SOIL STRENGTH OF CHEMICALLY STABILIZED ROAD SUBBASE MATERIALS WITH LIME SLUDGE AND FLY ASH: A STATISTICAL EVALUATION USING ANOVA

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ABSTRACT*: In engineering research, statistics is used to investigate, interpret data, and respond to research questions. For instance, in chemical stabilization, the analysis of variance (ANOVA) lends credibility to the interpretation of data in terms of the efficacy of added treatment to a chemically stabilized subbase. It can be used further to determine whether the extra treatment has a significant impact on the California Bearing Ratio (CBR) between group sample mean scores obtained in various experimental treatment groups. In this work, an assessment on the soil strength of stabilized road subbase materials with lime sludge (LA) and fly ash (FA) using ANOVA was conducted. The observed group sample score variance across groups and within groups of samples from soil samples A, B, C, D, E, and F was then compared. Now the untreated soil (sample A) contained 1% cement, 10% LS and 0% FA, respectively. On the other hand, the treated samples B, C, D, E, and F were composed of similar amounts of cement and LS but had varying FA percentages from 10% to 50%. The CBR was then measured to the soil samples. The results demonstrated that the addition of FA had an absolute effect which significantly increased soil strengths with CBR values of 31%, 122%, 170%, 178%, and 287%. A post hoc t-test was conducted since the ANOVA had an F-value of 32591.56, which was higher than the F-statistics (Fcrit) of 3.106 and a P-value of $2.34x10^{-24}$, which was less than 0.05 (5 percent significant level). The two-tailed t-test likewise revealed less than 5% significance level of error for the same sample comparisons A&F and B&F, with $1.2x10^{-10}$ and $6.9x10^{-11}$ demonstrating confidence levels of 99.9999 percent. LSD of 1.45 and maximum absolute average differences of CBR values of 225% and 256% are observed. As a result, it can be observed that FA additions greatly increased soil strength, particularly in soil sample F, which had a maximum CBR value of percent.*

Keywords: chemical stabilization, lime sludge, fly ash, ANOVA, statistics

1. INTRODUCTION

A key component in geotechnical engineering is soil stabilization which calls for the enhancement of soil engineering features to achieve a desirable soil state. It is a method of treating soil to increase its tensile strength and durability, extending the range of applications for which it is appropriate [1]. Low bearing capacity, excessive settlement, water permeability, and the possibility of soil liquefaction all contribute to the requirement for soil stabilization [2]. The stability and endurance of constructions including roads, buildings, embankments, and foundations were significantly threatened by these soil conditions. Different soil stabilizing methods have been developed to solve these issues. And one of these methods is chemical stabilization [3].

In chemical stabilization, cement and lime are the most commonly used chemicals in the soil treatment [4]. However, the over-employment of these chemicals in soil stabilization have resulted to high construction cost consistently. Locally, Caingles et al. [5] utilized both lime sludge (LS) and fly ash (FA) for road subbase stabilization, replacing the said chemicals relative to the purpose. In their work, the treated and untreated (control group) soil samples were the input parameters in assessing the soil strength through the California Bearing Ratio (CBR) values. The untreated soil sample had 1% cement, 10% LS and 0% FA. On the other hand, the treated soil samples contained a varying FA levels of 10%, 20%, 30%, 40% and 50%, respectively, apart from the cement and LS contents. The results indicated that CBR values have increased for samples that have been treated; indicating promising effects of FA on soil strength.

The study of Caingles et al. [5] just demonstrated promising potentials in stabilization for said agro-industrial products, primarily FA. Generally, both are already tested in construction as they contain necessary oxides that allow them to exhibit pozzolanic and cementitious values [6-13]. However, a statistical method like the Analysis of Variance (ANOVA) is necessary to support the said outcome of the study. For a study involving chemical stabilization, ANOVA can be used to analyze, interpret and assess the statistical significance of the impact of a given chemical on a given characteristic.

ANOVA enables comparisons across several treatment groups' statistical differences at once and breaks down the overall variation in the data into its various components, including the treatment effect for between-group variation and the residual or error effect for within-group variation [14]. The sum of squares (SS) must be calculated to determine the variation between and within treatment groups. The mean square between groups is divided by the mean square within groups to calculate the F-statistic. To establish the statistical significance, the obtained F-statistic is contrasted with a critical value [15]. Additionally, ANOVA offers a statistical framework for quantifying and contrasting significant effects [16]. If it finds significant differences among treatment groups, post hoc tests are then carried out to ascertain which particular groups significantly differ from one another [17]. Therefore, in the work of Caingles et al. [5], it is just important to conduct such test to look into the significant treatment effects of FA onto the Californnia bearing ratio (CBR) values in order to corroborate the findings of the study.

