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EFFECT OF FLY-ASH ON THE STRENGTH DEVELOPMENT OF COASTAL SOILS-A CASE STUDY FOR THE SOUTHERN COASTAL ZONE OF BANGLADESH

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Abstract

The rapid demand for urbanization expands the requirements of infrastructures and owing to the scarcity of available firm land; people are now built structures on soft soils. However, the application of a deep foundation for a low-rise structure may not be economically feasible for developing countries. The economic, as well as safe foundation, can be ensured by adopting traditional ground stability approaches. However, replacement of the industrial by-product, which possess minimum environmental threat may be a plausible option for ground stability. Therefore, an attempt is taken in this research to study the improvement of soft coastal soil by replacing with eco-friendly fly ash. The eastern bank of the river Karnaphuli, which has increasing industrial and residential demand is taken as a case study in this research. A series of experimental set-ups have been conducted to evaluate the strength development with different fly ash contents. It is found that the strength of fly ash treated soils increases with fly ash content up to a threshold value, and beyond that, the strength decreases. In addition, compaction and plasticity characteristics are also investigated through experimental observations and show better performance criteria with increasing fly ash contents. In a nutshell, this approach of replacing fly ash is suitable for coastal soil, and the experimental investigation reveals that an optimum 20% of fly ash content is justified.

Keywords: Fly ash, Coastal soil of Bangladesh, Ground improvement, Eco friendly, Sustainability

1.0 INTRODUCTION

Bangladesh is a deltaic plain, and most of its formation is sedimentary deposition of suspended materials carried all the way from Himalayan through the large, tidal river system. Therefore, most of the geological formation is quaternary deposition of fine-grained soils[1]. The physical geology of Bangladesh broadly classified into two distinct zones: the eastern and northern hilly regions and the deltaic plain of the Ganges, the Brahmaputra, and the Meghna River systems. Although some high elevation is seen on the northern part, the elevation is less than 10 meter above mean sea level in most of the part of the country. The scenario is much violent on southern coastline, where elevation is almost same as mean sea level. The resultant is frequent submergence of coastal low-lying lands. Despite the adverse geological condition, those least developed coastal planes are being considered for the urbanization and industrialization to meet up the increasing economic growth of the country. To be specific, the coastline of Chattogram city has given high priority for the ongoing developments of the country's infrastructures. Chattogram is the second largest city of Bangladesh and the major sea port of the country is situated in this city. The tidal deposits are represented by the alteration of sand, grayish silty sand and sticky clay. Most of the tidal sediments are underlain by the fine, medium-grained yellowish-brown silty sand and sands of Dupitila formation [2]. That tidal deposit eventually makes a soft upper layer of current formation except the central location, which has small hillocks. The center core of the city reaches almost to its yield point to accommodate inhabitants and industrial developments [3]. Despite the soft geology of the coastline of Chattogram city, the government has put many development projects along the coastline. For example, the country's first underwater tunnel is aligned along this coastline aiming to develop the eastern bank of the river Karnaphuli. However, the soft fine-grained soils at the upper formation need deep pile foundation for most of the structures. Even the low-rise structures have to be rested on deep foundation, which increase the cost and eventually retard the expansion of the economy.

Identifying the problems, an engineering solution is necessary at earliest time. To the date, improvement of soft soils with effective techniques is a conventional approach for the mentioned problem. The most typical approach is to mix binders with the existing soft soils to increase the load carrying capacity [4–7]. The physiochemical characteristics of stabilizer plays an important role in soil stabilization. The most conventional soil stabilizers are lime, Portland cement, fly ash, bottom ash, blast furnace slag, rice husk ash etc. However, the adverse environmental effect of cement discourage engineers to use it in ground improvement [7, 8]. Rather, eco-friendly and low-cost available materials are much beneficial for the improvement works. Fly ash is abundant in coal based power plant, mostly dumped in open space causes hazards for nature [9]. Fly ash represents pozzolanic behavior in presence of water that release calcium oxides. The time-dependent cementation process (pozzolanic reaction) results the formation of cemented compounds characterized by their high shear strength and low volume change [10–14]. Due to these pozzolanic characteristics, the micropores of soil matrix reduced which reflected as strength and plasticity characteristics improvement of soft soil [15–17]. In Bangladesh, plenty of fly ash produces every year from the coal-based power plant and utilizing this waste materials in ground improvement may be beneficial from both engineering and economic point of view.

