The effects of bottom ash in coastal sand

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Abstract. In the construction industry, breakage of sand particles is very common especially at the very early stage of the pile driving work. The breakage of sand particles will result in change of size spectrum and alter its engineering properties. In this research, the effectiveness of bottom ash in improving the engineering properties of crushed sandy soil was studied. The bottom ash of 5%, 10%, 15% and 20% was added into the sand and crushed with 500 and 1000 blows under the Automatic Compactor machine. The engineering properties of different proportion of bottom ash mixture before crushing and after crushing with 500 and 1000 blows were tested. The engineering properties which were measured include the coefficient of uniformity, breakage index, fouling index, permeability and bearing capacity. Results show that adding of bottom ash into the crushable sand improved the load bearing capacity. By adding 20% of bottom ash, the bearing capacity of the crushed sandy soil can be improved by 55% meanwhile the permeability of the sandy soil can be improved by 200%.

1. Introduction

Sand is a natural granular construction material which is formed by the weathering of rocks. Due to its high accessibility, sand has been widely used in construction for many centuries. During construction, breakage of sand particles and reduction in size of particles may occur under crushing impact. For instance, when the piles are driven into the sand, sand will normally experience stresses which are high enough to break the particles. The breakage of particles will result in the increase of percentage of fine particles and change the grading [1]. The design of foundations is usually done using soil parameters obtained from in-situ or the laboratory test. The calculations are done assuming that the soil parameters will always remain unchanged or at least with some minor error after the post design work. However, in reality the sand will experience crushing impact hence the size of sand may change during the construction work. The changes in size of sand will alter the mechanical behaviour and engineering properties of the granular sand such as strength, volume change, pore pressure developments and permeability [2]. These changes are highly depends on the amount of sand particle crushed due to the applied crushing load. The occurrence of the changes in gradation of sand is uncontrollable and irreversible. This change indicates that the quality of sand which exists at the end of the piling activity will be different from the original sand that exists on site. The changes of mechanical behaviour in soil may result in failure of the construction due to the under estimation of bearing capacity. Therefore it is vital to determine the crushability of granular sand that is used for geotechnical applications and predict the bearing capacity accurately. Over the decades, researchers have carried out many studies on how to improve the impact and the quality of crushable sand and one of the possible solutions would be adding bottom ash as partial replacement to the sand filler. Studies of engineering properties of the physical and chemical characteristic of bottom ash had shown that the engineering behaviour of the bottom ash is almost similar with the natural granular sand. More extensive research has to be carried out to find the specific usage and the benefits of bottom ash as an alternative material in construction industry.

For example, in 1972 an experimental research [3] was carried out using the standard proctor compaction test and one dimensional compression test on West Virginia bottom ash. The laboratory data showed that at low stress levels, the compressibility of bottom ash was comparable to natural granular soils at similar relative densities. Another study [4] pointed out the possibility of coal bottom ash to replace sand in embankments and the result also showed that the bottom ash had acceptable environmental properties when testing done to its leachate [5]. The overall review from the past reports shows the possibility of bottom ash to be used as to replacement of sand. In this research, the possible effect of the bottom ash to act as the partial sand replacement was studied. A series of tests was conducted to determine the effect of bottom ash in improving the crushability and permeability of the crushable sandy soil as well as improving the bearing capacity of the crushable sand.

2. Literature review

2.1. Sand particle breakage

The particle crushing of sand often affects the stiffness and strength of soil and particle size distribution [6]. The particle crushing is proven as an irrecoverable process, and the sand have become more compacted through inter-particle slip and rotation [7]. Some of the engineering practice in estimating the bearing capacity of pile had to consider the variation of mechanical properties of sand due to particle crushing. In practice, the deep penetration problem such as pile driving and cone penetration testing will create a sufficient stress levels for particle breakage to occur [8]. Figure 1 shows the image of how the sand grains was before and after the event of crushing through laboratory testing.