2. MATERIALS AND METHODS

2.1. Raw Materials

The coal fly ash was obtained from a coal-fired power station in Villanueva, Misamis Oriental, Philippines while the lime sludge was from a sugar milling facility in Bukidnon, Philippines. These components were evenly combined with cement and soil after being air dried, sieved through a no. 200 sieve, and sieved again. Prior to combining with soil, lime sludge fly ash, and water, Type I Ordinary Portland Cement (OPC) also underwent sieving using the no. 200. The soil samples were then extensively blended to create a uniform slurry.

2.2. Preparation of Soil Samples, Lime Sludge, Fly Ash and Cement

As recommended by the Philippine's Department of Public Works and Highways (DPWH), random soil samples were taken from the site. Samples of the soil were put in a pristine container and kept. In the Philippines' Bukidnon and Villanueva, lime sludge and fly ash were gathered from a sugar mill and a coal-fired power station. The Philippines' Misamis Oriental province, particularly in Cagayan de Oro, was where the Type I Ordinary Portland Cement was acquired. According to Caingles et al. [5], these materials underwent physical, index and mechanical tests.

2.3. Preparation of Blended Samples

Variations of the blended samples A, B, C, D, E, and F are displayed in Table 1. The proportion of soil in Sample A, the untreated sample, was 100%, while the percentages of OPC, LS, and FA were 1%, 10%, and 0%, respectively. The proportions of the treated samples, Samples B, C, D, E, and F, are 100% soil, 1% and 10% for OPC and LS, and 10%, 20%, 30%, 40%, and 50%, respectively, for FA. According to the DPWH Blue Book (2013) of the Philippines, the maximum amount of cement applied was within 1% for the sets of the mixture since the amount of cement to be added to the soil aggregate shall be from 6 to 10 mass percent of the dry soil.

Table 1. Variations of Soil Samples

Soil Samples	Aggregate Base/Subbase Course	(% OPC + %LS + %FA)
A	100% Soil	1%OPC + 10%LS
B	100% Soil	1%OPC + 10%LS + 10% FA
C	100% Soil	1%OPC + 10%LS + 20% FA
D	100% Soil	1%OPC + 10%LS + 30% FA
E	100% Soil	1%OPC + 10%LS + 40% FA
F	100% Soil	1%OPC + 10%LS + 50% FA

For untreated sample, the amount of water for CBR test was computed using Equation 1.

$$\text{Weight of water} = \left(\frac{\text{Weight of soil}}{1+\frac{\text{HMC}}{100}}\right) \text{ x } \left(\frac{\text{OMC}-\text{HMC}}{100}\right) \quad \text{Eq. 1}$$

$$\text{Weight of water} = \left[\left(\frac{\text{Weight of soil}}{1+\frac{\text{HMC}}{100}}\right) + \text{Weight of LSA} + \text{Weight of FA} + \text{Weight of OPC}\right] \text{ x } \left(\frac{\text{OMC}-\text{HMC}}{100}\right) \quad \text{Eq. 2}$$

where the hygroscopic moisture content (HMC) is the in-situ moisture content of the soil obtained by oven-drying the soil samples for 24 hours at 100+10^{o}C and OMC is the optimum moisture content. For treated samples, the amount of water and weight of stabilizers were calculated using Equations 2 - 5 below.

$$\text{Weight of LSA} = \left(\frac{\text{Weight of soil}}{1+\frac{\text{HMC}}{100}} \text{x \% of LSA}\right) \quad \text{Eq. 3}$$

$$\text{Weight of FA} = \left(\frac{\text{Weight of soil}}{1+\frac{\text{HMC}}{100}} \text{x \% of FA}\right) \quad \text{Eq. 4}$$

$$\text{Weight of OPC} = \left(\frac{\text{Weight of soil}}{1+\frac{\text{HMC}}{100}} \text{x \% of OPC}\right) \quad \text{Eq. 5}$$

2.4. Analysis of Variance (ANOVA)

In order to answer the question, "Are there significant differences in the mean scores obtained in the different treatment groups?", ANOVA was used in this study. The ratio of variance between and within groups or F-value is calculated according to the ANOVA procedures [18]. F-value ascertains whether the variations in the group means are noteworthy. This is done by contrasting the estimated F-value with the F-sampling statistic's distribution. When the null hypothesis is true, the likelihood of various F-values occurring is represented by the F-statistic sampling distribution. According to the null hypothesis, there are no differences in the means of the treatment groups. The likelihood of detecting an F-value equal to or greater than that estimated from the randomly collected data under the null hypothesis is determined by comparing the calculated F-value with the relevant F-distribution. The null hypothesis is rejected if there is a sufficiently low likelihood that this F-value will be seen under the null hypothesis. Additionally, a key idea in ANOVA is variance, sometimes known as variation. However, while within group variance reflects the deviation of scores from their treatment group means and between group variance reflects the deviation of scores from their treatment group means, it is clear that the total variance reflects the deviation of all observed scores from the mean of these scores. It measures how much the observed or calculated scores deviate from the mean.

