# Improvement of Engineering Characteristics of Poor Quality Soil by mixing with Bottom Ash

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**Abstract— Huge quantity of bottom ash is generated as a by-product of burning of coal when generating electricity at Norochcholai power plant. However, only very small quantity of bottom ash is used by the industry to produce concrete blocks and remaining is stockpiled at Norochcholai creating an environmental pollution. As such, possibility to utilize bottom ash for road embankment and pavement construction was studied in this research study. Different percentages of bottom ash were mixed with poor quality soils, which were not satisfied the filling material requirements in the specification, to improve the engineering characteristic of soils. Based on the results, it can be noted that by blending 30% of bottom ash with poor quality soil, it can be used as an embankment Type 1 and Type 2 filling material. Further, it was found that by adding 10% of cement to soil-bentonite mixture, it can be utilized as a subbase material. Hence, it can be concluded that bottom ash can be used successfully as a mechanically stabilizer to improve the engineering characteristics of poor quality soil.**

***Keywords—bottom ash, CBR value, cement, poor quality soil***

## I. INTRODUCTION

Due to rapid urbanization, there is a boom in the construction industry in Sri Lanka. As a result, many road projects such as Central Expressway, Ruwanpura Expressway, iRoad Development programme etc. are now in progress. Due to these infrastructure development projects in the country, the amount of materials required for embankment and subbase construction has increased significantly. For example, 14.4 million $m^3$ of embankment material and 566,000 $m^3$ of subbase material have been used by the Southern Expressway Extension Project from Matara to Beliatta. Due to this high demand, construction industry is facing with a shortage of good quality construction materials. Therefore, it is a challenge faced by the civil engineers to find good quality materials for the road construction.

In order to overcome this problem, many researchers [1], [2], [3] have utilized industrial wastes such as fly ash, bottom ash, blast furnace slag, rice husk ash, silica fume etc. to stabilize the soil. However, only very limited research studies have been conducted in Sri Lanka to stabilize the poor quality soil using industrial waste. As such, the possibility to improve engineering characteristics of poor quality soils by mixing with bottom ash was studied in this research. Bottom ash is a by-product of coal combustion from coal-fired power plants. The growing demand for electricity has resulted in the construction of coal-fired power plants and as a result, the production of bottom ash has continued to increase. Disposal of bottom ash has become more costly to the power industry and costs are ultimately transferred to the power customers.

Coal fired power plants at Norochcholai in Puttalam district of Sri Lanka generates 43% of the total energy production of the country. It was reported that power plant at Norochcholai consumes approximately 2640 tons of coal per day and produces more than 220 tons of coal ash and out of that nearly 40 tons is bottom ash. However, bottom ash is very rarely used in the construction industry and huge volume of bottom ashes are dumped near the coal power plant and this becomes a major environmental and social problem. This clearly indicates the necessity to find out an appropriate solution to utilize this waste for construction industry without creating a detriment environment.

The research reported in this paper is an attempt made to improve the engineering properties of poor quality soils which were not satisfied the requirements to use as embankment filling material according to ICTAD SCV/5 [4]. Poor quality soils were mixed with different proportions of bottom ash to achieve the requirements specified and results are presented.


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## II. Material and Methodology

### A. Material

Materials used in this research study were disposed coal bottom ash collected from Norochcholai thermal power plant located in Puttalam district of Sri Lank and poor quality soil samples taken from disposal yard at Southern expressway Extension Project from Matara to Beliatta section.

Physical properties of selected soil and bottom ash are illustrated in Table 1. Particle size distribution of soil and bottom ash are presented in Fig. 1. It can be seen that poor quality soil mainly consists of fine grained soil whereas bottom ash mainly consists of sand. Since soil possess relatively high liquid limit and plasticity index, which does not satisfy the ICTAD SCV/5 [4] to use as embankment filling material. However, bottom is a non-plastic material. According to Unified Soil Classification System (USCS), soil can be classified as MH (Silt of high plasticity) while bottom ash can be classified as SP-SM (poorly graded sand – Silty sand).

California Bearing Ratio (CBR) is widely used in the determination of suitability of materials for embankment and pavement construction. Based on the basic properties presented in Table 1, it can be noted that soil marginally satisfied the requirements of Type II embankment material (CBR > 5%).

