a p-Value = 0.3 87 for the compressive strength for the rammed earth blocks with 5%, a p-Value = 0. 982 for compressive strength for rammed earth blocks with 10% and a p-Value=0. 805 for compressive strength for rammed earth blocks with 15% by weight of cement, so the null hypothesis is accepted (H0: the samples comply with normal distribution) given that p>0.05, for each of the four cases studied (pattern, 5%, 10% and 15% addition)

After that, the test of equality of variances or hocedasticity of variances is carried out by applying the parametric Levene test between the standard sample and each of the samples added with cement as shown in the TABLE V. Levene's test's foundational assumption, or null hypothesis, is that all groups being analyzed have equal variances, suggesting the absence of notable variance discrepancies among them. The alternative hypothesis (H1) posits that at a minimum, one of the population variances deviates from the rest.

$$H0 : \sigma_1^2 = \sigma_2^2$$
$$H1 : \sigma_1^2 \neq \sigma_2^2$$

Should the Levene test produce a statistically significant outcome (that is, the p-value falls below the established significance threshold, typically 0.05), the null hypothesis would be dismissed, leading to the conclusion that the population variances are not equivalent.

TABLE V
Test of independent samples

| | Levene test | |
|---|---|---|
| | F | Gis. |
| Pattern – 5% cement | 0.979 | 0.331 |
| Pattern – 10% cement | 1.409 | 0.245 |
| Pattern – 15% cement | 0.498 | 0.486 |

Note: Applied to conventional rammed earth blocks and average compressive strength for rammed earth blocks with 5%, 10% and 15% by weight of portland cement type.

As shown in TABLE V, for all cases the significance value p>0.05; that is, the null hypothesis in which the variances are equal is satisfied. With this, you can proceed to apply the parametric test Student's t, which assumes that the variances are equal. Had this not occurred, Welch's t-test could have been used, which does not assume equality of variances.

Considering that all samples complied with Gaussian distribution. The parametric test Student's t of two independent samples was applied, pairing the standard samples with each of the samples added with cement. Here, the null hypothesis (H0) posits that the difference in the averages of the two populations from which the samples are drawn is not statistically significant. In essence, it asserts that the disparity between the means of these populations amounts to zero; H0: $\mu1 - \mu2 = 0$ and H1: $\mu1 - \mu2 \neq 0$. The test is either a bilateral hypothesis or a two-tail test. The outcomes of the Student's t-test are displayed in Table VI.

TABLE VI
Student's t-test

| | t | Gl | Gis. |
|---|---|---|---|
| Standard vs 5% added cement | -14.076 | 28 | 3.1612E-14 |
| Pattern vs 10% added cement | -31.767 | 28 | 1.6524E-23 |
| Pattern vs 15% added cement | -45,136 | 28 | 1.066E-27 |

Note: Paired differences between conventional rammed earth blocks and the compressive strength of rammed earth blocks of 5%, 10% and 15% by weight of cement.

When applying the t test, the significance level indicator P-Value close to zero was obtained, which is less than 0.05; so the null hypothesis is rejected in all cases, concluding that cement has an influence on the compressive strength of BTC made with aggregates from Colpa Alta, Huánuco.

However, to quantitatively determine the degree of influence or level of correlation between the added cement and the compressive strength of the reinforced earth walls, it is necessary to introduce multivariate analysis taking into account that samples have been made for different percentages of incorporated cement (standard, 5% cement, 10% cement and 15% cement; that is, 4 study groups). To introduce us to multivariate analysis, the homogeneity of variances test or Levene test is applied for the four groups of studies. The null hypothesis (H0) and the alternative hypothesis are as follows:

$$H0:\ \sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma_4^2$$

$$H1:\ at\ least\ one\ of\ the\ measures\ is\ different$$

The TABLE VII shows the results of the Levene test. The significance level p is 0.298 > 0.05, so the null hypothesis is accepted.

TABLE VII
Homogeneity of Variances Test

| | | Levene statistics | Gl1 | Gl2 | Gis. |
|---|---|---|---|---|---|
| Resistance | Based on the average | 1.258 | 3 | 56 | 0.298 |

Note: Levene test for all four study groups.

The results of Table VIII are important since when performing the bivariate analysis between the standard sample and another sample added with cement, they resulted with a value $p<0.05$, for which the null hypothesis of equality of variances had been accepted. Now when performing the multivariate analysis, the equality of variances is reaffirmed.

After that, the next step is to apply the Analysis of Variances known as one-factor ANOVA. This is based on the principle of decomposition of the total variance into two components: the variance attributable to the effect of the factor under study (variance between groups) and the variance attributable to random error (variance within groups). The null hypothesis (H0) in the one-factor ANOVA holds that all the means of the groups are equal, that is, there are no significant differences between them:

$$H0:\ \mu_1 = \mu_2 = \mu_3 = \mu_4$$

In this context, μ1, μ2, μ3, and μ4 denote the mean values for the four investigated groups (pattern, 5% cement, 10% cement, and 15% cement addition). The alternative hypothesis (H1) postulates that a minimum of one population mean differs from the remaining ones:

$$H1:\ at\ least\ one\ of\ the\ measures\ is\ different$$

Where μ1, μ2, μ 3, μ4 represent the means of the populations of the 4 groups under study (pattern, 5% cement, 10% cement and 15% added cement). TABLE VIII shows the results of the test and the null hypothesis is verified because p = 1.422E-18 < 0.05. This also reaffirms the bivariate analysis between two samples.

