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EFFECTIVENESS OF GRANULATED BLAST FURNACE SLAG OVER SAND AS OVERLAY FOR THE STABILIZATION OF SOFT CLAY

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Abstract- The effectiveness of granulated blast furnace slag (GBS) and natural sand as overlay for the stabilization of the soft clay bed has been studied by small-scale model tests in the laboratory. The test beds were subjected to transverse loading by a rigid strip footing. Footing load and footing settlement on the fill surface have been measured during the tests. The influence of GBS and natural sand layer on the overall performance of the system has been systematically studied through a series of tests. The test results indicate that with the provision of GBS and natural sand in soft clay a substantial improvement can be obtained in terms of increase in the bearing capacity ratio and reduction in the footing settlement. 89% and 114 % increase in the bearing capacity of the strip footing can be obtained by laying the GBS and natural sand layer respectively above the soft clay. As compared to GBS bed only 14 % increase in bearing capacity observed of the sand bed overlay on soft clay.

Keywords*- Soft clay; granulated blast furnace slag; natural sand; strip footing; Bearing Capacity ratio.*

I. INTRODUCTION

Rapid growth of civilization has forced the engineer's to use the site which is not ideal as per the geotechnical engineering. In these sites, the poor soil condition often create problems to geotechnical engineers associated with the foundation design and construction works of civil engineering structures such as buildings, highways, railways, airfields, embankments, dams, storage tanks, car parks and temporary working platform. Construction of civil engineering structures in such poor sites creates problem due to excessive settlement and low bearing capacity of the soil at foundation level. It is really a challenging task for the engineers to improve such site conditions.

Various ground improvement techniques can be utilized depending upon the type and condition of soil to improve the strength of the soil, to reduce the settlement and to minimize the construction cost & construction time. In recent past, the domain of ground improvement have been flourished very fast and quite a number of improvement techniques have been developed with due consideration of effectiveness and economy i.e. classical soil replacement, pre-compression by preloading or by dewatering along with or without the use of sand drains, compaction by hammers, vibroflotation, dynamic consolidation, compaction grouting, compaction with water jets, thermal stabilization, ground freezing, chemical stabilization, use of stone/granular pile/column, lime/cement column, electrokinetic stabilization and soil reinforcement. The selection of specific techniques depends upon the evaluation of various factors related to the specific projects and site condition, availability of required material in sufficient amount, environmental impact, and energy consumption. The bearing capacity of footings on soft clay can be improved considerably by placing a layer of compact granular fill of limited thickness with geotextile or geogrid reinforcement at sand clay interface [15, 16, 17 and 21].

Engineered granular fills reinforced with single or multi layers of geosynthetic are placed on the soft soil in many practical situations to improve the soil condition [18 and 19]. This geosynthetic-reinforced granular fill soft soil system is now being used frequently as foundation for unpaved roads, shallow foundation, low embankment, storage tanks, heavy industrial equipment, car parks etc. In many times, expensive and time consuming conventional designs and several environmental constraints such as lack of non-availability of good quality granular materials in required quantities led to the adoption of some other suitable material and adoption of modern techniques of ground improvement which is viable solution, both technically and economically.

During the past 45 years or so, several attempts have been made to evaluate the ultimate and allowable bearing capacities of shallow square and strip foundations supported by sand reinforced with various materials such as metal strips [6, 13 and 29] metal bars [6], rope fibres [14] and geotextiles [37].

In most of the previous studies Fine grained soil (natural sand) is used as a granular layer [4, 6, 10, 13, 14, 20, 24, 26, 27, 28, 29, 32-36, 37, 38, 39, 40 and 41,]. In the present scenario, there is a limited availability of fine grained soil (natural sand) in most of the construction sites. It is also not feasible to use the sand as a granular fill due to its increasing price day by day. Sources of natural sand are becoming scarcer day by day as excavation of sand from river basin is limited due to environmental concern. Now day's government laws are stringent in respect of licensing and very few licenses are issued to the auction bidders for dredging out the good quality sand along the certain locations of the river. This also causes the non availability along with inordinate delay of natural sand supply in abundance. Due to meandering of river course and due to continuous dredging of sand in the existing river bed nearer to location has been practically replaced by a location which is far away from the actual sites. The new location away from present site increases the cost of natural sand due to higher transportation cost. All metro and mega cities in India are facing acute shortage of good quality natural sand.