2.2. Effect of sand particle breakage

Over the past few decades, many theoretical and experimental studies have been conducted to understand the effect of sand particle breakage on engineering properties. It has been proven that the breakage of sand particle had affected the engineering properties of sand such as particle size distribution, shear strength and hydraulic conductivity behaviour [10-12]. Understanding the mechanism and simulation of sand particle breakage will assist in many ways to design a proper structure in places where abundance of granular soil in found.

2.2.1. Effect on particle size distribution

The sand particle could be crushed into smaller size under high stress. It was found that small grains from fractures could lead to the shift of particle size distribution. From the previous study, a uniform grading of sample will shift to a well graded distribution as stress increased and breakage progressed further [9]. As the breakage of sand particles towards the critical state, the soil gradation eventually tends to shift to well-graded [10]. These shifts affect the mechanical properties of granular sand and the crushing strength against further breakage. This explain that a very well-graded and fractal soil will not experience dramatic breakage.

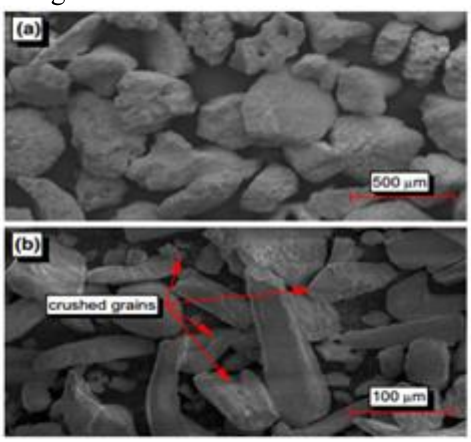

Figure 1. SEM carbonate sands: (a) grains from the original and (b) grains after testing [11]

2.2.2. Effect on shear strength

In the past a research was carried out using monotonic test on variation mixture of crushed non plastic silica fines contents with Ottawa sand [12]. These tests showed that when the fines content in sand increase, the behaviour of Ottawa sand will become more dilative, with less strain-softening reaction occurrence. The steady line in void ratio-effective stress space will be altered as the fines content is changed. The study of the effect of static liquefaction behaviour of four different sands had shown that as the fine content of sand increased, the specimens will behave with lower peak stress and exhibited more contractive behaviour [12]. Many studies have been carried out to understand the effect of particle breakage in sands on stress strain conditions. The strength and bearing capacity were reduced when particle breakage increased [8].

2.2.3. Effect on hydraulic conductivity

The particle size of the crushable sandy soil will affect the permeability of the sand. The particle crushing reduces the mean pore size and the hydraulic conductivity of the soil will decrease and become less permeable when the fines content increase. For instance, the sand particles which located at underlying the layers of dam are subjected to high stress may cause the sand particles to break, and slow down the pore-water pressure dissipation and pore pressure distribution in earth dam [12].

2.3. Quantifying particle breakage

The experimental testing of sand particle crushing is not an easy task to interpret since the breakage of sand particle is not visually clear even after a careful inspection. Therefore a theoretical model of the evolution of crushing is needed to make post-test observation so that the sand crushing strength can be determined.

2.3.1. Breakage index and crushing coefficient

The index of particle breakage, B_g was defined with the assumption that the sand particles which retained in larger sieve size will decrease meanwhile there will be an increase in the amount of sand particles retained in smaller size sieve. In this experiment, the change in weight of soil retained minus the weight of soil retained before the test was plotted for each particle size fraction with respect to its corresponding size [13]. The general shape of the sand is normally determined by the D_{50}, the 50% of the sand by weight. The change in D_{50} can also be used to assess the rate of particle breakage. The breakage index of D_{50} is defined as the ratio of 50% of the size of sand before the test to the 50% of the size of the sand after the test. Since a log scale is used to plot the particle size distribution curve, the ratio of breakage index can also be determined by the horizontal distance between the initial and final sand size curves at 15% finer [14].

