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Stabilization of expansive soil using industrial wastes

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Abstract. Swelling and shrinkage characteristics of expansive fine grained soil cause volumetric changes followed by distress and damage to the structures. Soil stabilization can be explained as the alteration of the soil properties by chemical, mechanical or any other means in order to enhance the engineering properties of the soil. Utilization of industrial wastes in soil stabilization is cost effective and environment friendly. This paper presents an experimental study on stabilization of expansive soil using industrial wastes, viz. fly ash and dolochar. The paper includes the evaluation of engineering properties like unconfined compressive strength and California bearing ratio (CBR) of expansive soil collected from Balasore district of Odisha stabilized with fly ash and dolochar in different proportions and to predict the influence of these additives on engineering properties and strength characteristics of expansive soil. Both fly ash and dolochar were found to increase the CBR and decrease many index properties such as liquid limit, plastic limit, plasticity index, swelling index and UCS, thus enhancing the strength parameters of expansive soil.

Keywords: California bearing ratio; dolochar; expansive soil; fly ash; maximum dry density; optimum moisture content; scanning electron microscope; stabilization; un-confined compressive strength; X-ray diffraction

1. Introduction

Red soil with Kaolinite and Illite minerals is available in plenty in Odisha and is the highest occurring soil followed by mixed red and yellow soil. Expansive soil with montmorillonite mineral is sporadically found in many districts. Lateritic Soil is predominant in some districts. In coastal areas and deltaic region, Deltaic alluvial and Coastal Saline and alluvial soils are predominant. Failure of foundation resting on expansive soil is a common phenomenon due to swelling and shrinkage characteristics of these soils when it undergoes cyclic wetting and drying.

It has always been a challenge to the geo-technical engineers to improve the soil strength parameters of locally available expansive soils through various innovative and cost effective techniques, which includes controlled compaction, proportioning and/or the addition of suitable industrial wastes etc. Various industrial wastes such as fly ash, ground granulated blast-furnace slag (GGBS), lime dust, rice husk ash and dolochar are dumped near plant areas which cause

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environmental hazards. But these wastes produce cementitius bond when mixed with soil. Fly ash and dolochar are common waste products in Odisha which may be used as additives in improving undesirable properties of expansive soil.

In the recent past, many researchers have observed that the industrial wastes such as fly ash, rice husk ash, quarry dust, cement kiln dust, iron ore tailings etc. are good additives to the expansive soil to enhance its strength/durability characteristics. Sridharan *et al*. (1997) studied the effect of fly ash on the unconfined strength of black cotton soil. With varying percentages of lime content they had shown that at very low lime contents, sufficient strength can be achieved for a soil–reactive fly ash mixture which cannot be attained for soils without fly ash. Phanikumar and Sharma (2004) studied the effect of fly ash on engineering properties of expansive soil. They revealed that the swelling characteristics reduced whereas the mechanical characteristics are improved with the addition of fly ash in the expansive soil.

Many researchers like Cocka (2001), Pandian *et al*. (2002), Edil *et al*. (2006), Bera *et al*. (2007), Sharma *et al*. (2008), Zha *et al*. (2008), Solanki *et al*. (2009), Brooks *et al*. (2010), Hossain and Mol (2011), Seco *et al*. (2011), Bose (2012), Mishra (2012), Singh and Goswami (2012), Udayashankar and Puranik (2012), Mir and Sridharan (2014), Sivapullaiah and Jha (2014), Voottipruex and Jamsawang (2014), Kang *et al*. (2015), Kolay and Ramesh (2016) etc, studied the engineering properties of expansive soil by the addition of industrial waste such as fly ash or rice husk ash. They have shown that fly ash or rice husk ash is an useful additive to expansive soil.

The durability of quarry fines modified black cotton soil sub-grade stabilised with cement kiln dust was studied by Amadi (2014). He concluded that on addition of 10% quarry fines and 8-16% cement kiln dust to the black cotton soil, the mixture got more stable with prolonged saturation. Osinubi *et al*. (2015) studied the effect of iron ore tailings (IOT) on the engineering characteristics of cement modified tropical black clay by treating the natural soil up to 4% cement and 10% IOT by dry weight of soil. They observed an optimal blend of 4% cement and 6% IOT improved the workability of soil mixture with increase in curing period.

Although stabilization is an effective alternative for improving soil properties, the engineering properties derived from stabilization vary widely due to heterogeneity in soil composition, differences in micro and macro structure of soils, heterogeneity of geologic deposits, and due to differences in physical and chemical interactions between the soil and candidate stabilizers. These variations necessitate the consideration of site-specific treatment options validated through testing of soil-stabilizer mixtures (Little and Nair 2009).

