A Study On The Effect Of Phosphogypsum On The Properties Of Subgrade Soil Mixed With Fly Ash

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Abstract. The present study is an attempt to enlighten the direction of utilization of industrial wastage materials such as Phosphogypsum and Fly Ash, by mixing them with subgrade soil to improve the load bearing capacity of silty - sandy soil. With the increasing urbanization, industrial growth and installation of various plants generate huge volume of wastes. The soil subgrade plays a pivoted role in the load carrying capacity in both flexible and rigid pavement. For the laboratory investigation the silty - sandy soil samples have been collected from Rabindranath Tagore Hostel inside the N.I.T. Agartala campus, Tripura, India. Each soil samples have been collected from the depth of 3 meters below the natural ground surface. The Fly Ash sample has been collected from Kolaghat Thermal Power Plant, West Bengal, India. Different tests were performed as per the requirements of Indian Standard Codes to know the Compaction properties, Unconfined Compressive Strength and C.B.R. values of the original soils and the soils treated with Fly Ash and Phosphogypsum. It is observed from the test results that, for soil blended with Fly Ash and phosphogypsum, the values of C.B.R. and Unconfined Compressive Strengths are significantly higher compared to that of untreated natural soil and soil mixed with phosphogypsum. From the tests it can also be concluded that soil content with 30% Fly Ash and 6% Phosphogypsum can be used as a subgrade material. Also the thickness of the subgrade layer can be reduced as the subgrade is good. So the construction cost of the pavement may be reduced.

Keywords: Subgrade Soil, Fly Ash, California Bearing Ratio (C.B.R.), Phosphogypsum (PG).

1 Introduction

Soil Stabilization or Improvement, in a broad sense, include the various techniques employed for modifying the properties of soil to improve its engineering performances. It is being used for many of construction and engineering works where the main objective is to increase the strength or stability of soil and to reduce the construction cost by making best use of the locally available materials. In the present day world, the Engineers usually face a series of potential soil problems due to the bad soil layers. In such cases the improvement of the strength behavior of the soil stabilized with various materials may be an excellent solution. For the improvement of the strength behavior of soil, the several materials may be used as an additive, such as cement, lime and also some industrial waste products for example, fly ash, phosphogypsum etc. The use of those industrial waste products as a material to stabilizing the soil may help economically and environmentally to a great extent.

Several studies have been carried out by number of Researchers [1], [5] - [8] on the improvement of engineering properties of soil by adding fly ash, phosphogypsum, etc.

2 Objective of the Present Study

The strength parameter of soil is one of the important geotechnical propertied used in the various field. The present study is based on the strength behavior of soil mixed with fly ash to understand the effect of fly ash on different parameters of the soil. Subsequently it has also been studied the effect of phosphogypsum on the optimum proportion of soil-fly ash mixture. The compaction characteristics, strength parameters and the deformation of the soil under different loading are studied by mixing soil-fly ash- phosphogypsum samples.

3 Materials and Methodology

3.1 Materials

The soil samples have been collected from newly constructed Rabindranath Tagore Hostel inside the N.I.T. Agartala campus, Tripura, India. The soil samples are extracted 3 meters below the natural ground surface. After collection the soils, these are oven dried & pulverized. Fly ash was collected from Kolaghat Thermal Power Plant, West Bengal, India. Raw Phosphogypsum is collected from the stockpile of a fertilizer and chemical production unit, Odisha, India. The different physical and engineering properties of the soil, fly ash and phosphogypsum samples have been tabulated in Tables 1, 2 and 3 respectively.

Table 1. Physical and Engineering Properties of the Silty- Sandy Soil Sample.

Properties	Experimental Results
Specific gravity	2.60
Sand (4.75-0.075mm) (%)	53.28
Silt (0.075-0.002mm) (%)	35.32
Clay (< 0.002mm) (%)	11.40
Soil group symbol	*SW - SM*
Maximum dry density (gm/cc) [Heavy compaction]	2.00
Optimum moisture content (%)[Heavy compaction]	11.80

Table 2. Physical and Engineering Properties of the Fly Ash Sample.