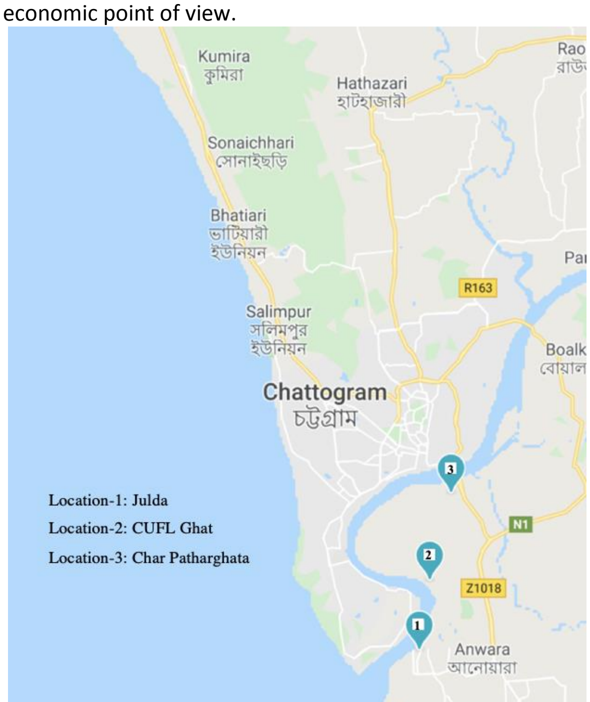

Figure 1 Study area

Till date, the quantitative discussion on the strength development of fly ash treated coastal soils of Bangladesh has rarely been available.

Therefore, this research works investigates the strength development of fly ash treated coastal soils collected from southern coastal zone of Bangladesh. Specifically, the improvement of unconfined compressive strength, liquid limit, plastic limit and compaction characteristics of the stabilized coastal soils are discussed in the subsequent sections and finally, the optimum dosage of fly ash is determined.

2.0 METHODOLOGY

2.1 Materials Used

The potential for future expansion of industrialization was considered as prime criteria to select location for soil sampling. Soft Clayey soil samples were collected from three selected locations at eastern bank of Karnaphuli River. Figure 1 shows the map of study area representing the specific position sampling location. These samples are designated as Location-1 (Julda), Location-2 (CUFL Ghat), and Location-3 (Char Patharghata) in proceeding sections.

The distribution of particle sizes (ASTM D 7928) for soils at all locations and gradation of fly ash is shown in Figure 2. Further tests were conducted (shown in Table 1) for engineering classification of those soil samples. All the soil samples were classified as clay (CL) according to unified soil classification system (ASTM D 2487). The liquidity index of all soil samples was found above 0.5, which indicated that the soils were soft in natural condition, so the coastal soils collected from southern zone of BangladeshF can be designated as soft clayey soil.

Class F fly ash was used in present study to stabilize coastal soft soils collected from above mentioned locations. The oxide composition of fly ash was found by X-ray fluoresce (XRF) analysis as given in Table 2. From oxide component, it was observed that the major constituents of fly ash were silica and alumina. The silica content was found approximately 62% and alumina content as 22%, these silica and alumina actively participated in pozzolanic reaction. The physical properties of fly ash are shown in Table 1.

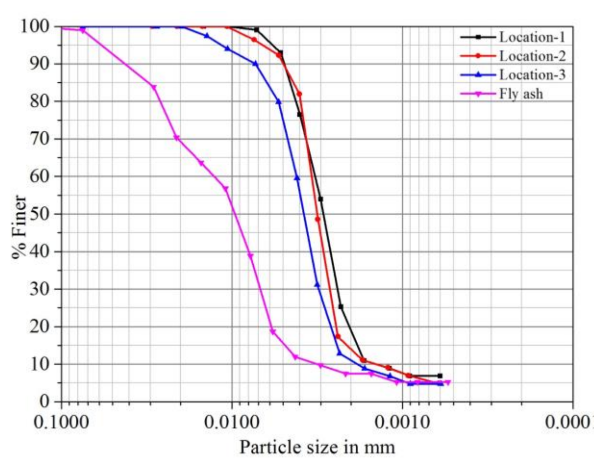

Figure 2 Particle size distribution of soils and fly ash

Table 1 Physical Properties of materials

Properties	Fly ash	Soil Sample		
		Location-1	Location-2	Location-3
Specific gravity	2.22	2.72	2.70	2.70
Liquid limit (%)	---	*41.0*	*43.2*	*42.4*
Plastic limit (%)	---	*21.0*	*22.2*	*23.1*
Plasticity Index (%)	---	*20.0*	*21.0*	*19.3*
Natural moisture content (%)	*0.23*	*33.3*	*33.8*	*33.2*
Liquidity index	---	*0.62*	*0.55*	*0.52*