From the review of literature, it is observed that no research has been carried out so far in stabilization of the expansive soil of eastern India (state of Odisha) using the local industrial wastes as additives. Hence, in this research an attempt has been taken to study the influence of industrial wastes such as dolochar and fly ash on strength characteristics of expansive soil which can satisfactorily be used for construction of road, pavements, foundation, etc.

2. Experimental Investigation

The present investigation aims at analyzing local expansive soil having low bearing power and suggesting strength improvement techniques by systematic and scientific use of fly ash and dolochar in different proportions.

The additives such as fly ash and dolochar were added to the virgin expansive soil till 30% by dry weight of soil at an increment of 5%.

The present investigation comprised of following steps:

(i) Characterization of the expansive soil and additives.
(ii) Carrying out the required tests to study the improved characteristics of stabilized soil with regard to density and California bearing ratio (CBR).
(iii) Deciding optimum and cost effective blending proportion for higher un-confined compressive strength (UCS).

2.1 Planning and methodology of experiment

This paper aims at stabilization of expansive soil. For this research work, initially expansive soil was collected from regions of Eastern India. Commonly available industrial wastes such as fly ash and dolochar were also collected from local industries. The collected soil samples and additives were tested for determining their index properties and other strength parameter as per Bureau of Indian Standards (BIS).

Fly ash and dolochar were added to the virgin expansive soil in different percentages by weight of dry expansive soil at 5% increment till 30%. The Atterberg's limits and differential free swell of samples were determined as per IS 2720-1985b, Part 5 and IS 2720-1977, Part 40 respectively. Optimum Moisture Content and Maximum Dry Density for each blended samples were determined by Standard Proctor method following IS 2720-1980, Part 8. California Bearing Ratio tests were conducted as per IS 2720-1979, Part 16 on samples remoulded at their respective MDD and OMC condition. Un-confined Compressive Strength tests were conducted as per IS 2720-1973. Part 10 on samples remolded at their MDD and OMC condition and then saturated by soaking in water for 9 days.

2.2 Materials used and their properties

The soil was collected from Balasore district of eastern India, after excavating till required depth where water table was high during sample collection. This soil was classified as highly compressible (CH) as per Indian Standard Classification System (IS: 1498 1970). The industrial wastes such as fly ash and dolochar were collected from industries such as BIRLA Tyres Ltd., Balasore and ISPAT Alloys Ltd., Balasore respectively. Various tests were performed on the virgin soil, additives and mixed samples for their characterization.

Table 1 presents the physical properties of expansive soil and additives used. The grain size analysis of expansive soil, fly ash and dolochar were carried out as per IS 2720-1985, Part 4, which are presented in Fig. 1.

2.2.1 Expansive soil

As per IS 1498-1970 the expansive soil used is classified as highly compressible clay (CH). From Fig. 1, the mean grain size (D50) of the soil is found to be 0.0055 mm. Further it is observed from Table 1 that the soil is highly plastic and highly swelling.

The scanning electron microscopic (SEM) view of expansive soil used in this study is reported in Figs. 2(a)-(b). Fig. 2(a) shows that the angularity of soil particles is between 1.054 to 1.25; thus indicating the particles is sub-angular in nature. Many particles are roughly rounded in nature with irregular voids. The mineralogical analysis of the soil is also reported in the Table 2. The X- ray diffraction test is presented in Fig. 3.

Table 1 Physical properties of soil and additives

Engineering properties	Soil	Fly ash	Dolochar
Sieve analysis (Dry & wet)			
20 mm to 4.75 mm (%)	0	0	0
4.75 mm to 2 mm (%)	0	0	27.76
2 mm to 425 μ (%)	0.12	0.31	53.95
425 μ to 75 μ (%)	0.35	15.19	10.59
75 μ to 2 μ (%)	59.53	77.0	7.7
< 2 μ (%)	40	7.5	0
Liquid limit (%)	56	43	18
Plastic limit (%)	28	----	----
Plasticity index (%)	28	Non plastic	Non plastic
Shrinkage limit (%)	16.81	----	----
Shrinkage ratio (%)	1.765	----	----
Specific gravity	2.688	2.470	3.215
Differential free swelling index (%)	60	0	0
D_{60} in mm	0.008	0.0498	1.5
D_{30} in mm	----	0.0095	0.7
D_{10} in mm	----	0.0025	0.2
Maximum dry density (KN/m^3)	17.8	12.2	26.34
Optimum moisture content (%)	16.1	35.0	6.7
Un soaked CBR (%)	16.99	35.70	40.08
Soaked CBR (%)	3.61	13.89	38.4
Unconfined compressive strength (KPa)	149	----	----