With uncertainty in supply of sand, price fluctuation in sand is very high from source to source. Due to this price fluctuation, it becomes very difficult for engineers to use the sand as a granular fill. Hence, it is required to choose some other suitable materials that can be used in place of the sand as a granular fill. Various researchers have used some other materials as fill materials i.e. crushed aggregate [22, 30, and 31], fly ash [1 and 2], crushed lime stone [40].

In the present study, blast furnace slag in the granulated form has been chosen to use as a granular fill in place of natural sand. Granulated blast furnace slag is a byproduct of the iron/steel industries. It is produced by quenching the slag with water in the manufacturing process of iron/steel.

Blast-furnace slag is defined by the American Society for Testing and Materials (ASTM) as "the non-metallic product consisting essentially of silicates and alumino-silicates of calcium and other bases that is "developed in a molten condition simultaneously with iron in a blast furnace."

The GBS is basically inorganic in nature. It contains mainly inorganic constituents such as silica (30–35%), calcium oxide (28–35%), magnesium oxide (1–6%), and Al2O3/Fe2O3 18–25%.

II. EXPERIMENTAL INVESTIGATION

a. Material collection and Properties

1) Soil

The soil has been collected from Tatibandh-Atari rural road of Raipur district, Chhattisgarh, India for the study. The soil has 70% fines fraction smaller than 75 micron sieve size. Fig. 1 depicts the particle size distribution of the soil. The liquid limit, plastic limit and specific gravity of the soil were found to be 44%, 16% and 2.56, respectively. As per the unified soil classification system (USCS) the soil has been classified as clay with low plasticity (CL). The maximum dry density and optimum moisture content of soil has been evaluated by modified compaction test as 18.7 kN/m^3 and 10.5 % respectively. Soil properties are presented in Table I.

a) Soft soil state

In this study soil has been used in the soft state. To evaluate the soft state of the clay, unconfined compressive strength (UCS) tests were carried out on clay samples at different water content. Variation of UCS of the clay with water content has been presented in Fig. 2. Water content of 30% has been chosen to get the soft state of the clay. Water content of the clay was maintained at 30% throughout the series of tests and the corresponding UCS value of the clay (20 kPa) has been determined from Fig. 2. The bulk unit weight of the clay at 30% water content was determined to maintain identical unit weight in all the tests.

