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Direct shear test results of lahar sand with rice hull ash for reinforced fill application

Résultats des tests de cisaillement directs du sable de lahar avec de la cendre de coque de riz pour une application de remblai renforcée

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ABSTRACT: The utilization of rice hull ash (RHA), a waste product derived from a power-generating facility in the Philippines, combined with lahar sand obtained from a vast deposit in the central plains of Luzon that are currently being used in the local construction industry, has been explored in this study. Direct shear tests were conducted to determine the maximum amount of rice hull ash (RHA) that can be mixed with lahar sand and that would exhibit acceptable values of shear strength parameters, particularly effective friction angle, as a reinforced fill or structural backfill material. From the conducted tests, it has been found that lahar sand with 15% RHA by weight fraction was the recommended mix, resulting to an average effective friction angle of 35.75°, which is slightly higher than the 34° minimum recommended friction angle by AASHTO and local guidelines. The mix was tested also through compaction tests to obtain relevant compaction parameters. The average optimum moisture content of the mix was found to be about 30% at a maximum dry density (MDD) of 13.29 kN/m^3. Moreover, the recommended mix was found to have an average dry unit weight of 13.53 kN/m^3, comparable to other lightweight fill materials.

KEYWORDS: rice hull ash, lahar sand, direct shear test, friction angle, reinforced fill.

1 INTRODUCTION

In 2017, the government of the Philippines has announced that there will be as much as eight trillion pesos of infrastructure programs for President Rodrigo Duterte's "Build, Build, Build" projects, and recently it has been said also that Philippines is in the golden age of infrastructure. With the vast civil engineering projects currently being implemented to boost the local economy, the Philippines has been reported to be suffering from natural resources depletion, which is part due to quarrying. Although quarrying industry remains a vital component of the economy amid the administration's ambitious infrastructure program, regulations must be strictly enforced. Quarrying activities in the country comprise extractive processes for building materials such as limestone for cement manufacturing, as well as gravel and sand, known as aggregates, as primary ingredients on concrete structures and as major backfill materials in the construction of highway embankments and revetments, for the foundation of roads, and in retaining structures, among others. Therefore, a balance on the extraction of mineral resources and ways to maximize the use of locally available materials could provide solution to the imposed challenge.

Lahar deposits, abundant in the plains of Central Luzon, Philippines (see Fig. 1) from the eruption of Mt. Pinatubo on June 15, 1991, have become a very important source of sand materials for various government and private sector infrastructure and construction projects. From the United States Geological Survey's website, in the first few years following the 1991 Mt. Pinatubo eruption, more than 3 cubic kilometers (equivalent to 300 million dump-truck loads) of debris on `the lowlands surrounding the volcano, burying hundreds of square kilometers of land have been deposited. During heavy rains, lahars can transport and deposit tens of millions of cubic meters of mud in a single day. Lahars form when water from intense rainfall, or the sudden failure of a natural dam, mixes with this loose volcanic material, creating mudflows that can be particularly dangerous and destructive.

In 1999, as per Presidential Proclamation No. 66, signed by then-President Joseph Ejercito Estrada, lahar deposits having known to continue to pose grave danger to lives and properties, public infrastructure like the mega-dike and critical bridges, as well as private infrastructure, particularly during extended rainy periods like the La Niña, lahar-affected river systems and their embankments in the provinces of Pampanga, Tarlac and Zambales were declared as "Environmentally Critical Areas". As such, pursuant to Section 5 of R.A. 7942, the said provinces were established as mineral reservation under the administration of the Department of Environment and Natural Resources, for the purpose of exploring, developing, exploiting, and utilizing of all the lahar deposits in these areas. Since then, lahar deposits have been extracted continuously for different government projects as well as private-funded works.