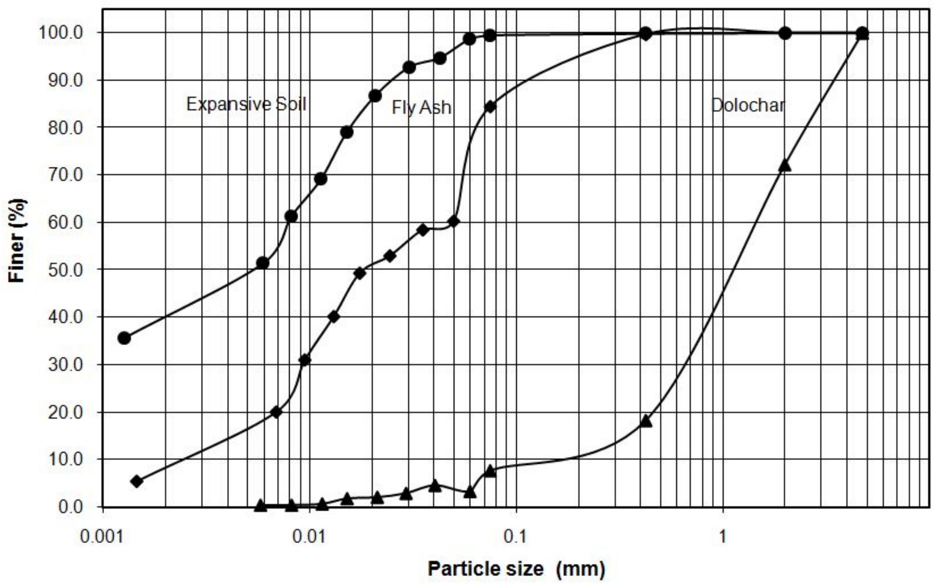
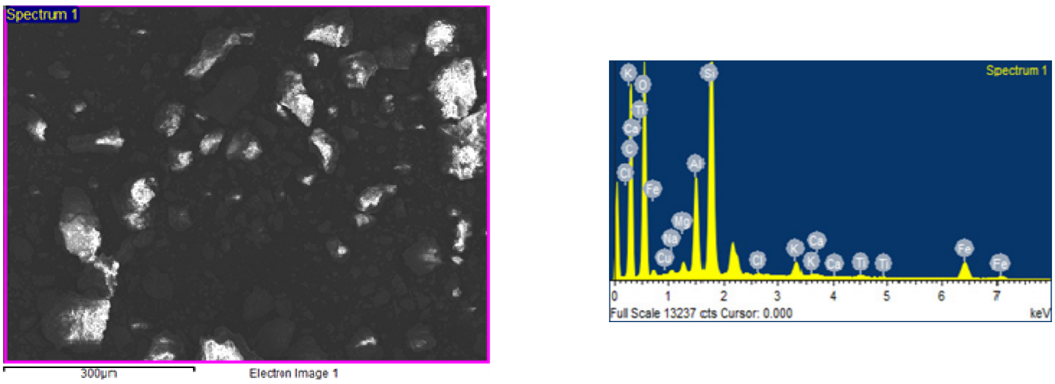


Fig. 1 Particle size distribution curves of expansive soil, fly ash and dolochar

Table 2 Presence of minerals in expansive soil

Minerals	% by weight
C as $CaCO_3$	45.68
O as SiO_2	39.54
Na	0.22
Mg as MgO	0.38
Al as Al_2O_3	2.81
Si as SiO_2	7.60
Cl as KCl	0.09
K as Feldspar	0.69
Ca as Wollastonite	0.08
Ti	0.15
Fe	2.55
Cu	0.21