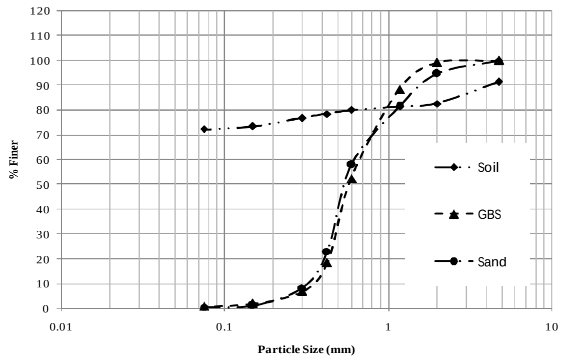

Fig. 1 Gradation Curve for soil, GBS and sand

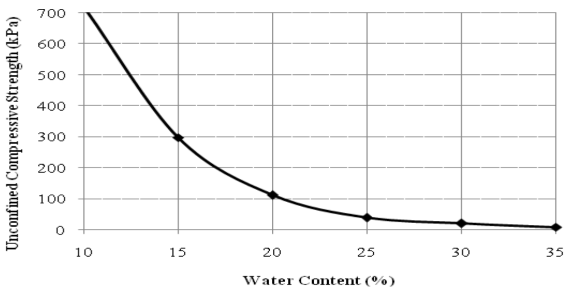

Fig. 2 Variation of unconfined compressive strength of clay with water content

TABLE I. PROPERTIES OF SOIL

Parameters	Quantity
Specific gravity	2.57
Liquid limit (%)	43.8
Plastic limit (%)	15.9
Plasticity index	27.9
Optimum moisture content (%)	10.5
Maximum dry unit weight (kN/m^3)	18.7
Bulk unit weight at 30 % water content (w.c.) (kN/m^3)	17.98
Dry unit weight at 30 % w.c. (kN/m^3)	13.51
Unconfined compressive strength at 30 % w. c. (kN/m^2)	20.25
Cohesion at 30 % w.c. (kN/m^2)	14.7
Angle of Internal Friction at 30 % w.c.	11.3°
Classification based on Plasticity Characteristics (USCS)	CL

2) Granulated Blast Furnace Slag

Blast furnace slag has been collected in the granulated form from the blast furnace of the Bhilai Steel Plant, Chhattisgarh, India. The dry granulated blast furnace slag (GBS) has been used in this study. Particle size distribution is of dry slag is shown in Fig 1. It has a coefficient of uniformity (C_u) of 1.89, coefficient of curvature (C_c) of 0.94, effective particle size (D_{10}) of 0.36 mm, and specific gravity of 2.57. The slag is classified as poorly graded sand with letter symbol SP according to the USCS. In the model test the average unit weight and relative density (ID) of sand was kept at 14.07 kN/m^3 and 85%, respectively.

3) Natural sand

The dry natural sand passing 4.75 mm sieve has been used in this study. Particle size distribution is of dry sand is presented in Fig 1. It has a coefficient of uniformity (C_u) of 1.94, coefficient of curvature (C_c) of 1.07, effective particle size (D_{10}) of 0.32 mm, and specific gravity of 2.63. The sand is classified as poorly graded sand with letter symbol SP according to the USCS. In the model test the average unit weight and relative density (ID) of sand was kept at 16.45 kN/m^3 and 85%, respectively.

TABLE II. PROPERTIES OF GBS AND SAND

Parameters	GBS	Sand
Specific gravity	2.57	2.63
Maximum dry unit weight (kN/m^3)	14.53	16.86
Minimum dry unit weight (kN/m^3)	11.89	14.40
Average compacted bulk unit weight (kN/m^3)	14.07	16.45
Relative density of compaction (%)	85.0	85.0
Effective particle size (D_{10}) (mm)	0.36	0.32
Uniformity coefficient (C_u)	1.89	1.94
Coefficient of curvature (C_c)	0.94	1.07
Classification as per USCS	SP	SP

b. Experimental Setup

The model tests were conducted in a test bed-cum-loading frame assembly in the laboratory. The soil beds were prepared in a test tank with inside dimensions of 1829 mm length, 305 mm width and 914 mm height. The model footing used was made of a rigid steel plate and measured 76.2 mm wide and 25.4 mm thickness. The base of the model footing was made rough by cementing a thin layer of sand to it with epoxy glue. Mechanical jack-frame arrangement was used to apply load on the soil stratum through the footing plate (as shown in Fig. 3). Two linear variable displacement transducers (LVDTs) have been placed on the footing at equal distance from both side of the loading plunger for measuring the settlement during the application of load. Hammer of weight 11.5 kg and base diameter 14.0 cm have been used to compact the clay. Slag and sand have been compacted through raining technique. In all the tests the depth of clay bed was maintained at 360 mm. The first test was carried out on clay bed without any improvement techniques and the load-settlement behaviour was investigated. Thereafter, other tests were carried out on soft clay improved by laying the granulated blast furnace slag and sand bed above the clay bed. Summary of the tests conducted has been presented in Table III. Fig. 3 shows the photographic view of of the experimental setup.