2.4.1. Single Factor ANOVA

The initial variance estimates calculated in ANOVA is known as the sum of squares (SS). The total sum of squares is conceived as the deviation of all observed scores from the general mean and is determined using Equation 6 or 7.

$$SS_{total} = \sum_{i=1}^{N} Y_i^2 - \frac{\left(\sum_{i=1}^{N} Y_i\right)^2}{N} \qquad \text{Eq. 6}$$

$$SS_{total} = SS_{between\ groups} + SS_{within\ groups} \qquad \text{Eq. 7}$$

where N denotes the number of samples, the subscript i indexes the individual samples and takes the values from 1 to N, Y_i is the i[th] sample score/result, $\sum_{i=1}^{N} Y_i$ is the sum of all the sample score/result. The within groups sum of squares is calculated by summing separate treatment groups sum of square estimates as shown in Equation 8.

$$SS_{within\ groups} = SS_1 + SS_2 + \cdots \ldots + SS_n \qquad \text{Eq. 8}$$

The between groups sum of squares is calculated using Equation 9.

$$SS_{between\ groups} = \sum_{j=1}^{p} N_j\left(\bar{Y}_j - \bar{Y}_G\right)^2 \qquad \text{Eq. 9}$$

The sample standard deviation (s) is given as,

$$s = \sqrt{\frac{\sum_{i=1}^{N} Y_i^2 - \left[\frac{(\sum_{i=1}^{N} Y_i)^2}{N}\right]}{N-1}} \qquad \text{Eq. 10}$$

3. RESULTS AND DISCUSSION

3.1. CBR Values of Untreated and Treated Subbase Course

Table 2 shows the result of CBR values of soil samples A, B, C, D, E, and F.

Table 2. CBR Values of Soil Samples

Soil Samples	Aggregate Base/Subbase Course	(%OPC + %LS+ %FA)	CBR Value (%)
A	100% Soil	1%OPC+10%LS	62
B	100% Soil	1%OPC +10%LS +10% FA	31
C	100% Soil	1%OPC +10%LS +20% FA	122
D	100% Soil	1%OPC +10%LS +30% FA	170
E	100% Soil	1%OPC+10%LS + 40% FA	178
F	100% Soil	1%OPC +10%LS + 50% FA	287

While soil samples B, C, D, E, and F (treated samples) have CBR values of 31%, 122%, 170%, 178%, and 287%, respectively, soil sample A (an untreated sample) has a CBR value of 62%. Among the treated samples, it was found that soil samples F and B had the greatest and lowest CBR values, respectively. This is because higher lime sludge content is needed for flocculation, but lesser lime sludge content did not respond well and the CBR value scarcely changed [19]. Additionally, as we increased the amount of fly ash till 50%, the soak CBR values of soil samples B to F were amplified because to the pozzolanic reaction between the alumina and silica in cement, lime sludge, and fly ash with water, i.e., the pH of the soil water rises as a result of the increased hydroxyl ion from the lime sludge, which may cause silicate and aluminum to start dissolving [20]. The fact that silica and/or alumina were released during the pozzolanic reaction and combined with calcium to produce hydrates of calcium silicate and/or calcium aluminate, cementing the soil together, further contributed to the amplification of CBR values [21].

3.2. Analysis of Variance (ANOVA)

Results of the California Bearing Ratio (CBR) values of soil samples A, B, C, D, E, and F were tabulated in Table 3 as shown.

Table 3. CBR Values of Soil Samples (%)

Sample Number	Soil Sample A	Soil Sample B	Soil Sample C	Soil Sample D	Soil Sample E	Soil Sample F
1	61	31	121	170	177	286
2	62	30	122	170	178	287
3	62	31	124	171	178	287
Average	62	31	122	170	178	287

The average CBR values for samples A through F are 62%, 31%, 122%, 170%, 178%, and 287%, respectively. Equations 6 to 10 were used to determine the sum of squares overall, within groups, between groups, and sample standard deviation for samples A through F. The results are displayed in Table 4.

