HYDRAULIC CONDUCTIVITY CHARACTERISTICS OF ROAD BASE MATERIALS BLENDED WITH FLY ASH AND BOTTOM ASH

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ABSTRACT: Hydraulic conductivity, is the ability of water to flow through a soil, should be considered when designing roads. Hydraulic conductivity should be employed when designing roads that will provide good drainage as well. Fly ash and bottom ash were utilized as partial substitutes to conventional road base materials in road base construction. The study aimed to prove that employing fly ash and bottom ash would increase the hydraulic conductivity characteristics of road base while also decreasing the disposal costs of the said coal by-products. Series of experiments were conducted to test the horizontal and vertical hydraulic conductivity of pure fly ash, pure bottom ash, pure conventional road base materials, and blends comprising of the said soil components. It was also established that horizontal and vertical hydraulic conductivity had a significant difference wherein the flow of water at the horizontal-direction is greater compared to the vertical-direction.

Keywords: Hydraulic conductivity, Fly Ash, Coal Ash, Waste Utilization

1. INTRODUCTION

When designing structures, it is very important for engineers to understand the soil underneath because it will affect the way it is designed [1]. Roads, in general, play an important role in the drainage capacity when there is an occurrence of a heavy downpour of water. Most of the time, an engineer place focus on the strength characteristics of roads when in fact, hydraulic conductivity also plays an important role in the drainage capacity of these pathways. This study will concentrate on the hydraulic conductivity characteristics of fly ash and bottom ash as road base materials. Hydraulic conductivity is defined as the ability of water to flow through the material. It is also referred to as the "hydraulic conductivity" of the porous material [2].

Hydraulic conductivity can be a fundamental factor in determining the strength and capacity of fly and bottom ashes as road base materials. Through acquiring the size and shape of the ashes' pores and their connectivity, the researchers will be able to determine their hydraulic conductivity characteristics. With these, they can establish whether fly and bottom ashes will meet the standards of suitable hydraulic conductivity as road base materials. Road base is a blend of gravel and fine materials that will form a hard surface with a high level of mechanical strength when compacted [3]. Good drainage can increase as well as maintain the strength of the subgrade. On the other hand bad drainage would have negative effects in terms of the strength of the subgrade

[4,5]. With these, the researches would incorporate fly ash and bottom ash to the road base materials to ensure the proper and efficient drainage.

Fly ash and bottom ash are the two most common by-products of coal. Fly ash comprises 80% of the total coal by-products left at the boiler, while 20% is composed of bottom ash in fuel gas [6]. This study aims to reduce disposal costs of fly ashes and bottom ashes through utilizing these as road base materials. Through this, they are thriving for a safe disposal of these coal by-products while also providing a new input to how these can be properly and successfully utilized. This will serve as a study on how to reduce disposal of fly and bottom ashes while also putting emphasis on effectively hampering harmful emissions of solid particles and gases into the atmosphere and the improper disposal of hazardous elements.

The study endeavored to present the hydraulic conductivity characteristic of road base materials blended with fly ash and bottom ash. Moreover, the main objective of this proposal is to evaluate the suitability of conventional road subgrade, sub-base, and base materials blended with specific proportion and gradation of fly ash (as partial substitute for fines) and bottom ash (as partial substitute for fine aggregates) for highway embankments with respect to the standard hydraulic conductivity characteristic of road embankments.

2. METHODOLOGY

The fly ash and bottom ash which was

collected from a single and specific thermal power plant in the Philippines. Shown on Table 1 are the soil mixtures that were checked on the effect of specific proportions and gradations of fly ash (as a partial substitute for fines) and bottom ash (as a partial substitute for fine aggregates) for highway embankments with respect to the standard hydraulic conductivity characteristic of road embankments.