TABLE III. SUMMARY OF THE EXPERIMENTAL PROGRAMME

Case	Description	Thickness of Layer	H/B ratio
A	Clay bed	360 mm	-
B	Slag overlay on clay bed	152.4 mm	2.0
C	Sand overlay on clay bed	152.4 mm	2.0

a.

b. **Preparation of clay bed**

In all the tests, identical technique was adopted to prepare the clay bed. The clayey soil was first pulverised with wooden mallet and passed through 4.75 mm sieve. To maintain similar properties throughout the tests, clay bed was prepared at 30% water content in all the cases. The bulk unit weight at 30% water content was found as 17.98 kN/m^3. The required weight of clay in each layer was calculated based on bulk unit weight of 17.98 kN/m^3. Before filling the tank with clay, polythene sheet was laid on internal walls of the tank to avoid any friction between clay and walls of tank and to prevent loss of water. To prepare the test bed, the moist soil was placed in the test box and compacted in 25-mm thick layers till the desired height was reached. For each layer the required amount of soil to produce a desired bulk density was weighted out and placed in the test box. The soil was then gently levelled out and compacted to proper depth by placing a steel sheet on the surface and hitting the board with a drop hammer, using depth marking on the sides of the box as guide. Through a series of trials the amount of soil, height of fall and number of blows of the drop hammer required to achieve the desired density for each lift were determined a priori. By carefully controlling the water content and compaction, a fairly uniform test condition was achieved throughout the test programme. Each layer was compacted uniformly so as to achieve a uniform density in all the test beds. In order to verify the uniformity of the test bed undisturbed samples were collected from different locations in the test bed to determine the in situ unit weight, moisture content and unconfined compressive strength of the clay soil. The values of these parameters of the compacted soil at different locations of the test tank were found to be almost the same. These values are also matching with the 30 % of water content values (Table 1). Table IV presents the average properties of the compacted moist clay during the tests.

c. Preparation of GBS and Sand beds

The tank was filled with GBS over clay bed using raining technique. The height of fall to achieve the desired relative density was determined a priori by performing a series of trials with different heights of fall. The weight of GBS required to form a certain thickness of the bed was determined with the known unit weight of GBS (at 85% relative density). For different thicknesses of GBS, the required weight of GBS was calculated and preparation of bed was carried out in layers. The relative densities achieved were monitored by collecting samples in small aluminium cans of known volume placed at different locations in the test tank. The difference in densities measured at various locations was found to be less than 1%.

The preparation of sand bed over clay bed has been done in the same manner as GBS bed.

Fig. 3 Photogrphic view of the model test setup

TABLE IV. AVERAGE PARAMETERS OF CLAY BEDS AND % VARIATION FROM THE PARAMETERS OF 30 % WATER CONTENT

Average parameters of the clay beds	Quantity	% Variation
Moisture Content (%)	29.3	2.33
Bulk unit weight (kN/m^3)	17.33	3.61
Dry unit weight (kN/m^3)	13.14	2.73
Unconfined compressive strength (kN/m^2)	22.87	2.79

a. Test Procedure

Upon filling the tank up to the desired height, the fill surface was levelled and the footing was placed on a predetermined alignment such that the loads from the loading jack would be transferred concentrically to the footing. A recess was made into the footing plate at its centre to accommodate a ball bearing through which vertical loads were applied to the footing. The load transferred to the footing was measured through a proving ring placed between the ball bearing and the loading jack. Short-term loading test was conducted in all the cases.

Load was applied in equal increments and each increment of the load was maintained at least 1 hour and / or until negligible change in the settlement (rate of settlement less than 0.02mm/min) was observed. Footing settlements were measured at time interval of 1, 2, 4, 6, 9, 16, 25, 60 min and every 60 mins interval through two LVDTs having least count 0.01mm placed on either side of the centre line of the footing. Loading was applied until the total settlement of the footing attained was at least 20% of footing width i.e. 15.2 mm.