TABLE VIII
One-factor ANOVA test

| Sample | Sum of squares | Gl | Quadratic mean | F | Gis. |
|---|---|---|---|---|---|
| Between groups | 2912.070 | 3 | 970,69 | 999.165 | 1.422E-48 |
| Within groups | 54.404 | 56 | 0.972 | | |
| Total | 2966.474 | 59 | 30,44 | | |

Note: The ANOVA test allows us to compare the measurements of the four study groups.

It is important to note that the one-factor ANOVA does not identify which specific groups differ from each other. To determine which groups have different means, the Tukey test and the Bonferroni test, after performing the one-factor ANOVA, were performed to compare results as shown in Figure 3.

**Multiple Comparison**

Dependent Variable: Compressive Strenght

| | (I) Category | (J) Category | Difference of means (I-J) | Dev. Error | Sig. |
|---|---|---|---|---|---|
| HSD Tukey | Pattern Sample | 5% Added cement | -4,53000* | ,35991 | ,000 |
| | | 10% Added cement | -10,01200* | ,35991 | ,000 |
| | | 15% Added cement | -18,69733* | ,35991 | ,000 |
| | 5% Added cement | Pattern Sample | 4,53000* | ,35991 | ,000 |
| | | 10% Added cement | -5,48200* | ,35991 | ,000 |
| | | 15% Added cement | -14,16733* | ,35991 | ,000 |
| | 10% Added cement | Pattern Sample | 10,01200* | ,35991 | ,000 |
| | | 5% Added cement | 5,48200* | ,35991 | ,000 |
| | | 15% Added cement | -8,68533* | ,35991 | ,000 |
| | 15% Added cement | Pattern Sample | 18,69733* | ,35991 | ,000 |
| | | 5% Added cement | 14,16733* | ,35991 | ,000 |
| | | 10% Added cement | 8,68533* | ,35991 | ,000 |
| Bonferroni | Pattern Sample | 5% Added cement | -4,53000* | ,35991 | ,000 |
| | | 10% Added cement | -10,01200* | ,35991 | ,000 |
| | | 15% Added cement | -18,69733* | ,35991 | ,000 |
| | 5% Added cement | Pattern Sample | 4,53000* | ,35991 | ,000 |
| | | 10% Added cement | -5,48200* | ,35991 | ,000 |
| | | 15% Added cement | -14,16733* | ,35991 | ,000 |
| | 10% Added cement | Pattern Sample | 10,01200* | ,35991 | ,000 |
| | | 5% Added cement | 5,48200* | ,35991 | ,000 |
| | | 15% Added cement | -8,68533* | ,35991 | ,000 |
| | 15% Added cement | Pattern Sample | 18,69733* | ,35991 | ,000 |
| | | 5% Added cement | 14,16733* | ,35991 | ,000 |
| | | 10% Added cement | 8,68533* | ,35991 | ,000 |

*. The difference in means is significant at the 0.05 level

Fig. 3. Tukey and Bonferroni test results among study groups

From the analysis of Figure 3, a greater influence of cement added with 15% by weight in the variable compressive strength of reinforced earth walls is evident. However, as shown in TABLE IX, the deviation in the results is greater in this study group, an effect that does not occur in other groups where even the deviation is usually less than the pattern.

TABLE IX
Descriptive data of samples

| | | Resistance | |
|---|---|---|---|
| | | Stocking | Standard deviation |
| Category | Boss | 20.74 | 0.93 |
| | 5% Cement | 25.27 | 0.83 |
| | 10% Cement | 30.75 | 0.79 |
| | 15% Cement | 39.43 | 1.31 |

To determine the correlation, the variable "cement addition" can be classified as an ordinal type (0%, 5%, 10% and 15%). When performing this analysis, a correlation factor of 0.968 with Spearman's Rho factor and a significance level of 1.1475E-36<0.05 are identified, so it is considered that there is a "strong" correlation between the variable "cement addition" and "compressive strength.

However, it is also convenient to adapt the variable "cement addition" as a quantitative variable (0, 0.05, 0.10 and 0.15) to build a linear regression model.

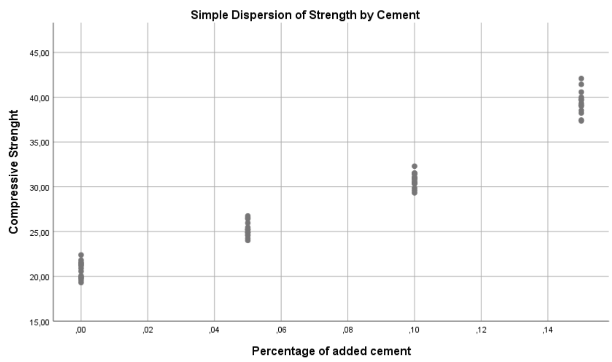


Fig. 4. Scatter plot considering the variables "added cement" and "compressive strength."