TABLE I. PHYSICAL PROPERTIES OF POOR QUALITY SOIL AND BOTTOM ASH

| Property | *Poor quality soil* | *Bottom Ash* |
|---|---|---|
| Fine content (%) | 51 | 10 |
| Sand content (%) | 48 | 88 |
| Gravel content (%) | 1 | 2 |
| Liquid Limit (%) | 56 | Non-plastic |
| Plastic Limit (%) | 30 | |
| Plasticity Index (%) | 26 | |
| Soil type according to USCS | MH | SP-SM |
| Specific Gravity | 2.34 | 1.13 |
| Maximum dry density (kg/m$^3$) | 1485 | 1298 |
| Optimum moisture content (%) | 19.5 | 32.5 |
| 4 day soaked CBR value (%) | 6.67 | 19.84 |

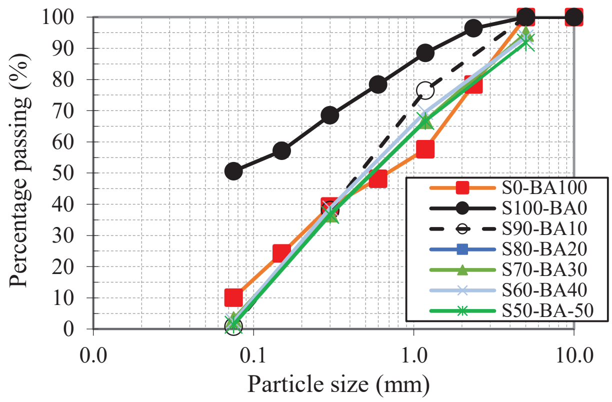


Fig. 1 - Particle size distribution of poor quality soil and bottom ash

In addition to the basic properties, toxicity and radioactivity properties of the bottom ash were investigated. Since heavy metals can be threaten to the heath of human beings and animals through the food chain, it is important to verify the availability of heavy metals within the bottom ash and results are presented in Table 2. The concentration after leaching procedure, a very small amount of Zn, As, Se, Sb and Ba were in the bottom ash and which were well below the regulatory values. Further, other heavy metals such as Chromium, Copper, Cadmium, Mercury and Lead were not detected within the bottom ash. As such, it can be concluded that by mixing bottom ash with insitu soil, it will not contaminate the ground water.

TABLE II. TOXICITY CHARACTERISTICS OF BOTTOM ASH

| Element | *Value (mg/l)* | *MCL* (mg/l)* |
|---|---|---|
| Chromium ($C_r$) | Not detected | 0.05 |
| Copper ($C_u$) | Not detected | 0 |
| Zinc ($Z_n$) | 0.03 | 1.00 |
| Arsenic ($A_s$) | 0.01 | 0.05 |
| Selenium ($S_e$) | 0.008 | 0.01 |
| Cadmium ($C_d$) | Not detected | 0.005 |
| Antimony ($S_b$) | 0.001 | 0.006 |
| Barium ($B_a$) | 0.58 | 2.00 |
| Mercury ($H_g$) | Not detected | 0.001 |
| Lead ($P_b$) | Not detected | 0.05 |

*Maximum Contamination Level according to National Environmental Act No. 47, 1980

TABLE III. RADIOACTIVITY OF BOTTOM ASH

| **Radio Nuclide** | ***Activity (Bq/g)*** | ***Upper limit* (Bq/g)*** |
|---|---|---|
| Pb-210 | 0.038 | 1.0 |
| K-40 | 0.199 | 4.0 |
| Ra-226 | 0.113 | 7.0 |
| Cs-137 | Not detected | 4.0 |
| Th-232 | 0.131 | 0.5 |
| U-235 | 0.014 | 4.0 |

Further, radioactivity analysis results are depicted in Table 3. The clearance levels for radionuclides in solid materials is also illustrated in the same table. According to the results, some radio nuclides were encountered in the bottom ash and those are well below the regulatory values published by [5], even below the radioactivity level of natural soil in Sri Lanka [6].

### B. *Methodology*

In order to improve the engineering characteristics of poor quality soil to use as embankment filling material and for subbase construction, poor quality soils were mixed in different percentages of bottom ash varying between 0 to 50% in steps of 10% on dry weight basis. Sample prepared by mixing nine parts soil (90%) with one part of bottom ash (10%) is designated as S90-BA10. On similar lines, in samples S80-BA20, S70-BA30, S60-BA40 and S50-BA50, bottom ash content was 20, 30, 40 and 50% respectively on total dry weight of the mixture. Unimproved soil is represented as S100-BA0 whereas bottom ash alone is designated as S0-BA100.