Table 2 Oxide compositions of Fly ash

Oxide	SiO_2	Fe_2O_3	Al_2O_3	Na_2O	MgO	CaO	TiO_2	SO_3	P_2O_5	K_2O
% present	62.1	6.6	22.4	0.2	1.0	1.5	2.7	0.2	1.0	2.3

2.2 Test Program

The collected soils were replaced by the weight of fly ash to check its effect on strength enhancement of parent soils. The background study suggested to replace the soils from 0% to 30% by weight and used in the current research. A total of six combinations with 5% increment of fly ash up to 30% was experimentally investigated. Firstly, all the collected soil samples were dried, pulverized and stored separately for further tests. At an early stage of this research, 18 Proctor tests were conducted on different soil-fly ash mix with different percentage of fly ash to establish moisture density relationship of individual mixes. The optimum moisture contents (OMCs) obtained from this stage were used to prepare re-molded cylindrical samples for unconfined compression (UCS) testing at three different curing ages of 0, 7 and 28 days. After the final curing period, the index properties of each sample, that is, its liquid limit (LL) and plastic index (PI), were determined experimentally. All these tests were performed maintaining corresponding standard procedure as described in ASTM (D 698, D 2166, D 4318)

3.0 RESULTS AND DISCUSSION

3.1 Discussion on unconfined compressive strength (UCS)

The ultimate goal of any ground improvement application is to increase the load-bearing capacity of a soil. Of various parameters, as the UCS is implicitly related to the undrained shear strength of a soil and is a rational parameter, a series of unconfined compressive strength test were conducted on fly ash stabilized coastal soil at 1mm/min strain rate until the specimen failed. At least three samples were tested and average value was represented as UCS of that mix. The compaction parameters (MDD and OMC) of corresponding soil-fly ash mixes were maintained to prepare re-molded soil samples with varying percentages of fly ash (0 to 30%) which were cured at room temperature (30±5°C) and ambient pressure in an airtight condition to retain their moisture. The UCS values were determined at 0, 7 and 28 days of curing to understand the strength improvement of the treated soils. Figure 3 represents the plots of UCS values of treated soil with fly ash content at different curing state for three distinct location. In natural state, samples were in so soft condition that the liquidity index was above 0.5 for all location and the UCS values were very low. To compare the UCS values of untreated soil with treated condition, samples were reformed maintaining the standard compaction effort and optimum water content of corresponding parent soil and tested thereafter. The UCS value of compacted untreated soil was found as 140 kPa, 160 kPa and 161kPa respectively for location-1, location-2 and location-3. It was seen that the UCS value of untreated soils are close enough regardless to location. At the initial condition (t = 0), the effect of variations in the fly ash content were negligible as variations in the UCS were very small at that stage. However, the UCS of the coastal soils increased gradually with curing time and higher fly ash contents. Significant improvement of UCS were observed after 7 days curing of fly ash treated coastal soils. With the increment of fly ash dosage, the UCS values showed increasing trend up to 20% fly ash content and decreases thereafter. The maximum strength improvement was noted for 20% fly ash treatment, which was 275kPa, 295kPa and 270 kPa respectively for location-1, location-2 and location-3 at final curing age.

Referring to Figure 3 (a), after completion of 7 days curing of 20% fly ash-soil mixes the strength improvement was found approximately 1.9 times compared to its untreated condition which turns to 2.0 times after 28 days and other location of coastal soils follows similar trend. Studies of a lime-embedded rice husk ash (RHA) treatment also indicated that the UCS of those treated soils increased by approximately 1.7 times [18]. This phenomenon revealed that the maximum pozzolanic reaction occurred during early age of curing and became slow down there after. From previous studies it was also noted that, cementation and pozzolanic reactions happen in a soil matrix for stabilization with additives of up to 20% by weight of soil [16, 19, 20]. The pozzolanic activity of fine particles of fly ash enhance the cohesion characteristics of clay-fly ash matrix. However, for a higher percentage, the process mentioned above reaches saturation level and an excess amount of additive remains unbonded which reduces the overall compressive strength of the soil [21]. After final curing, the peak compressive strengths were found to vary from 1.86 to 2.0 Mpa, which is far above the requirements (0.7 Mpa) for subgrade course construction [22]. Therefore, fly ash stabilization have promising protentional for strength development of soils in coastal region.