Table 1. Soil Mixtures used in the Study

Soil Mixtures	Other Notations	Bottom Ash Content (B) %
Blended Samples		
B0 (Pure CRBM)	F0B0C100	0
B20	F10B6.5C83.5	20
B40	F10B13C77	40
B60	F10B19.5C70.5	60
B80	F10B26C64	80
B100	F10B32.5C57.5	100
Controlled Samples		
No Fly Ash	B50F0C0	50
Pure Fly Ash	B0F100C0	0

A microscopic characterization test was done, furthermore, the determination of the index properties of fly ash, bottom ash, and conventional materials through applicable laboratory tests such as Specific Gravity of Soil Solids (ASTM D854) [7], Atterberg Limits (ASTM D4318 and ASTM D427) [8], Particle Size Analysis (ASTM D422) [9] and Maximum and Minimum Index Densities (ASTM D4253 and D4254) [10,11] commenced [12].

Similar ideas of obtaining the horizontal hydraulic conductivity of road base materials had been developed by Roads Division Engineering in collaboration Hydraulics Research Limited, Wallingford and they have also considered designing a horizontal permeameter, there are also other designs of permeameters that may be used [13]. The dimensions used were 1.0m x 0.3m x 0.3m respectively for the length, width and height of the box apparatus while the standpipe was at a length of 0.29 m, shown in Figures 1 and 2. As opposed to the design of the said literature, the researchers of this study wanted to scale down on the dimensions of their own apparatus because using similar measures would not only be impractical in terms of time and preparation, but also because it is an in-situ test. As much as possible, the researchers wanted to compare the horizontal hydraulic conductivity values with that of the vertical, and to be able to do that, both tests should be conducted in the laboratory.
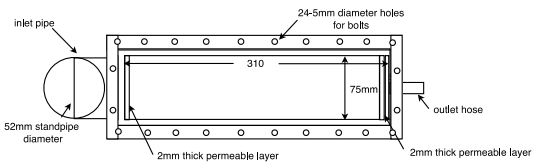

Fig. 1. Top View of Horizontal Permeameter

So as to properly compare the horizontal hydraulic conductivity with that of the vertical hydraulic conductivity, the researchers have thought of incorporating the concept vertical permeameter's design into the horizontal. The researchers of this study have formulated the design of the horizontal apparatus by first obtaining the area of the cylindrical vertical permeameter and then converting it into a rectangular box. As for the length of the rectangular box, it was obtained based on the diameter to height ratio of the vertical permeameter and the width to length ratio of the horizontal apparatus made by Roads Division Engineering (1990).
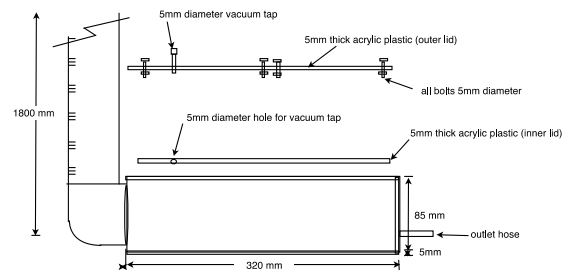

Fig 2. Side View of Horizontal Permeameter

This method was accomplished by comparing the falling-head hydraulic conductivity test results to that of the material requirements. If it passed the requirements by actually exceeding the values of k stated in AASHTO, then the results for that certain material blend are considered. On the other hand, if resulting hydraulic conductivity values are lower than the basis, the researchers responsible for testing the samples repeated the tests to really verify the hydraulic conductivity values. The hydraulic conductivity characteristics of the blended materials were also related to the obtained index properties of coal ashes for it was used to further analyze the results gathered.

3. RESULTS AND DISCUSSIONS

3.1 Index Properties

3.1.1 Microscopic Characterization

The particle shapes, surfaces, and textures were analyzed on a microscopic level in order to have more appropriate observations and analysis of the behavior of fly ash and bottom ash mainly during

the experimental process, CRBM was also subjected to the testing for the source of comparison in later analysis. SEM tests were used to analyze the morphology of all the samples.