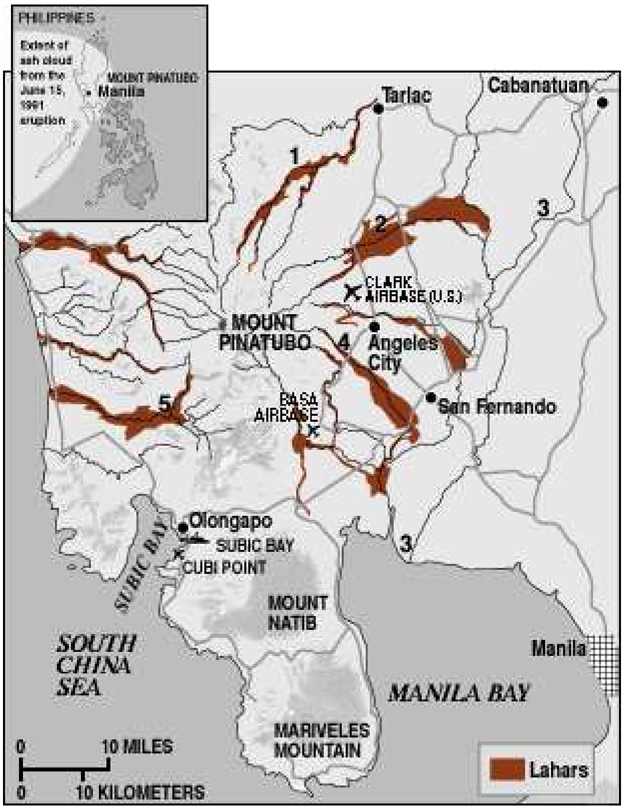


Figure 1. Vicinity of Mt. Pinatubo with lahar deposits (from USGS website).

Interestingly, in the Philippines, according to the latest data from the Philippine Statistics Authority, from January to December 2018, *palay* (or paddy) crop production is estimated at 19.07 million metric tons. In *palay*, the rice husk, also called rice hull, is the coating on a seed or grain of rice (see Fig. 2). It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. Each kilogram of milled white rice results in roughly 0.28 kilogram of rice husk as a by-product of rice production during milling. Rice husk is around 28% of the paddy.

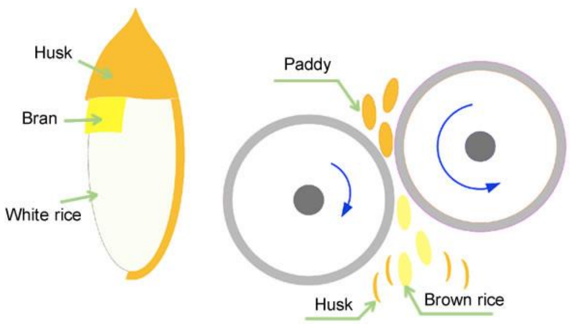


Figure 2. *Palay* or paddy grain (left) and its products after husking or milling (from International Rice Research Institute website).

Rice husk ash or rice hull ash (RHA) is obtained after burning rice husk (see Fig. 3). The amount of carbon remaining in ash depends on the combustion performance (*i.e.*, complete, or incomplete combustion). RHA has long considered a waste and is often dumped. To a lesser degree, RHA is used as soil conditioner, activated carbon, insulator, and others. More recently, creation of electrical power through burning rice husk on a small to medium scale—up to 5 megawatts—has been piloted throughout Asia.

Figure 3. Rice hull ash (RHA) used in this study.

Reinforced fill is the fill material for a mechanically stabilized earth wall (MSE wall) or reinforced soil slopes (RSS) in which the reinforcements, typically made of geosynthetics, are placed (refer to Fig. 4). The use of geosynthetics in various earth retaining structures has become popular in the Philippines and cost of fill materials represent a huge amount in a project. To find alternative fill materials that are economical and satisfy requirements is important.

Following AASHTO (2007) and local guidelines (NSCP, 2015), reinforced fill for MSE wall is required to have a minimum effective friction angle of 34° (for soil gradation with percent passing No. 200 sieve of 0-15%). For RSS, reinforced fill can have lower values of effective friction angle from 28° to 32° (considering soil gradation with percent passing No. 200 sieve of 0-50%), following recommendations from US Department of Transportation's Federal Highway Administration guidelines (Berg *et al*., 2009). In design, effective friction angle shall be no more than 40°, and cohesion value should always be assumed zero.