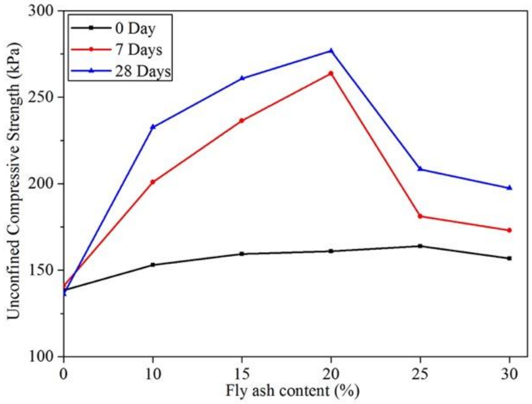

Figure 3 (a) UCS of location 1

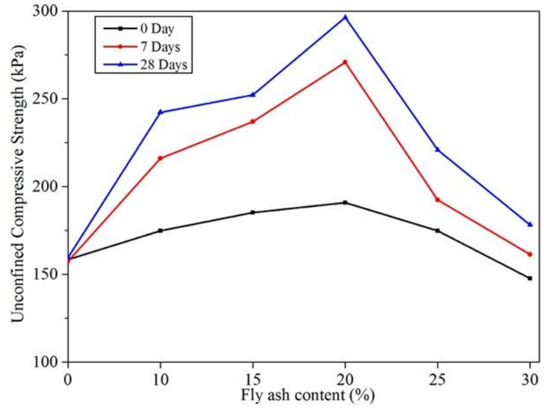

Figure 3 (b) UCS of location 2

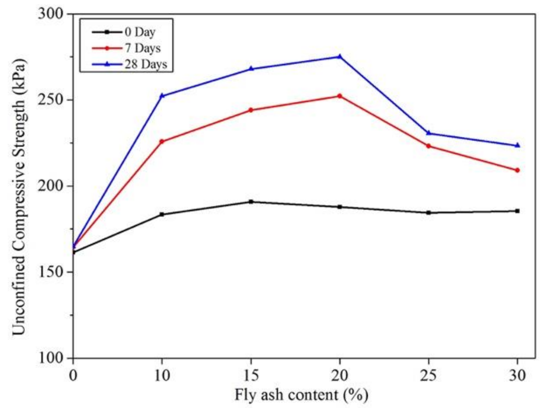

Figure 3 (c) UCS of location 3

Figure 3 Unconfined compressive strengths of fly ash-treated soils

3.2 *Discussion on index properties*

To observe the effect of fly ash treatment on Atterberg limits of coastal soils, the liquid limit, plastic limit and plasticity index of all soil-fly ash mixes were determined after the completion of final curing age. The soil-fly mixes were dried, pulverized as per standard requirements (ASTM D4318) and the Atterberg limits were tested thereafter. The liquid limits of raw coastal soils were found within 41.0% to 43.0% and the plasticity index within 19.5 % to 21.0%. Figures 4 and Figure 5 present variations in the LL and PI of three coastal soil specimens with fly ash contents, respectively, with significant reductions noted for 30% fly ash treatment although their trends showed abrupt variation for 10 % to 25% content. as shown in Figure 4 and Figure 5. The improvement in a soil's plasticity characteristics is influenced by cation exchange and flocculation process immediately following the application of stabilizing agent. The negatively charged clay particles are balanced by the cations present in the double layer and the thickness of the diffused double layer depends greatly on the repulsive forces acting between the particles [23]. However, the plasticity index of coastal soil was reduced up to 4.0% and the liquid limit reduced up to 8% as a result of fly ash treatment.

3.3 Discussion on compaction characteristics

The compaction parameters of individual fly ash-soil mixes were determined in laboratory. As shown in Figure 6, the maximum dry unit weight of original costal soils was observed to vary from 16.2 kN/m^3 to 16.6 kN/m^3. The maximum dry unit weight of fly ash stabilized soil decreased continuously with the increment of fly ash content. The least dry unit weight was found approximately 14.5 kN/m^3 for 30% fly ash treated coastal soils. Referring to the physical properties of materials (Table 2), the specific gravity of fly ash is too lower as compared to soil samples, which results continuous decreasing trend of fly ash added soil[24].

On the other hand, variation of optimum moisture content (OMC) presents increasing trend with the increment of fly ash content. Figure 7 shows the plot of optimum moisture contents, were the OMC of original costal soils were found to vary within 18.5% to 20%. Due to fly ash treatment OMC increased approximately 21.0% to 23.0%. The pozzolanic reaction in fly ash-soil matrix occurs in presence of water that may lead to absorption of additional water [24, 25]. However, from close observation of compaction data the variation of optimum moisture content and maximum dry unit weight were within a small range for fly ash-soil mixes compared to the untreated coastal soils.