2.3.2. Fouling index and percentage of fouling

Fouling refers to the condition of railroad ballast when voids in this unbound aggregate layer are filled with finer materials. Railroad ballast is uniformly-graded coarse aggregate placed between and immediately underneath the crossties. The purpose of ballast is to provide drainage and structural support for the heavy loading applied by trains. As ballast ages, it is progressively fouled with fine-grained materials filling the void spaces [15]. The fouling index and percentage of fouling is often use in determining the suitability of the ballasted track in railways. In order to sustain good performance it is essential to maintain proper drainage in the ballasted track. Railroad ballast usually contains uniformly graded material that creates a sufficiently large pore structure to facilitate rapid drainage. When it is degraded and aged, fine particles accumulate within the voids (ballast fouling) and decrease its drainage capacity. There are numerous fouling indices available in literature to quantify ballast fouling. The fouling Index is defined as a summation of percentage (by weight) passing the 4.75mm (No.4) sieve and 0.075mm (No.200) sieve. This may lead to a misinterpretation of the actual quantity of fouling if the fouled material contains more than one type of material having considerably different specific gravities [16].

2.4. Crushing of bottom ash and sandy soil
Some experimental work data of mixture of sand and bottom ash have been studied. For example, study on the effect of two types of bottom ash mixed with different types of soil in different proportion to the value of California Bearing Ratio. The results show that the California Bearing Ratio value increased as the proportion of bottom ash increased [17]. Besides that, there were also attempts to investigate the relationship of the percentage of bottom ash and the permeability. From the study, the result show that as the percentage of bottom in the mixture of various incinerator mixtures increased, the permeability of the mixture was increased too [18]. These previous researches showed the possibility of bottom ash to improve the load capacity of crushed sand.

3. Methodology
The collected sand was divided into three portions which were the sand without crushing, sand crushed with 500 blows and sand crushed with 1000 blows using automatic compactor. Each of the portions was tested with experiment of sieve analysis, California bearing ratio and permeability. The tests are repeated for each portion by adding bottom ash in percentage of 5%, 10 %, 15% and 20%.
The sieve analysis was conducted according to ASTM D422. About 500g of sand samples mixed with different proportion of bottom ash were shaken in mechanical sieve shaker for 10 minute and the weight of each sieve set was measured. The particle size distribution curves were drawn. The experiment was repeated with the sand that crushed for 500 and 1000 blows. The permeability test was carried out using ASTM D234 method, the constant head test. The time required for the water in permeameter that filled with sand to flow out and fill up a measuring cylinder of 1000ml was recorded. The test was repeated by adding different proportions of bottom ash and whole process is repeated with sand that crushed with 500 and 1000 blows. For the California Bearing Ratio measurement, the test was done according to ASTM 1883 method. The sand was mixed with different proportions of bottom ash and compacted in the mould by preparing at optimum moisture content accordingly. For unsoaked condition, the compacted soil was tested without soaking in water while for soaked condition, the compacted soil was immersed in water for 3 days. The test sample was tested on the penetration test machine. The load readings at penetration of every 0.25mm was recorded until it reached a 7.5mm penetration. The test was repeated with sand that was crushed with 500 and 1000 blows.

4. Results and Discussions

4.1. Crushability of sand
The data obtained from the particle size distribution curve were used for crushability analysis. The analysis includes the breakage index, crushing coefficient, fouling index and percentage of fouling. Figure 2 and Figure 3 show the breakage index and crushing coefficient for the sand that mixed with different proportion of bottom ash and undergo crushing for 500N and 1000N. The result shows that when the percentage of bottom ash added increased, the breakage index and crushing coefficient of the sand was decreased. This indicates an improvement in reducing the crushability of the sand where the sand will experience less crushing when bottom ash is added into the sand.