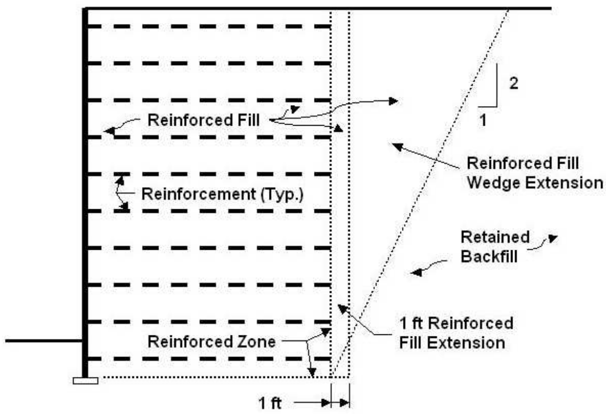


Figure 4. A typical cross-section of a mechanically stabilized earth wall showing the placements of reinforced fill (Berg et al., 2009).

2 MATERIALS AND METHOD

A 12-megawatt power-generating facility in San Jose City, Nueva Ecija, Philippines, uses rice husk for fuel. According to the obtained data, the operation of the rice husk power plant requires at least 330 tons of rice husks daily to produce the 12 megawatts output, which is subsequently sold to the nation's power grid. This result to tons and volumes of rice hull ash (RHA) regarded as waste. Likewise, the possible utilization of RHA would provide additional environmental benefits to the renewable energy objectives of the power plant.

With the vast deposits of lahar sand in Central Luzon and the tons of RHA from a power plant in Nueva Ecija, Philippines, the possible engineering use of the mixture for reinforced fill application, with the right proportion, has been explored.

2.1 *Lahar sand preparation*

Lahar sand was obtained from a local project site, weighed with the weighing balance, and prepared by oven-drying at a temperature of 110°C for about 24 hours following ASTM D 6913M, "Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis".

Particle size analysis was performed to determine the soil classification as per ASTM D 2487, "Standard Practice for Classification of Soil for Engineering Purposes".

2.2 *Rice hull ash preparation*

RHA was stored in sealed containers and the required volume of samples was weighed with the balance.

2.3 *Lahar sand and RHA mixtures preparation*

Lahar sand and RHA mixtures were prepared at the pre-established weight ratios (*i.e.* weight of rice hull ash divided by weight of lahar sand) as follows: 0% (control), 5%, 10%, 15%, 20%, and 25%. In each weight ratio, three samples were prepared and tested.

3 RESULTS AND DISCUSSIONS

3.1 *Physical properties of lahar sand and rice hull ash*

Results of sieve analysis for lahar sand are shown in Fig. 5. The initial mass of the sample before sieving was 200 g, while the average total mass of soil after sieving was found to be 198.83 g. The percent error obtained was 0.585%, which is below the 2% maximum error allowable.

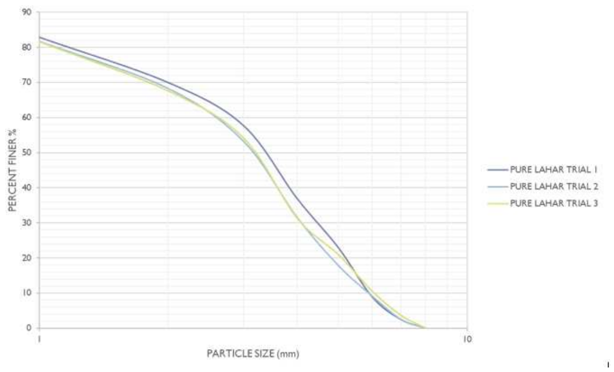


Figure 5. Particle size distribution curves of lahar sand samples.

The average percentage passing in sieve No.50 is 33.03%. From Fig. 5, the effective size (D_{10}) was calculated as 5.97mm, uniformity coefficient (Cu) from the relation of D_{60}/D_{10} was determined to be 2.94, and the coefficient of gradation (Cc), $D_{30}^2/D_{60}*D_{10}$ was 0.97. Therefore, the lahar sand sample was found to be SP, or poorly graded sand.

Similarly, sieve analyses were also performed on RHA samples. The average percentage passing in sieve No.50 was calculated to be 56.01%. D_{10} was determined to be 5.27 mm, C_u was 2.54, and C_c was computed to be 0.60. It can be noted that the RHA samples are of almost similar sizes to the lahar sand samples.

The determined average unit weight of lahar sand samples was 20.623 kN/m^3 (or average density of 2,102.243 kg/m^3). For RHA, the average unit weight of samples was 6.424 kN/m^3 (or an average density of 654.859 kg/m^3).