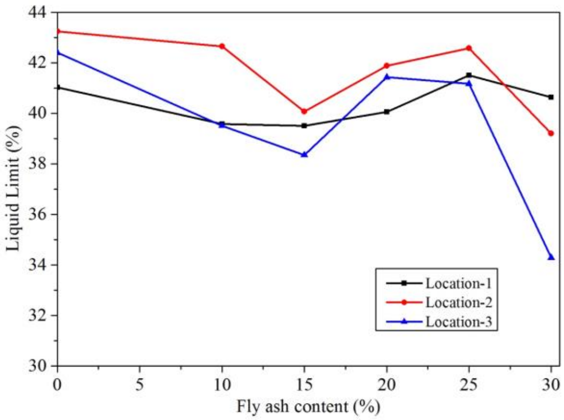

Figure 4 Variations of liquid limit with fly ash content

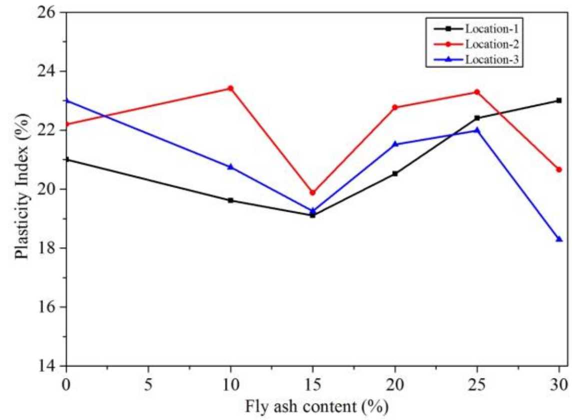

Figure 5 Variations of plasticity index with fly ash content

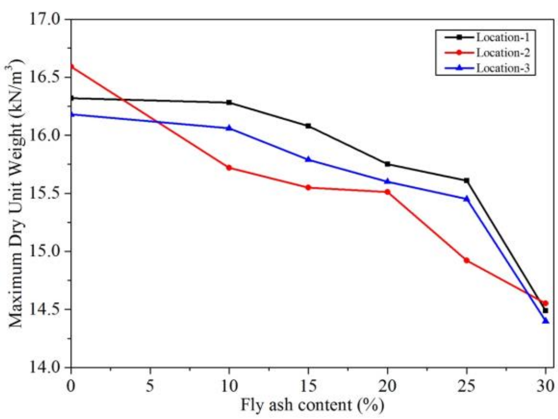

Figure 6 Variations in maximum dry unit weight with fly ash content

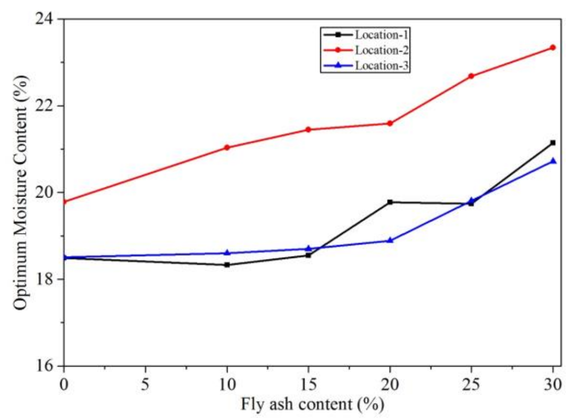

Figure 7 Variations in OMC with fly ash content

4.0 CONCLUSIONS

Three locations along the eastern bank of the river Karnaphuli were chosen in the current research to evaluate the strength development of coastal soils of Bangladesh. The eco-friendly and available waste product, namely fly natural soils replaced ash (Class F). The re-moulded samples were prepared based on the optimum moisture content and three curing days, 0, 7, and 28 days were investigated. The following conclusions can be drawn based on the experimental results obtained from fly ash stabilization of coastal soil:

1. Fly ash treatment significantly increased the unconfined compressive strength of coastal soil. The strength improvement occurs rapidly within first 7 days of curing and became slow thereafter.
2. After 28 days curing period UCS increased up to 2.0 times compared to untreated coastal soil and the maximum strength improvement was noted for 20% fly ash content, which also satisfy the requirements for subgrade.
3. The experimental results showed significant improvements in plasticity characteristics, plasticity index reduced approximately 4% due to pozzolanic activity of fly ash.
4. The optimum moisture content of fly ash treated coastal soil increased slightly with the increment of fly ash percentage meanwhile due to low particle density of fly ash, the maximum dry unit weight displayed reverse variation with increasing fly ash percentage.
5. In summary, this study confirmed the suitability of fly ash stabilization for significant improvement of coastal soil regardless its location and 20% fly ash content can be taken as optimum.

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