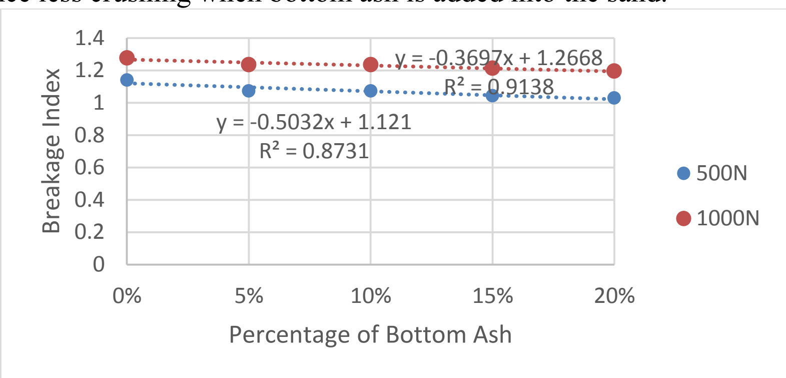

Figure 2. Breakage index for sand underwent crushing with different proportion of bottom ash

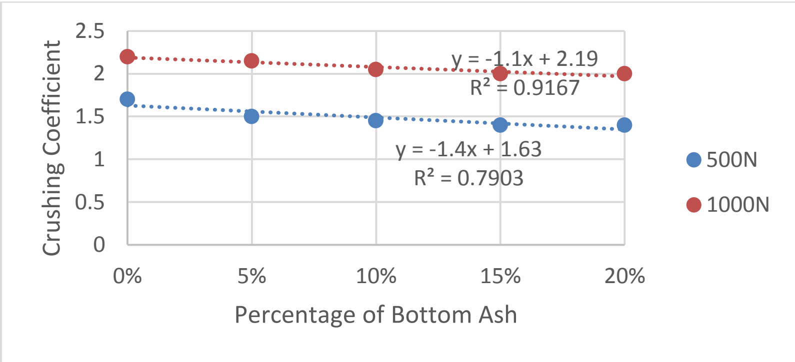

Figure 3. Crushing Coefficient of sand mixed with different proportion of bottom ash underwent crushing of 500N and 1000N

The fouling index and percentage of fouling were analysed from the particle size distribution curve. Figure 4 and Figure 5 showed the fouling index and percentage of fouling of sand mixed with different proportion of bottom ash that subjected to crushing of 500N and 1000N. The result shows that when bottom ash is added into the sand, the fouling index and percentage of fouling were reduced. This indicates that the bottom ash is able to reduce the fouling of the sand. The sand underwent less fouling when bottom ash is added into the sand under crushing.

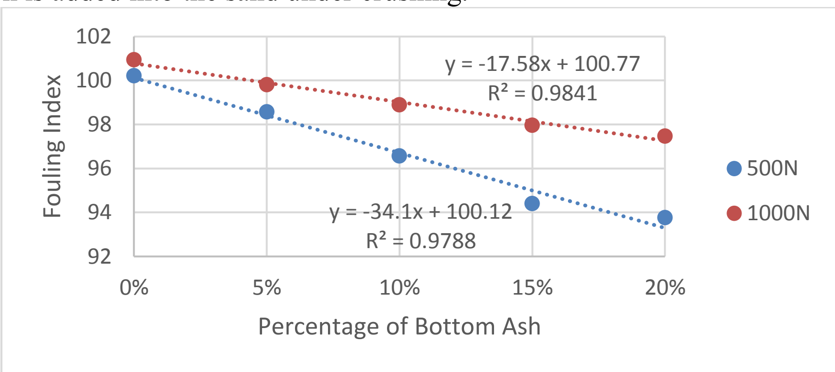

Figure 4. Fouling Index of sand mixed with different proportion of bottom ash underwent crushing of 500N and 1000N

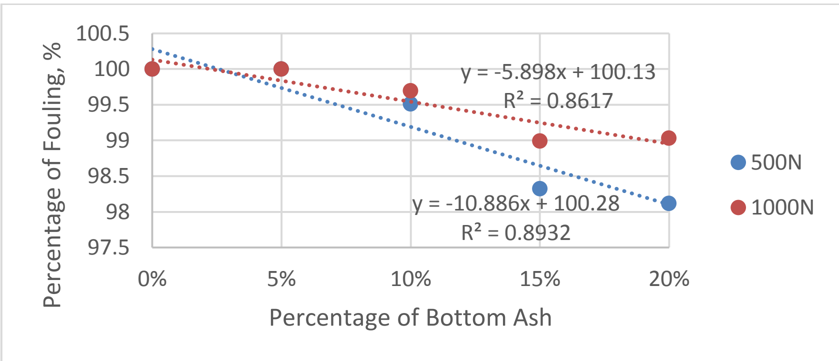

Figure 5. Percentage of fouling of sand mixed with different proportion of bottom ash underwent crushing of 500N and 1000N.