For each mix proportion, engineering characteristics were determined by conducting laboratory experiments and most improved mixture was selected for the embankment fill material. Small percentage (2, 5 and 10%) of cement was added to the selected mix proportion to further improve the engineering characteristics to use as subbase material.

## III. RESULTS AND DISCUSSION

### A. *Particle size distribution*

Particle size distribution of soil-bottom ash mixtures are presented in Fig. 1. Addition of bottom ash to the poor quality soil resulted in a mixture having low fine content due to the solidification effect, even the fine content is less than that of bottom ash. This clearly indicates the cementitious nature of the bottom ash. It can be noted that irrespective of the bottom ash content, all mixtures show similar pattern in the grading curves.

### B. *Atterberg Limits*

The variation of Atterberg Limits over bottom ash content is illustrated in Fig. 2. Based on the results it can be noted that by mixing more than 10% of bottom ash with soil, it satisfied the requirements of embankment Type I and Type II material with respect to Atterberg Limits. However, in order to use soil-bottom ash mixture as upper subbase material, it is necessary to add at least 25% of bottom ash to the poor quality soil. It is a noticeable feature that with the addition of bottom ash to the soil, Liquid Limit has been gradually decreased and reached to a constant value whereas Plastic Limit has been reduced insignificantly. As a result, it can be seen that Plasticity Index has been dropped significantly with the addition of more 10% of bottom ash. When the bottom ash content is more than 40%, the soi-bottom ash mixture becomes non-plastic.

### C. *Compaction Characteristics*

The Modified Proctor Compaction curves of soil-bottom ash mixtures are illustrated in Fig. 3. Upon addition of bottom ash in increasing proportions to the soil by weight, the maximum dry density increases with the bottom ash content up to a peak value and then decreases as shown in Fig. 3. It can be seen that peak value of maximum dry density was achieved when the optimum bottom ash content is about 30%. It is a clear evident that by adding small percentage of bottom ash, high plasticity soil can be transformed to use as an embankment Type II material (maximum dry density > 1500 kg/m$^3$). However, only the soil-bottom ash mixtures with bottom ash content of 30% was satisfied the Embankment Type I material requirements (maximum dry density > 1600 kg/m$^3$). None of the mixtures couldn't achieve the upper subbase material requirements (maximum dry density > 1750 kg/m$^3$) with respect to dry density.


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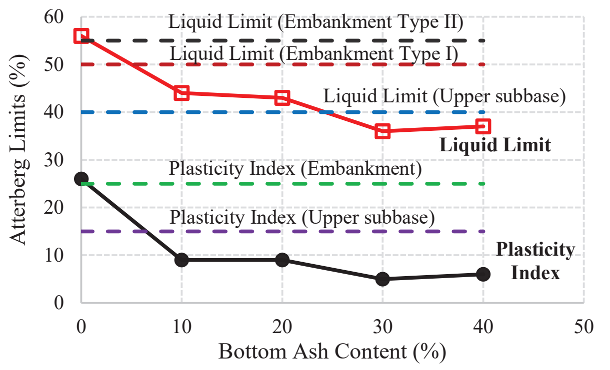