Properties	Experimental Results
Specific gravity	1.98
Sand (4.75-0.075mm) (%)	16.25
Silt(0.075-0.002mm) (%)	83.65
Clay(<0.002mm) (%)	6.10
Soil group symbol	*SM*
Plasticity Index (%)	Non - plastic
Maximum dry density (gm/cc) [Light compaction]	2.00
Optimum moisture content (%) [Light compaction]	11.80

Table 3. Chemical compositions in Phosphogypsum Sample.

Properties	P_2O_5	Na_2O	K_2O	Al_2O_3	Fe_2O_3	F	SO_3	Organic Compound	*pH* value
Compositions (%)	0.820	0.051	0.009	0.170	0.139	0.012	45.08	2.36	3.66

Phosphogypsum is a gray coloured, damp, fine grained powder, silty material. The avarage specific gravity of phosphogypsum is 2.45.

3.2 Methodology

The strength behaviour of the soils have been studied by mixing the fly ash and phosphogypsum in different proportions with the soil. The fly ash mix proportions in the present study are 10%, 20%, 30% and 40% by dry weight of the soil and phosphogypsum samples have been mixed at 3%, 6%, 9% and 12% by dry weight with 30% of fly ash mixed soil samples. The mixed proportions have been summarized Table 4.

Table 4. Different Proportions of Soil, Fly Ash and Phosphogypsum Samples.

Soil Mixtures	Description
Soil (*S*)	Soil sample only
Soil (*S*) - fly ash (FA) mix	Soil mixed with 10% fly ash by dry weight
	Soil mixed with 20% fly ash by dry weight
	Soil mixed with 30% fly ash by dry weight
	Soil mixed with 40% fly ash by dry weight
Soil (*S*) - fly ash (FA) - Phosphogypsum (PG) mix	Soil mixed with 30% fly ash and 3% PG by dry weight
	Soil mixed with 30% fly ash and 6% PG by dry weight
	Soil mixed with 30% fly ash and 9% PG by dry weight
	Soil mixed with 30% fly ash and 12% PG by dry weight

4 Results and Discussions

For evaluating the strength behaviour of soil different tests have been conducted as per [2] - [4].

4.1 Effect on compaction tests of soil, soil-fly ash mixture and soil - fly ash - phosphogypsum mixture

The heavy compaction tests have been conducted to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil, soil - fly ash and soil - fly ash - phosphogypsum samples. The values of MDD and OMC obtained by adding soil and fly ash are summarized in Table 5, from which it is observed that with the increase in fly ash content in soil, the maximum dry density of the soil-fly ash mixture decreases and optimum moisture content increases. It is due to the presence of hollow particle in fly ash, which increases the optimum moisture content. The fly ash has major amount of silt size particles, whereas the soil has large amount of sand particles. As a result, in soil - fly ash mixed samples the amount of sand content decreases with increase in fly ash content and thereby the Maximum dry density decreases.

The heavy compaction tests have also been conducted considering samples with soil + 30% fly ash and 3%, 6%, 9% and 12% of phosphogypsum content respectively. The values of MDD and OMC are summarized in Table 6. It has been observed that, for fly ash content 30% and phosphogypsum content of 6%, the MDD value is maximum and OMC value is minimum.

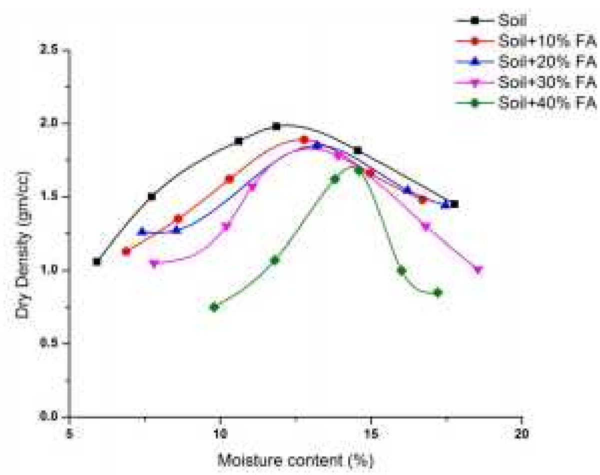

Fig. 1. Variation of dry density with moisture content of soil and soil-fly ash (FA) mixture in the modified compaction test.