At first glance it can be observed that bottom ash looks similarly like the sand that can be seen on the beach which are small and angular particles with coarse complexions, shown in Figure 3. The core of a bottom ash particle are angular in shape and is somehow porous making them easy to crush. These observations were similar to the findings to some studies [14] in where the researchers observed that bottom ash particles exhibited angular and irregular shapes.
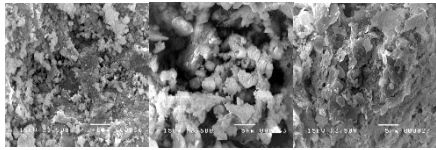

Fig 3. SEM of Bottom Ash, Fly Ash and Conventional Road Base Materials (CRBM)

On the other hand it was observed that the microscopic characteristics of Fly Ash are quite different that from Bottom Ash. By the naked eye, Fly Ash is brown in color and powder like in texture. They have smaller particles compared to bottom ash. The core of a fly ash particle possesses a more spherical and round shape, shown in Figure 3. They also possess a smoother texture and are more porous. On a same microscopic scale it was observed that it has more voids compared to bottom ash.

SEM was also used to observe CRBM to see its difference from the two coal ashes. Under the naked eye, CRBM is mostly angular and flat in shape. It was observed that on a microscopic level, the agglomerate of CRBM are of rough texture more similar but not entirely the same to the Bottom Ash particles. It also is composed entirely of indefinite shapes which are very close to each other, shown in Figure 3.

3.1.2 Grain Size Distribution

Grain Size Distribution Curve of pure fly ash. It can be seen that most of the particles are ranging from 0.001 to 0.075 mm which passes the #200 sieve, as such it falls under the classification of the size of silt; thus it can be considered as such. The coefficient of uniformity as well as curvature was also considered, it was calculated that the fly ash samples had values of 1.43 and 1.157 respectively; as such it falls under the classification of being poorly graded. On the other hand a similar analysis was made for the pure bottom ash. As such it can be said that Bottom Ash can be considered under the classification that of sand. The coefficient of

Uniformity was computed to be 4, while the Coefficient of curvature was 1, therefore it can be said that the bottom ash sample was poorly graded.

3.1.3 Specific Gravity

The specific gravities of the different blends have followed an exponential form, which seems to have been the best fit line that depended on specific bottom ash contents. As the percentage of bottom ash increased in a blend, the specific gravity decreased, shown in Table 2. The reason for this behavior is because of the fact that as the bottom ash content increased, the amount of CRBM decreased. The existence of these CRBM, namely the sand and gravel is denser than that of the bottom ash. The specific gravities of the different blends also largely depended on its morphology.

Table 2. Specific Gravity of the Soil Blends

Soil Mixtures	G_s
Blended Samples	
B0 (Pure CRBM)	2.813
B20	2.780
B40	2.745
B60	2.695
B80	2.572
B100	2.519
Controlled Samples	
No Fly Ash B50F0C0	2.763
Pure Fly Ash B0F100C0	2.335

3.1.4 Atterberg Limits

Liquid limit of around 15.6 was achieved and 13.65 for the plastic limit. Having plasticity index of less than 3 of either the theoretical formula or the polynomial equations, thus fines content of CRBM is considered to be non-plastic. Fly ashes are non-plastic that makes it very difficult to perform the Atterberg test. From observation, experiments and researches, fly ash and bottom ash can be considered as non-plastic.

3.1.5 Compaction Behavior

Proctor test was used to determine the optimum moisture content (OMC) and maximum dry unit weight. These variables were acquired through using the equation of the curve produced when the different water contents and dry densities were plotted. Differentiation of the equation for the curve per blend was done and equated this to zero.