Fig. 2 - Variation of Atterberg Limits over Bottom ash content

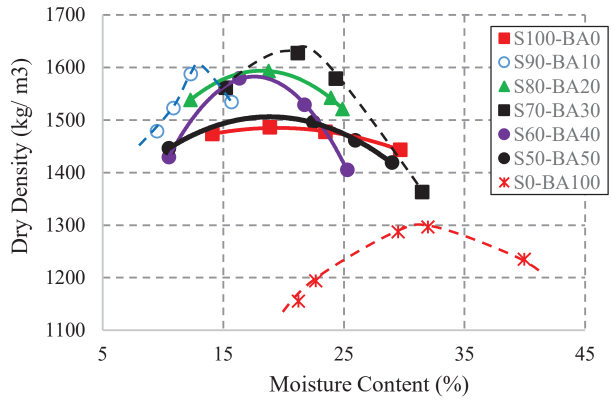


Fig. 3 – Compaction curves of soil-bottom ash mixtures

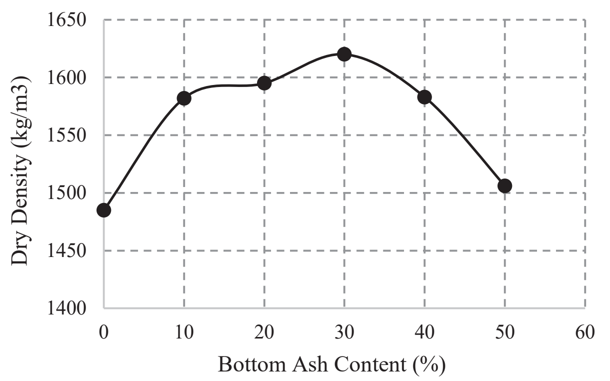


Fig. 4 - Variation of maximum dry density of soil-bottom ash mixture over Bottom ash content

## D. *California Bearing Ratio (CBR)*

The variation of CBR values of soil-bottom ash mixtures is presented in Fig. 5. It clearly indicated that there is no any noticeable improvement in 4 day soaked CBR value until soil amended with 30% of bottom ash. Even soil amended with 50% of bottom ash, it couldn't achieve the requirements of lower subbase (CBR > 15%). Further, it can be noted that unamended soil satisfied the requirements of Embankment Type II material (CBR > 5%) and it is necessary to add 30% of bottom ash to achieve the requirements of Embankment Type I material (CBR > 7%). These findings clearly illustrated that in order to achieve the sufficient improvement in 4 day soaked CBR value of soil-bottom ash mixtures, it is necessary to add some kind of binding agent to further enhance the solidification effect.

## E. *Effect of Cement on Engineering Properties of Bottom Ash ammended Soil*

The possibility to further improve the soil-bottom ash mixtures were studied by adding different proportions of cement to the sample of S70-BA30. This sample was selected as optimum bottom ash content to achieve peak value of maximum dry density would be 30%. The variation of 4 day soaked CBR value over cement content of selected sample is illustrated in Fig. 6. It can be seen that with the addition of 2% of cement to S70-B30, CBR value has been increased by 120%. Further, it can be noted that there is no any significant improvement in CBR value with the addition of 5% of cement when compared with that of 2% of cement. However, when the cement content has been increased to 10%, CBR value has been drastically increased, *i.e.* 314% increment in CBR value with respect to natural soil. Based on these results, it can be concluded that at least 10% of cement is necessary to improve the soil-bottom ash mixture upto the subbase material requirement.

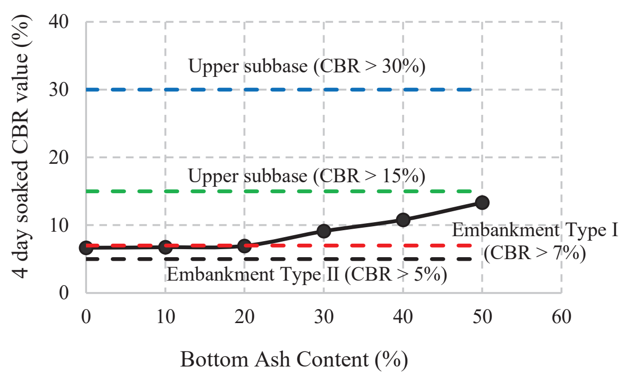


Fig. 5 – Variation of 4 day soaked CBR value of soil-bottom ash mixtures over bottom ash content

The effect of curing period on CBR value is presented in Table 4. It is very clear that 1 day after mixing of 2-5 % of cement, there is no any noticeable improvement in CBR value. However, after 4 days of curing, CBR value of soil-bottom ash-cement mixture has been increased by 100-120%. If the cement content is greater than 10%, there is a significant improvement in CBR value due to quick hardening effect. However, there is no any significant improvement in CBR value between 1 day and 4 day soaked samples when the cement content is greater than 10%.

Similar to the strength gain in concrete, soil-bottom ash-cement mixtures achieved 75-90% of 28 days CBR value within 4 days when the cement content is less than 10%. In the contrary, when the cement content is more than 10%, CBR value of the mixture after 28 days is same as that of 4 day soaked value. As such, even cement is used as a binding agent, 4 day soaked CBR value is sufficient to make decisions regarding strength of the mixture.