Table 5. Variation of maximum dry density (MDD) and optimum moisture content (OMC) with soil and soil - fly ash (FA) mixture by the modified compaction test.

FA (%)	0	10	20	30	40
MDD (gm/cc)	2.00	1.93	1.89	1.83	1.71
OMC (%)	11.8	12.6	13.4	14.0	14.7

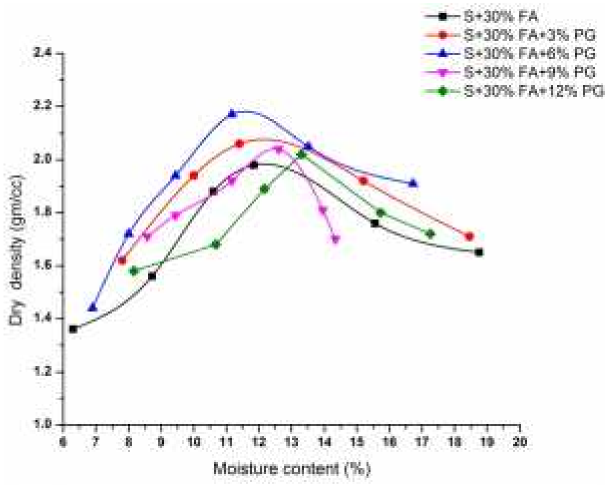

Fig. 2. Variation of dry density with moisture content of soil, soil-fly ash (FA) and soil-fly ash- phosphogypsum (PG) mixture in the modified compaction test.

Table 6. Variation of maximum dry density (MDD) and optimum moisture content (OMC) with soil, soil - fly ash (FA) and soil-fly ash- phosphogypsum (PG) mixture by the modified compaction test.

FA (%)	30	30	30	30	30
PG (%)	0	3	6	9	12
MDD (gm/cc)	2.00	2.10	2.21	2.08	1.96
OMC (%)	11.80	11.40	11.17	12.61	13.31

4.2 Effect on California Bearing Ratio of soil, soil-fly ash mixture and soil - fly ash - phosphogypsum mixture

The California bearing ratio (CBR) test on N.I.T. Agartala campus soil, soil mixed with fly ash and soil- fly ash-Phosphogypsum mixtures have been conducted in laboratory. The results of CBR value of soil-fly ash and soil-fly ash-Phosphogypsum mixture with different proportion of fly ash and phosphogypsum are shown in figures 3 and 4 and also in Tables 7 and 8.

It has been observed from Table 7 that the soil mixed with 30% of fly ash content has maximum CBR value in both the cases (both soaked and un-soaked). It is due to the large sand content in soil as compared to silt and clay, and in case of fly ash, major amount of particles are of silt size. Thus, the voids between sand particles are filled with these silt size particles of fly ash. During the cat-ion exchange process in the soil-fly ash mix, the sodium ions in the soil are replaced by the calcium ions of fly ash thus reduces the settlement and hence increases the CBR value. Both soaked and un-soaked CBR value follows the similar trend, but soaked CBR value is lower as compared to un-socked CBR value.

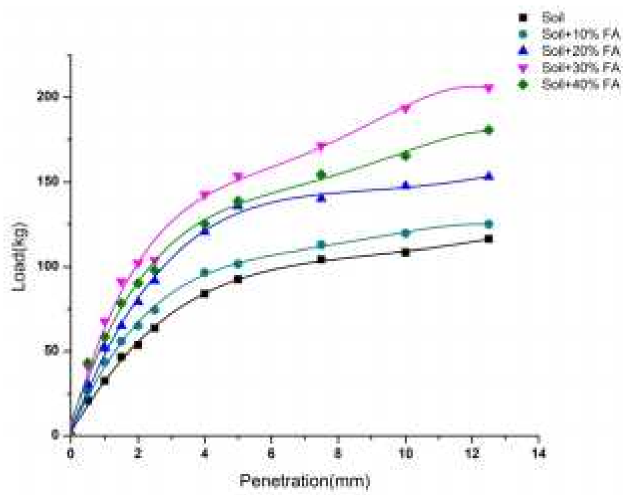

Fig. 3. Load vs. penetration graph for soil-fly ash (FA) mixture in soaked condition to find the CBR values.