Conventional road base materials demonstrated the highest maximum dry density. However, it also presented the least percentage of OMC. This

indicates that with a little amount of water, conventional road base materials already reached OMC promptly. This justifies that conventional road base materials reach OMC even with little amount of water. Also it tends to display the highest maximum dry density because of its relatively high specific gravity that affects the total dry mass at OMC. Pure fly ash and bottom ash exhibited diverse results from each other. Pure bottom ash had a low percentage of OMC. Fly ash had a significantly higher percentage of OMC. However, comparing their maximum dry densities, fly ash had a lower value than that of the bottom ash. These results show that fly ash contained more mass of water in the voids distributed among its total dry mass in contrast to that of bottom ash. Since fly ash is considered to exhibit particle size as that of fines, it is characterized to be absorbent of water gradually. Before it can be considered saturated, more water is employed for fly ash than bottom ash. It was observed that as the percentage of bottom ash was increased while the percentage of conventional road base materials was decreased for a blend, OMC increased also in value, shown in Figure 4. This explains that more bottom ash content with less conventional road base materials made the blend require more water to reach OMC.
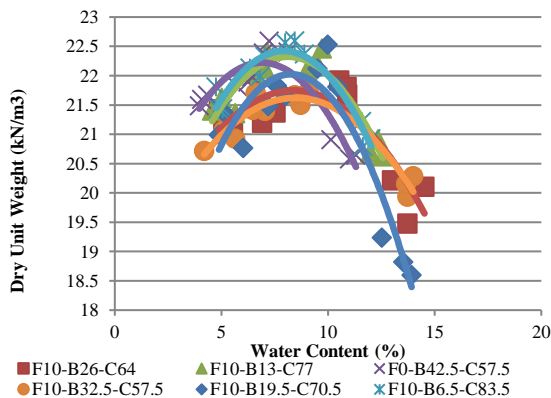

Fig. 4 Dry Unit Weight and Water Content at different blends

3.1.6 Maximum and Minimum Index Densities

The maximum and minimum index densities and void ratio of the blended soil samples and controlled soil samples, which are the CRBM, pure bottom ash, pure fly ash and CRBM blended only with bottom ash (F0-B42.5-C57.5) were determined using the standard testing method of ASTM with designations D4253 and D4254. Pure fly ash has significantly larger values of void ratio compared to bottom ash and CRBM. The results were logical since fly ash is more porous compared to bottom ash and to CRBM that is clearly shown to the SEM photomicrographs. Thus, it tends to increase the volume of voids over the volume of fly ash. The same logic occurs when bottom ash is

compared to CRBM. As for the index densities, fly ash obtained the lowest value compared to other control samples. This simply justifies that fly ash produces a higher volume of voids over the mass of the ashes perse. Looking at the controlled blend that has no fly ash content, it produced a higher void ratio and lower dry density when compared to 100% BA- blend. This means that the fines content of bottom ash produces more voids as compared to the fines content of fly ash. This can be defended through the amount of fly ash being mixed to other blends is greater in volume than of the bottom ash. The low specific gravity of fly ash was able to let more fly ash to fill the empty and small spaces of the blended soil samples compared to the fines of bottom ash that has higher specific gravity. For the blended samples, the maximum and minimum void ratio decrease as the bottom ash content increases. Though the morphology of bottom ash particles is more porous compared to CRBM particles, the grain size of bottom ash gives better interlocking property compared to CRBM. This is because of the physical characteristic of CRBM particles, which are more angular in shape compared to bottom ash.

3.2 Hydraulic Conductivity

3.2.1 Vertical Hydraulic conductivity

Among the controlled samples (CRBM, pure bottom ash and pure fly ash), bottom ash has the highest value of the hydraulic conductivity that ranges from 1.00E-03 to 1.00E-02. The said values are considered to be a very stable and good to be used as road base material. Pure bottom ash had even surpassed the hydraulic conductivity characteristic of CRBM.