3.2 *Mechanical properties of lahar sand and rice hull ash mixtures*

3.2.1 *Direct shear test results*

Result of direct shear tests of pure lahar sand samples is presented in Fig. 6. The horizontal axis represents the normal stress applied to the samples that was varied from 4.20 kPa to 31.46 kPa. The vertical axis represents the shear stress that were obtained from the direct shear tests. The average effective friction angle of 50.52° and average apparent cohesion of 1.20 kPa were obtained for pure lahar sand samples.

Direct shear test result for lahar sand with 5% RHA is presented in Fig. 7. Overall, the average effective friction angle of 40.15° and average apparent cohesion of 0.78 kPa were obtained for the mixture.

In Fig. 8, the result for the shear strength of lahar sand with 10% rice hull ash is presented. The average effective friction angle of 35.78° and average apparent cohesion of 0.67 kPa were obtained for the mixture.

Results of shear strength of lahar sand with 15% rice hull ash is presented in Fig. 9. The average effective friction angle of 35.75° and average apparent cohesion of 0.67 kPa were obtained for the mixture.

Result of shear strength of lahar sand with 20% rice hull ash is shown in Fig. 10. Overall, the average effective friction angle of 32.6° and average apparent cohesion of 0.60 kPa were obtained for the mixture.

Result of shear strength of lahar sand with 25% rice hull ash is presented in Fig. 11. The average effective friction angle of 28.49° and average apparent cohesion of 0.50 kPa were obtained for the mixture.

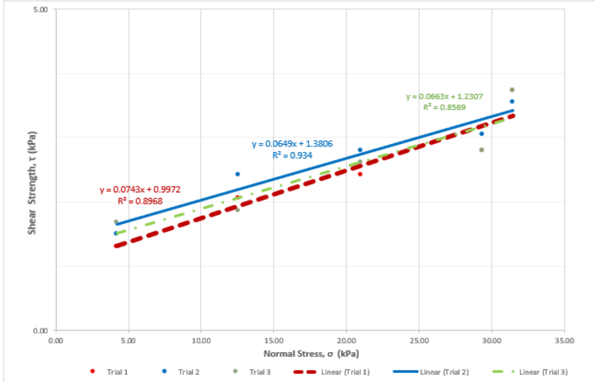


Figure 6. Direct shear test results of pure lahar sand.

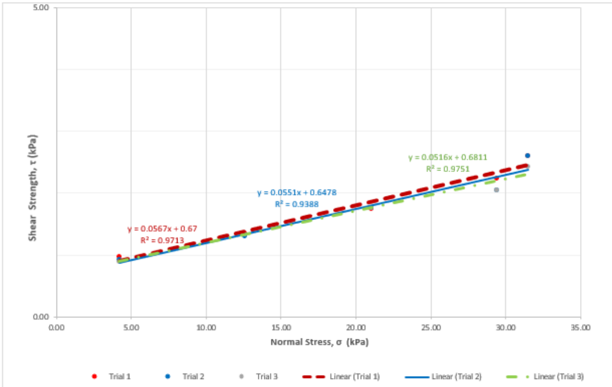


Figure 7. Direct shear test results of lahar sand with 5% RHA.

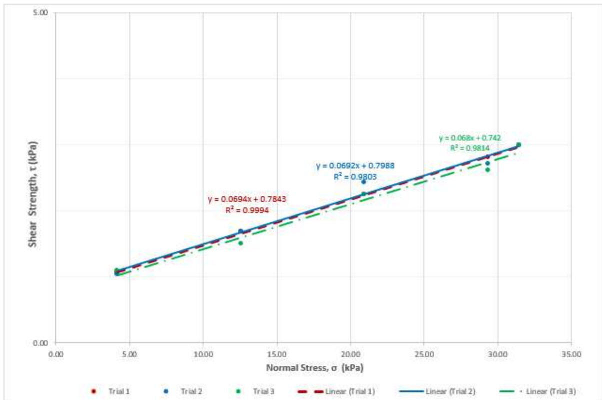


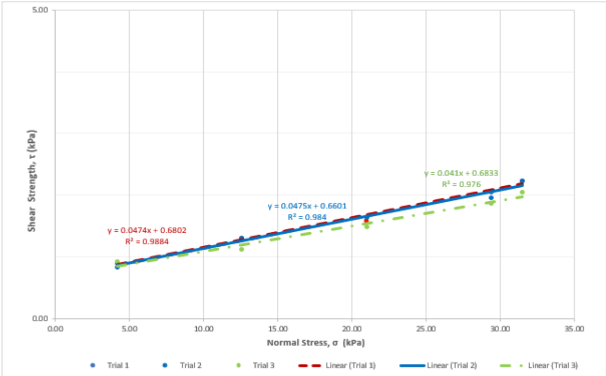
Figure 8. Direct shear test results of lahar sand with 10% RHA.