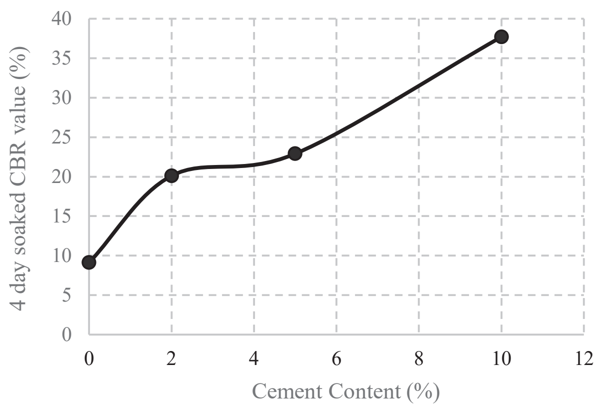


Fig. 5 - Variation of 4 day soaked CBR value of S70-BA30 mixture over cement content

TABLE IV. EFFECT OF CURING PERIOD ON CBR VALUE OF S70-BA30

| ***Cement content (%)*** | ***CBR Value (%)*** | | |
|---|---|---|---|
| | ***1-day soaked*** | ***4-day soaked*** | ***28-day soaked*** |
| 0 | - | 9.1 | - |
| 2 | 9.1 | 20.1 | 22.0 |
| 5 | 11.5 | 22.9 | 28.6 |
| 10 | 33.3 | 37.7 | 35.6 |

In order to study the most critical factor on soil improvement with respect to CBR value, soil alone mixed with 2% of cement and results are presented in Fig. 6. It can be clearly seen that by only adding cement or bottom ash to natural soil, 4 day soaked CBR value can not be improved substantially. However, by adding small percentage of cement, there is a significant improvement in CBR value. As such, it can be concluded that solidification effect is significantly improved when bottom ash amended with small percentage of cement.

## IV. CONCLUSIONS

In this research study, the possibility to use bottom ash to improve the engineering characteristics of poor quality soil as an embankment and pavement construction material in road construction industry in Sri Lanka was evaluated. Based on the results of detailed laboratory experiments and analysis following conclusions can be drawn:

1. The toxicity characteristics of bottom ash indicated that it will not contaminate the ground water when it contacts with insitu soil. Further, radioactivity level of the bottom ash illustrated that radio nuclides within the bottom ash is well below the regulatory values. As such, bottom ash can successfully utilize to improve the engineering characteristics of high plasticity poor quality soil.
2. Due to solidification effect, when soil mixed with bottom ash, fine content of the soil-bottom ash mixture has been decreased significantly. As such, plasticity behaviour of the soil gradually diminishes with the increase of bottom ash content and eventually becomes non-plastic when the bottom ash content is greater than 50%.

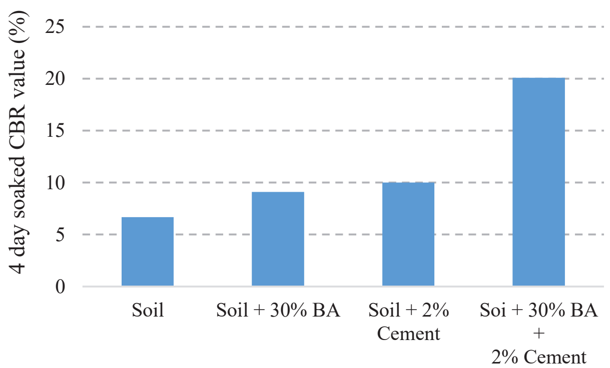


Fig. 6 – Effect of bottom ash and cement on soil improvement


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3. Maximum dry density of soil-bottom ash mixture increases with the bottom ash content upto 30% and decreases with further addition of bottom ash. Further, there is no any noticeable improvement in 4 day soaked CBR value of soil-bottom ash mixture until bottom ash content upto 30%. As such, in order to use high plasticity soil as Embankment Type 2 material, it is necessary to add 30% of bottom ash.
4. Laboratory experiments clearly illustrated that it is necessary to add some kind of binding agent to enhance the solidification effect of soil-bottom ash mixture to utilize as subbase material.
5. Addition of cement to soil-bottom ash mixture had a great impact on strength and pozzolanic characteristics with curing and showed significant improvement in the presence of 10% of cement. As such, by adding 30% of bottom ash and 10% of cement, mixture can be used as subgrade material.
6. Based on the laboratory test results, it can be concluded that bottom ash in combination with cement has the potential to be used as stabilizing agent in the construction of subgrade and subbase.

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