Moreover, pure fly ash has a very poor hydraulic conductivity that can be considered to use as an impervious layer for other embankment applications but not as a road base material. By looking at Blend F0-B42.5-C57.5, it can be said that replacing bottom ash with the fines content of the soil samples have an effect on the hydraulic conductivity.

By blending bottom ash and fly ash at conventional road base materials, the value of hydraulic conductivity with respect to void ratio, relative compaction and relative density varied at different percentage of bottom ash content. A graphical representation of the hydraulic conductivity of bottom ash as a function of void ratio was accomplished, shown in Figure 5. Different proportions of bottom ash, namely 20%, 40%, 60%, 80%, and 100%, were tested using the Falling Head Hydraulic conductivity Test. At these ratios, various hydraulic conductivities were attained. A graph showing the relationship

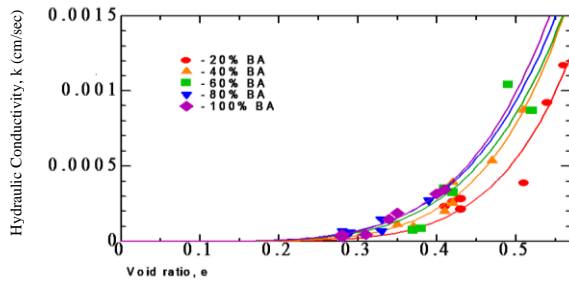between the hydraulic conductivity and void ratio was then arranged.

Fig. 5. Hydraulic conductivities of different blends at varying void ratio

It can be observed that there was an increasing trend based on the values of hydraulic conductivity and void ratio. This explains that as the void ratio, e, increased, the hydraulic conductivity, k, also increased. Thus, the soil became more permeable when there was a higher void ratio. A specific function was employed in conveying the relationship between k and e. The resulting hydraulic conductivity, k is in cm/sec.

The relationship between e and hydraulic conductivity was also influenced by the amount of bottom ash incorporated in the blend. Furthermore, it produced higher void ratio and hydraulic conductivity when there was a greater amount of bottom ash in a blend. The bottom ash content in a blend signified that as one decrease the fraction of bottom ash, the void ratio becomes smaller and hydraulic conductivity of the soil also becomes weaker.

3.2.2 Horizontal Hydraulic conductivity

The horizontal hydraulic conductivity was also considered in this study as have been stated in the objectives. An apparatus was devised in such a way that the horizontal hydraulic conductivity of corresponding desired relative compactions can be measured; involved parameters such as the consequent particle sizes' weights for desired relative compaction, void ratios, hydraulic gradient, etc, were also taken into consideration in relation and similar to the vertical set-up.

From the obtained data it was observed that the hydraulic conductivity of all sample tests had a familiar trend in where the hydraulic conductivity decreases as the relative compaction increases. As explained earlier, this trend can be attributed to the reason that due to the increased compaction rate, the voids present in the sample would be lessened as the sample gets more compacted.

3.3 Model

Many models may be considered in the study [15, 16, 17, 18]. The experiments conducted for

the different blends had been reasonably included within its limits which is $10^{-6}< k <10^{-3}$ for sand and sandy soils. Looking at the results, it can also be supposed that the blend/s that qualify both USCS recommendations and good hydraulic conductivity are the ones that have around 40% to 60% bottom ash content for a desired relative compaction, blends 3 and 4 for this study.

A multiple regression was also produced so as to predict the hydraulic conductivity at different percent bottom ash content and void ratio. The equation is shown below:

$$k = exp^{-14.2634+0.88735B+13.361e} \text{ Eq. 1}$$

Where:

B = percent bottom ash content; (%)
e = desired void ratio; and
k = predicted vertical hydraulic conductivity (cm/sec).