4.2. California bearing ratio

Figure 6 and Figure 7 showed the unsoaked CBR value and soaked CBR value when the sand is mixed with different proportion of bottom ash. By adding the bottom ash, the CBR percentage value of the sand had increased. The higher the percentage of bottom ash added into the sand, the greater the increase in the CBR value, which indicates a better improvement in the bearing capacity of the sand.

The sand which crushed with 500 blows and 1000 blows had the same engineering properties where the bottom ash improved the bearing capacity. The result obtained was similar with the literature review when different percentage of bottom ash mixed with uncrush sand.

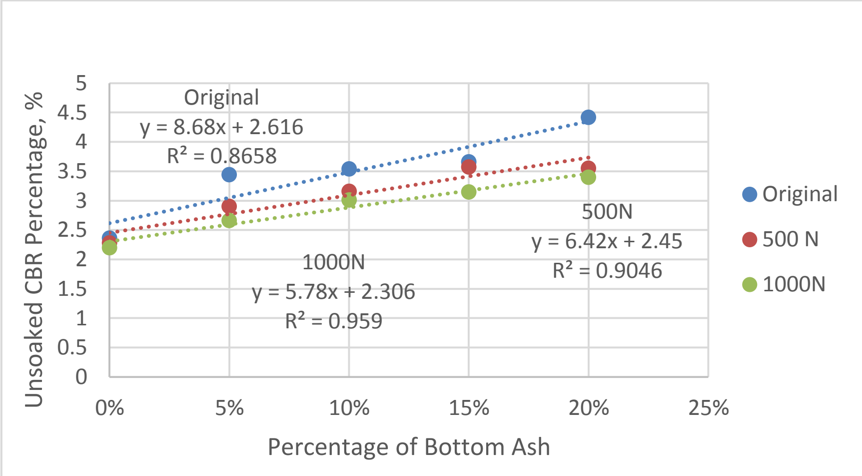

Figure 6. Unsoaked CBR percentage of sand mixed with different proportion of bottom ash sand mixed with different proportion of bottom ash.

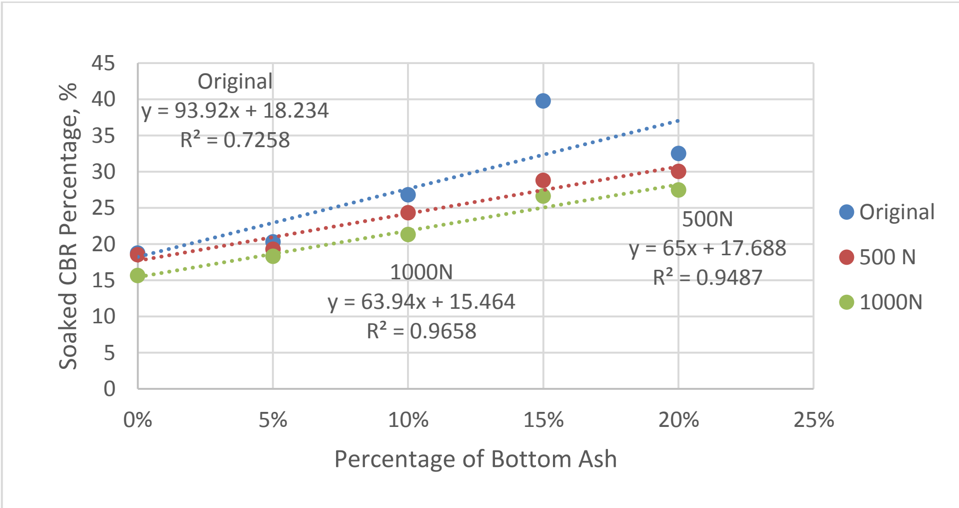

Figure 7. Soaked CBR percentage of sand mixed with different proportion of bottom ash sand mixed with different proportion of bottom ash.