Table 4. Calculated Standard Deviation and other ANOVA Parameters

Parameters	Soil Sample A	Soil Sample B	Soil Sample C	Soil Sample D	Soil Sample E	Soil Sample F
Total $\sum_{i=1}^{N_j} Y_{ij}$	185	92	367	511	533	860
Mean $(\bar{Y}_j)$	62	31	122	170	178	287
$\bar{Y}_j^2$	3802.8	940.4	14965.4	29013.4	31565.4	82177.8
$\sum Y_{ij}^2$	11409	2822	44901	87041	94697	246534
s^2	0.33	0.33	2.33	0.33	0.33	0.33
s	0.58	0.58	1.53	0.58	0.58	0.58

As indicated in Table 5, the sum of squares within and between groups, total, mean square, F-value, P-value, and F-critical were determined using the calculated parameters in Table 4. The null hypothesis that there are no significant differences between the means of the treatment groups is rejected since the F-value is greater than the F-statistic (Fcrit) and the P-value is lower than 0.05 (5 percent significance level). To ascertain and assess which treatment groups vary from the other groups, a post hoc t-test must be performed [22].

Table 5. Calculated Sum of Squares, Degree of Freedoms, Mean Square, F-value and P-Value

Source of Variation	Sum of Squares (SS)	Degree of Freedom (df)	Mean Square (MS)	F	P-Value	F_{crit}
Between groups	126744.9	5	25348.99	32591.56	2.34E-24	3.106
Within groups	9.3333	12	0.7778			
Total	126754.3	17				

In order to identify which treatment group(s) differs from the other treatment group(s), various comparison methods including the Least Square Difference (LSD) and two-tailed t-test with Equal and Unequal variances were used, as indicated in Table 6.

Table 6. LSD and Two-Tailed Post hoc t-Test

Soil Samples	LSD		Two-tailed t-Test	Evaluation	
	Calc. LSD	Abs. ave. diff.		LSD	Two-Tailed
A & B	1.45	31	3.2E-07	Significant	Significant
A & C	1.45	61	8.3E-06	Significant	Significant
A & D	1.45	109	2.1E-09	Significant	Significant
A & E	1.45	116	1.6E-09	Significant	Significant
A & F	1.45	225	1.2E-10	Significant	Significant
B & C	1.45	92	2.4E-06	Significant	Significant
B & D	1.45	140	7.8E-10	Significant	Significant
B & E	1.45	147	6.3E-10	Significant	Significant
B & F	1.45	256	6.9E-11	Significant	Significant
C & D	1.45	48	1.7E-05	Significant	Significant
C & E	1.45	55	1.1E-05	Significant	Significant
C & F	1.45	164	4.2E-07	Significant	Significant
D & E	1.45	7	1.0E-04	Significant	Significant
D & F	1.45	116	1.6E-09	Significant	Significant
E & F	1.45	109	2.1E-09	Significant	Significant

For all soil sample comparisons in Table 6 (A & B, A & C, A & D, A & E, A & F, B & C, B & D, B & E, B & F, C & D, C & E, C & F, D & E, D & F, and E & F), the use of Fly Ash (FA) has a noticeable impact on the soil's strength as shown by the CBR values. We can also see that adding FA makes a big effect in the comparisons of soil samples A and F and B and F, where the absolute average differences are at their highest at 225% and 256%, respectively. Additionally, the two-tailed t-test result that showed less than 5% significance level of error for soil sample comparisons of A & F and B & F with 0.00000000012 (1.2E-10) and 0.000000000069 (6.9E-11) and showed confidence levels of 99.999999 percent for both sample comparisons that FA additions effectively contributed an increase in soil strength specifically also supported the LSD result.

4. CONCLUSIONS

Based on the findings, it is concluded that adding FA to soil samples with 100% soil, 1% OPC, 10% LS, and varying amounts of FA at 10%, 20%, 30%, 40%, and 50% had an absolute effect in the soil samples and significantly increased soil strengths of soil samples B, C, D, E, and F as evidenced by the increase CBR values of 31%, 122%, 170%, 178%, and 287%. The omnibus F-test, which offers statistics of the overall result of the experiment of the six treatment groups, had recently been confirmed and validated by the ANOVA and the post hoc t-test map out which group(s) is(are) significantly different from the other treatment groups, i.e., showing the LSD result of 1.45 of soil sample comparisons A & F and B & F, where the absolute average differences of CBR values are maximum at 225% and 256%, respectively, and the two-tailed t-test indicating less than 0.05 (5 percent significance level), the F-value is greater than the F-statistic (F_{crit}).

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