Equation 1 produced a coefficient of correlation of above 95% which indicates that it is highly correlated, shown in Figure 6. Further statistical analysis was also done to verify the accuracy of the derived multiple regression equation. The results showed that Equation 1 is acceptable in predicting the vertical hydraulic conductivity given the percent bottom ash content and void ratio.
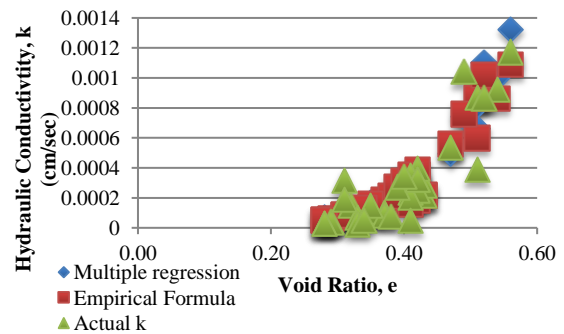

Fig 6. Validation of the Model

Statistical analysis was performed for specific gravity, maximum and minimum index density and void ratio, empirical formulas for vertical hydraulic conductivity and multiple regression. From the analysis, given a level of confidence of 95%, all tStat and P-value was satisfied. Given that there was no value of t-Stat between 1.96 and -1.96 and a P-value greater than 0.005. Thus, all correlation done in the mentioned analyses are considered to be acceptable. In addition, all the graphs for the comparison of the actual and predicted hydraulic conductivity produced a slope almost equal to one of an angle of 45 degrees. From here we could say that using the derived

empirical formulas for the different blends would generate consistent results to the actual hydraulic conductivity.

4. CONCLUSIONS AND RECOMMENDATIONS

This study aimed to present the hydraulic conductivity characteristic of road base materials blended with fly ash and bottom ash and to evaluate the suitability of conventional road subgrade, sub-base, and base materials blended with specific proportion and gradation of fly ash (as partial substitute for fines) and bottom ash (as partial substitute for fine aggregates) for highway embankments with respect to the standard hydraulic conductivity characteristic of road embankments. With thorough researches, analysis with the literature related to this study and actual laboratory experiments performed by the researchers, the following conclusions are drawn:

1. From SEM tests, fly ash had the most visible voids as compared to bottom ash and CRBM. This had greatly affected the index properties of the soil samples as well as the hydraulic conductivity characteristics of the blended soil samples.
2. The horizontal and vertical hydraulic conductivity of CRBM and pure BA had a significant difference wherein the flow of water at the horizontal-direction is greater compared to the vertical-direction which means that hydraulic conductivity largely depends on the axis of flow and compaction.
3. Blending bottom ash and fly ash has a great effect on the hydraulic conductivity of soils. Among the designed blends, the 40% to 60% substitute of bottom ash to conventional road base materials incurred the highest vertical hydraulic conductivity at different relative compaction but not for the higher relative compaction (RC = 100%) where the amount of bottom ash did not have a significant effect to the hydraulic conductivity.
4. The hydraulic conductivity values obtained for all the blends at the required compaction of 95% range from 1.00x10-06 to 1.00x10-05, which is considered to be a fairly stable material as a road embankment according to USCS recommendation for road embankments.
5. Using the derived empirical model for hydraulic conductivity produces a good projection of the results, which can also be proven acceptable through statistical analysis.

For future researches, further experiments on different coal ashes of different origins or class may be conducted where the resulting hydraulic conductivities may be compared with the outcomes in this thesis. Conducting more researches would not only define the hydraulic conductivity characteristics for the variety of coal ash by-products even more, but also provide engineers with information when it comes to designing road embankments.

It is also recommended for future studies that fly ash content which is ten percent of all blend compositions may be removed and replaced with bottom ash and/or conventional road base material and distinguish if it will have better hydraulic conductivity results than that of the ones conducted in this study.

Moreover, it would be recommendable for future researchers to study the horizontal hydraulic conductivity of the conventional road base materials blended with fly ash and bottom ash. It will be helpful to verify the ratio of horizontal over vertical hydraulic conductivity and confirm if it has a satisfactory rate of flow at the x-direction as a good consideration for road base materials.

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