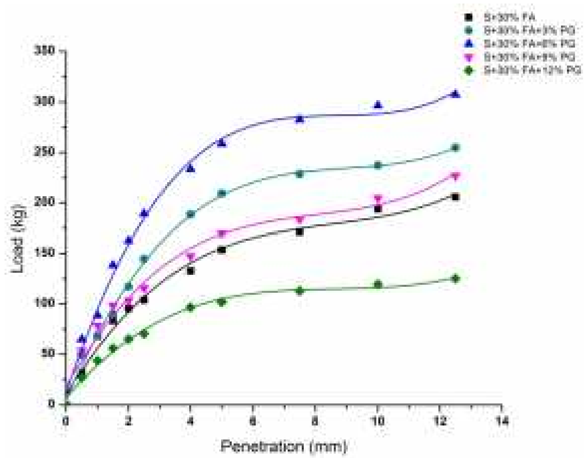

Fig. 4. Load vs. penetration graph for soil-fly ash (FA)- phosphogypsum (PG) mixture in soaked condition to find the CBR values.

Table 7. Variation of California Bearing Ratio (CBR) with soil and soil - fly ash (FA) mixture under soaked and un-soaked conditions.

FA (%)	0	10	20	30	40
Un-Soaked CBR (%)	6.30	7.07	7.97	9.51	9.13
Soaked CBR (%)	4.65	5.43	6.70	7.58	7.09

In case of soil-fly ash-phosphogypsum mixture (Table 8), it is observed that the CBR value increases significantly with increase in PG content up to 6%, after that the CBR value decreases with the increase in PG content. It is observed that the maximum un-soaked and soaked CBR values are 18.78% and 13.83% respectively for the soil mixed with 30% fly ash and 6% PG content. Whereas the un-soaked and soaked CBR percentage for normal soil sample are 6.3% and 4.65% (Table 7). The gain in strength of soil-fly ash-phosphogypsum mix is primarily a result of pozzolanic reaction between fly ash and PG, due to formation of various types of cementing compound.

Table 8. Variation of California Bearing Ratio (CBR) with soil, soil – fly ash (FA) and soil - fly ash (FA) – phosphogypsum (PG) mixture under soaked and un-soaked conditions.

FA (%)	30	30	30	30	30
PG (%)	0	3	6	9	12
Un-Soaked CBR (%)	9.51	13.37	18.78	11.70	8.23
Soaked CBR (%)	7.58	10.56	13.83	8.43	5.14

4.3 Effect on unconfined compressive strength of soil, soil - fly ash mixture and soil - fly ash - phosphogypsum mixture

The unconfined compressive strength test on soil, soil mixed with fly ash and soil-fly ash-phosphogypsum mixture has been performed in the laboratory. The typical stress vs. strain curves for soil, soil-fly ash and soil - fly ash - phosphogypsum mixtures have been shown in figures 5 and 6.

The results from the UCS test on the soil and soil mixed with fly ash are summarized in Table 9. From the table, it is observed that unconfined compressive strength of the soil increases with the increase in fly ash content up to 30% after that the UCS value decreases with the further increment of fly ash content. The reason behind UCS value increment is, during cat-ion exchange in the soil-fly ash mix, sodium ions in the soil are replaced by the calcium ions and formation of bonding.

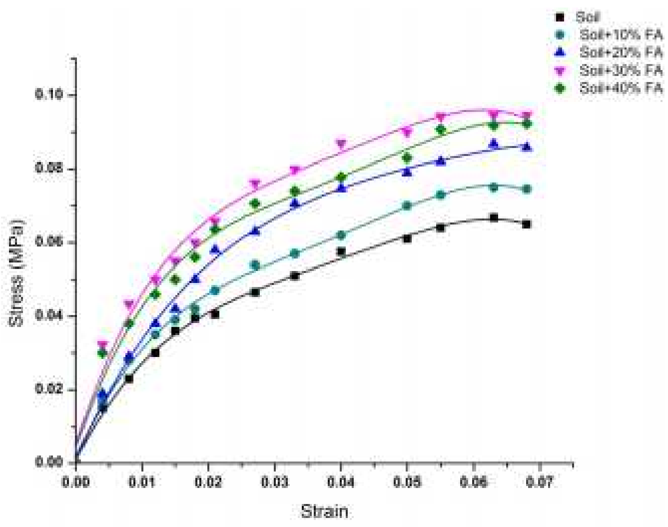

Fig. 5. Unconfined compressive strength curves of soil and soil-fly ash mixture.