When making the determination by Pearson's correlation factor, it is identified that the factor is equivalent to 0.979 with a significance 8.6049E-42 so it is accepted that there is a strong correlation between the variables. With this, we proceed to build the linear regression model. The model equation has the structure:

$$Y = \beta_0 + \beta_1 x \qquad (1)$$

Where:

$\beta_0$ : $constant\ y\ \beta_1$: $linear\ coefficient$

TABLE X shows the results of the determined model, where β0 = 19.81 and β1 = 123.418. This means that a minimum average strength of 19.81 kg/cm² is expected for samples without cement addition and 1.23148 kg/cm² for each cement addition percentage unit.

TABLE X
Determination of the linear regression model

| Model | Non-standardized coefficients β | Dev. Error | Standardized coefficients Beta | t | Gis. |
|---|---|---|---|---|---|
| 1 (Constant) | 19,810 | 0,315 | | 62,982 | ,000 |
| Cement | 123,148 | 3,362 | ,979 | 36,624 | ,000 |

Dependent variable: Compressive strength

The structure of the linear regression model describing the average compressive strength with the addition of Portland cement type I using High Colpa aggregates in Huánuco is:

$$Y = 19.81 + 123.148x \qquad (2)$$

Where:

Y: Compressive strength expected (kg/cm²)

X: % cement added (expressed in decimal places)

The R2 coefficient, indicative of the goodness of fit in linear regression models, has a value of R2 = 0.959. This indicates that the regression model can explain 95.9% of the variability in compressive strength through the variable of cement addition. The remaining 4.1% is attributable to other variables not incorporated into the model. An R2 value approaching 1 signifies that the regression model exhibits a strong fit to the data and elucidates a significant portion of the variability in the independent variable. Figure 5 shows the linear regression model including confidence intervals of 95%

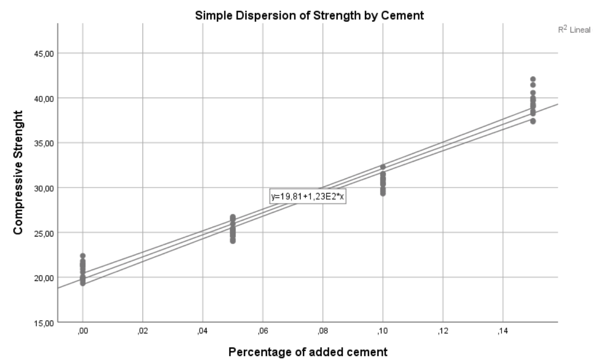


Fig. 5. Linear regression model with confidence intervals

Figure 6 depicts the regression model alongside prediction intervals. Contrary to confidence intervals, prediction intervals offer a more cautious approach to estimating at the 95% level.

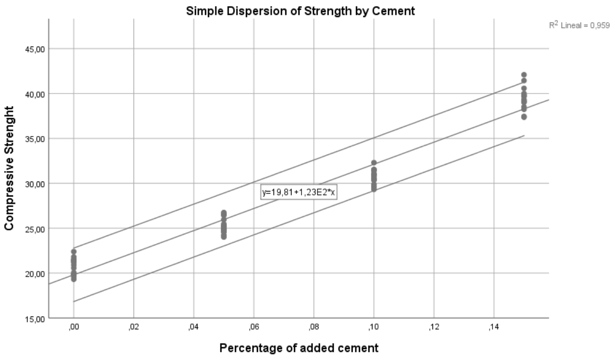

Fig. 6. Linear regression model with prediction intervals

## CONCLUSIONS

- The 3 tests according to [6], carried out in the Colpa Alta - Huánuco quarry for the prior verification of the adequate clay content, complied as indicated by the same.
- It was verified through the tests of granulometric analysis, liquid limit and plastic limit, described in [9], [10], that the samples extracted comply with the provisions for the preparation of BTC according to NTP-E.080 [6].
- The stabilization designed with 5%, 10% and 15% are adequate to quantify the impact of this material on increasing compressive strength, showing that there is a strong correlation between the added percentage of cement and the compressive strength. The results of this investigation are limited to this range of application (5%, 10% and 15%)
- The rise in the average compressive strength of the BTC correlated with the amount of cement added by weight; that is, a higher cement content in the aggregate used will allow a greater compressive strength. The mathematical model of linear regression determined is $Y = 19.81 + 123.148x$, where “x" is the added % of cement while “Y" is the compressive strength of rammed earth walls expressed in kg/cm$^2$.
- ~It was determined that cement significantly and positively influences the compressive strength of BTC; being that samples with addition of 15% to weight influence greater incidence but are those that have results with greater deviation from samples with 5% and 10% by weight.

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