III. RESULTS AND DISCUSSION

b.

c. Load-settlement charactristics

The term bearing capacity ratio (BCR) is commonly used to express and compare the test data of the stabilized and clay soils. The following well-established definition [Binquet and Lee 1975a] is used for BCR:

$$BCR = q_R / q_0 \qquad (1)$$

Where q_R and q_0 are the bearing capacity for the stabilized (granular-fill layer placed on the natural clay deposit) and natural clay soils, respectively. The granular-fill layer thickness H and the settlement of footing plate are normalized by the width of the footing plate B [Laman and Yildiz 2003]. The bearing capacity was defined as the tangent intersection between the initial, stiff, straighter portion of the loading-pressure-settlement curve and the following steeper, straight portion of the curve (Admas and Collin 1997). All the test and numerical results were interpreted using this approach.

Fig 4 shows the load-settlement characteristics of the unim-proved clay bed, clay bed improved by overlaying of 152.4 mm thick (H/B = 2) GBS layer and sand layer. Parametic study has been done priori to evaluate the effective thickness bed of GBS bed, which gives maximum bearing capacity. In brevity, in this paper only H/B = 2 case has been discussed. Ultimate bearing capacity has been found with two tangent method (Admas and Collin 1997) in all the cases and bearing capacity ratio has been found using equation (1) and tabulated in Table V.

From Fig. 4, it has been observed that the placement of GBS and sand bed over soft clay increases the load-carrying capacity of the soft soil. As compared to unimproved clay bed, an improvement of 89% and 115% in load-carrying capacity has been observed when the clay bed is improved with overlaying of GBS and sand bed respectively. As compared to GBS overlay on clay bed, 14% improvement in bearing-carrying capacity has been observed when sand bed is placed over soft clay. For a ultimate loading intensity of clay bed 1.35 kN, as compared to unimproved soil, the settlement has been reduced by 69% and 85% when the soil is improved by overlaying GBS and sand respectively. As compared to GBS bed, sand bed reduced the settlement by 50% at the same loading intensity.

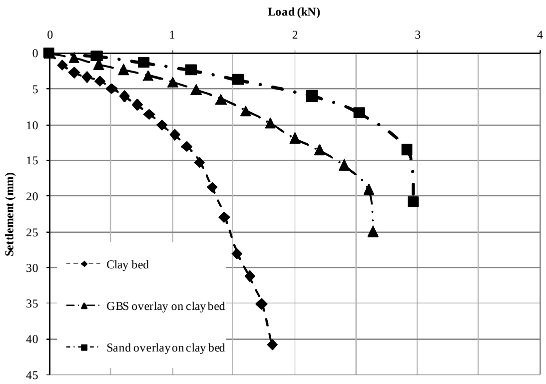

Fig. 4. Load-settlement characteristics of clay bed, GBS overlay and sand overlay on clay bed

TABLE V. SUMMARY OF THE EXPERIMENTAL RESULTS

Case	Description	Ultimate bearing Capacity	BCR
A	Clay bed	58.12 kN/m^2	1
B	GBS overlay on clay bed	109.79 kN/m^2	1.89
C	Sand overlay on clay bed	124.86 kN/m^2	2.15

IV. CONCLUSIONS

Based on the experimental results the following conclusions can be drawn:

1. The presence of granular bed i.e. GBS and sand on soft clay bed improves the load- carrying capacity and decreases the settlement of the soft clay bed.
2. As compared to unimproved soft clay, 89% and 115% improvement in load-carrying capacity have been observed by overlaying the GBS and sand bed respectively on soft clay bed.
3. Settlement has been reduced by 69% and 85% when the soil is improved by overlaying GBS and sand respectively at ultimate loading intensity of clay bed.
4. There is a marginal improvement in the bearing capacity of sand bed i.e. 14% as compared to GBS bed overlay on soft clay.
5. From the study it can be concluded that GBS is good alternative of sand for improving the soft soil at the places where it is available.

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