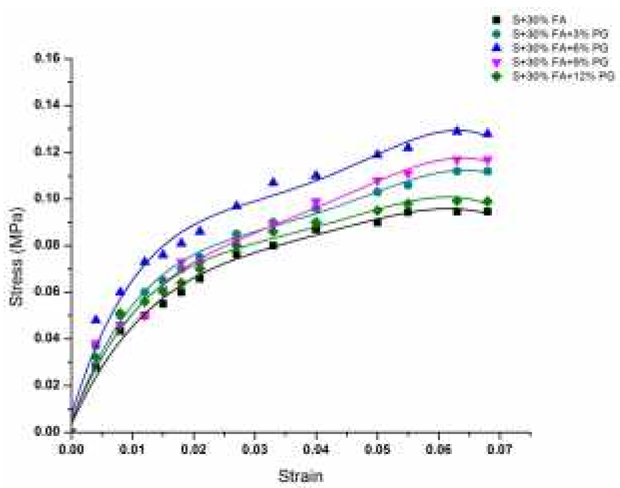

Fig. 6. Unconfined compressive strength curve of soil-fly ash mixtures and soil + 30% FA+ different percentages of phosphogypsum mix samples.

From the UCS test on the soil mixed with 30% fly ash and different percentages of phosphogypsum are presented in Table 10. From the table, it is observed that unconfined compressive strength of the stabilized soil samples increases with the increase in phosphogypsum content up to 6% after that the UCS value decreases with the further increment of phosphogypsum content. The reason behind UCS value increment is due to the potential strength increment of stabilized samples.

Table 9. Variation of Unconfined Compressive Strength (UCS) with soil and soil - fly ash (FA) mixture.

FA (%)	0	10	20	30	40
UCS (MPa)	0.067	0.075	0.088	0.095	0.093

Table 10. Variation of Unconfined Compressive Strength (UCS) with soil and soil - fly ash (FA) - phosphogypsum (PG)mixture.

FA (%)	30	30	30	30	30
PG (%)	0	3	6	9	12
UCS (MPa)	0.095	0.112	0.129	0.117	0.099

5 Conclusions

Based on the above results the following conclusions may be made:

* With the increase in fly ash content in soil, the maximum dry density of the soil-fly ash mixture decreases and optimum moisture content increases due to the presence of hollow particle in fly ash.

* For an optimum proportion of fly ash and phosphogypsum content in soil, the maximum dry density value is maximum and optimum moisture content value is minimum.

* The CBR value of soil - fly ash mixture is maximum at an optimum value of fly ash content under both un-soaked and soaked condition of CBR determination. Also the soaked CBR values are lower as compared to the un-soaked CBR values.

* The CBR value of soil - fly ash - phosphogypsum mixture is maximum at an optimum value of fly ash and phosphogypsum content under both un-soaked and soaked condition of CBR determination. Also the soaked CBR values are lower as compared to the un-soaked CBR values.

* The unconfined compressive strength of soil - fly ash mixture is maximum at an optimum value of fly ash content.

* The unconfined compressive strength of soil - fly ash - phosphogypsum mixture is maximum at an optimum value of fly ash and phosphogypsum content.

* The lattice planes are not closely placed and a sharp peak is observed, which shows that the voids are present and denser packing of lattice planes is possible. Buy for

Soil+30%FA+6%PG sample the lattice planes are closely placed, which shows that the voids are not more present in the mixed sample.

* Soil content with 30% fly ash and 6% phosphogypsum can be used as a subgrade material. Also the thickness of the subgrade layer can be reduced as the subgrade is good. So the construction cost of the pavement may be reduced.

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