4.3. Permeability

The sand is mixed with different proportion of bottom ash and the permeability of each sample was tested. Figure 8 show the permeability of sand mixed with different proportion of bottom ash that underwent crushing of 500N and 1000N. From Figure 8, when the percentage of bottom ash added into the sand increased, the permeability of the sand increased. This is because the bottom ash has larger particle size compared with the sand. Adding a well graded bottom ash into sand, will create more space between the sand particles and thus the permeability of the sand increases. Result is further supported in the literature review when bottom ash used in percentage of 0%, 20%, 40%, 60%, 80% and 100%. As the percentage of bottom ash increased, the coefficient of permeability also increased, which is similar to findings obtained in this research. This result is similar with result in this research where the permeability of bottom ash mixture increases when the percentage of bottom ash increased.

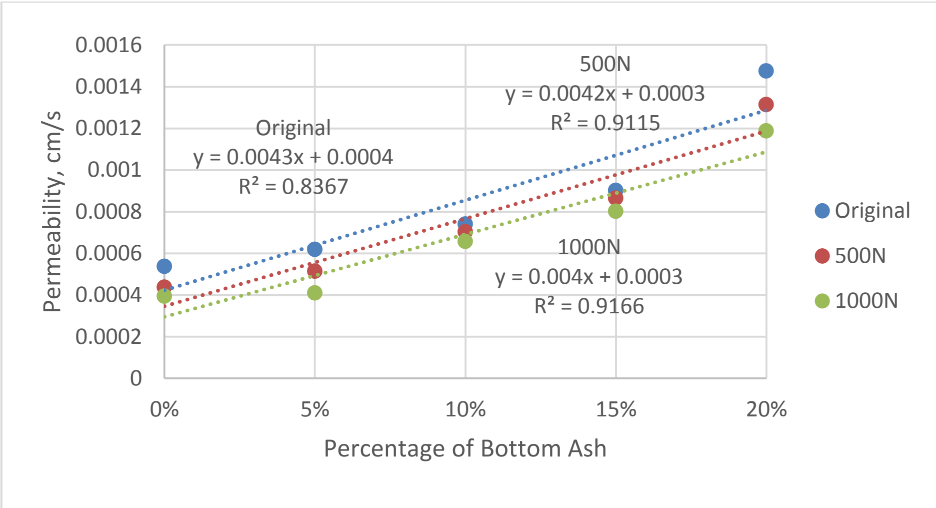

Figure 8. Permeability of sand mixed with different proportion of bottom ash underwent crushing of 500N and 1000N.

5. Conclusion

The ultimate aim of this research is to determine the effect of bottom ash when added to the crushed sand. Based on the preliminary result and analysis done, it can be concluded that:

1. The bottom ash is able to reduce the crushability of the sand by reducing the breakage index, crushing coefficient, fouling index and percentage of fouling. The higher the percentage of bottom ash added into the sand, the greater the reduction of crushability and the better the improvement to the capacity of the sand.
2. The bottom ash is able to increase the bearing capacity of the sand for both the soaked and unsoaked condition. The higher the percentage of bottom ash added into the sand, the greater the increment of the bearing capacity and the better the improvement of the capacity of the sand. This improvement in bearing capacity by adding bottom ash also shown in crushed sandy soil which are subjected to 500 and 1000 blows.
3. The bottom ash is able to increase the permeability of the sand. When the amount of bottom ash added into the sand increases, the permeability of the sand also increased. The greater the amount of bottom ash added, the better the improvement of the permeability of the sand. The improvement in permeability of crushed sandy soil was observed when subjected to 500 and 1000 blows.

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