In this, from the results of direct shear tests, the desired ratio of lahar sand with 15% RHA was chosen as the recommended mix as an alternative reinforced fill for MSE wall because it has the maximum contents of RHA with passing effective friction angle. Interestingly, higher weigh ratios up to 25% can also be explored for reinforced soil slope (RSS) structures. The summary of average of all direct shear test results are shown in Table 1 for comparison.

Moreover, the recommended mix (*i.e.* lahar sand with 15% RHA) was further tested to provide comparison of results and verify the properties of the mix. Based on succeeding tests, its average unit weight was estimated to be 13.525 kN/m^3 (or an average density of 1,378.685 kg/m^3) comparable to lightweight fill materials (Schaefer *et al*., 2016). From Standard Proctor test, the recommended mix has an average optimum moisture content (OMC) of 30% for an average maximum dry density of 13.29 kN/m^3 (or 1.35 kg/m^3). Overall, initial findings have shown the possible viability of lahar sand and RHA mixtures as reinforced fill for MSE wall and RSS structures.

Figure 9. Direct shear test results of lahar sand with 15% RHA.

Figure 10. Direct shear test results of lahar sand with 20% RHA.



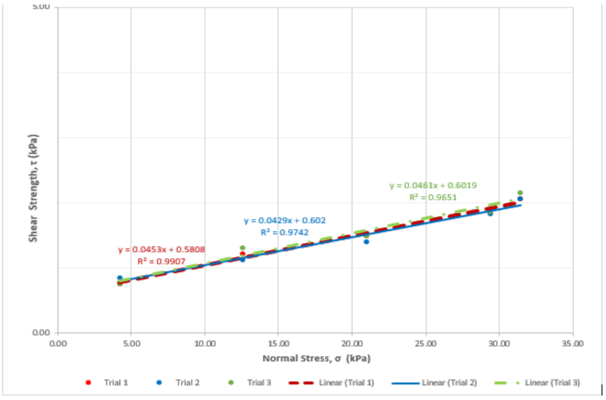


Figure 11. Direct shear test results of lahar sand with 25% RHA.

4 CONCLUSIONS

The main findings of this study are as follows:

- Lahar sand was found to be under the category of poorly graded sand or SP in the USCS soil classification (with D_{10} of 5.97 mm, C_u =2.94, and C_c= 0.97) and with average dry unit weight of 20.623 kN/m^3. Rice hull ash (RHA) was found to have an average dry unit weight of 6.424 kN/m^3.
- As per direct shear tests, lahar sand with 15% RHA was found to contain the maximum amount of rice hull ash that passes the minimum effective friction angle set for reinforced fill of MSE wall by AASHTO and local guidelines after obtaining an average effective friction angle of 35.75° and average effective apparent cohesion, albeit insignificant, of 0.67 kPa. In Standard Proctor test, the recommended mix has an average optimum moisture content of 30% and a maximum dry density (MDD) of 13.29 kN/m^3 (or 1.35 kg/m^3).
- The recommended mix (lahar sand with 15% RHA) has an average dry unit weight of 13.525 kN/m^3. This obtained value is comparable to other lightweight fill materials, which would be found advantageous if used on sites with soft soils.
- Lahar sand with higher RHA contents of 20% and 25% may still be applicable for reinforced fill alternatives of reinforced soil slopes.

Table 1. Summary of direct shear test results

Samples	*Friction Angle*	*Cohesion*
Lahar sand only (Control)	50.52°	1.20 kPa
Lahar sand + 5% RHA	40.15°	0.78 kPa
Lahar sand + 10% RHA	35.78°	0.67 kPa
Lahar sand + 15% RHA	35.75°	0.67 kPa
Lahar sand + 20% RHA	32.60°	0.60 kPa
Lahar sand + 25% RHA	28.49°	0.50 kPa

5 ACKNOWLEDGEMENT

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