(a) Image of soil particles (b) Intensity of minerals of soil

Fig. 2 Scanning electron microscope test result of expansive soil

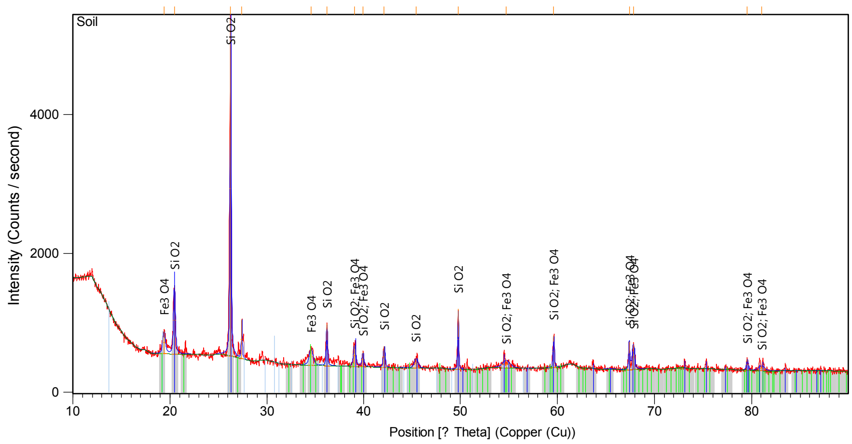


Fig. 3 X-Ray diffraction test result of expansive soil

2.2.2 Fly ash

From Table 1, it is seen that the sand and silt contents of the fly ash are 15.5% and 77% respectively, whereas the clay content is 7.5%. Because of low clay content, fly ash is non-plastic in nature. The differential free swell index of the fly ash is 0% which shows it is non-expansive in nature. Since fly ash is light weight fine-grained industrial waste material, it is very essential to know its chemical composition and class. Table 3, shows the chemical characteristics of fly ash.

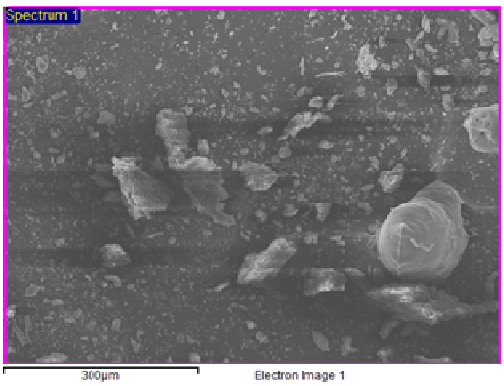
The said fly ash under study is ‘Class F’. The scanning electron microscopic view and X-ray diffraction test results on fly ash are presented in Figs. 4(a)-(b) and Fig. 5 respectively. The angularity of fly ash particles is between 1.154 to 1.711. This shows that the particles are sub-angular in nature with almost uniformly distributed regular voids. Many particles are roughly rounded.

2.2.3 Dolochar

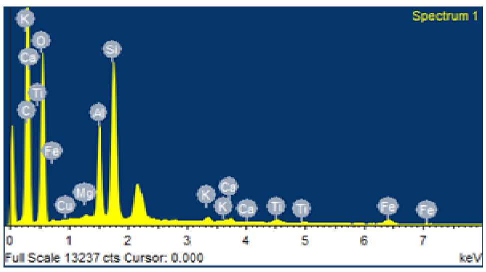
Before conducting physical tests on dolochar, the collected dolochar was broken into smaller particles and sieved through 4.75 mm IS sieve. The materials passing 4.75 mm sieve are taken for the testing purpose. Since dolochar is a solid industrial waste which is produced by direct reduction of iron for production of sponge iron, it has no clay content. It is also seen from the

Table 3 Chemical characteristics of fly ash

Characteristics	Percent (%) by mass
SiO_2	50.62
Al_2O_3	25.15
Fe_2O_3	3.62
$SiO_2 + Al_2O_3 + Fe_2O_3$	79.39
Total Ca as CaO	0.062
MgO	0.209
Sulphur as SO_3	0.016
Loss of Ignition	3.81
Moisture content	2.04



(a) Image of fly ash particles



(b) Intensity of minerals of fly ash

Fig. 4 Scanning electron microscopic view of fly ash

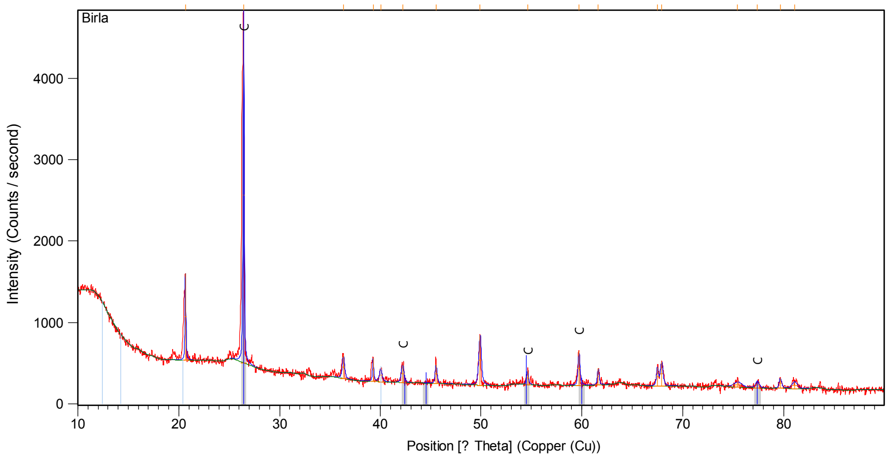


Fig. 5 X-Ray diffraction test result of fly ash

grain size analysis of dolochar which is presented in Table 1. Since it has no clay content, it is non-plastic and non-expansive in nature. As dolochar is a by-product of sponge iron, its specific gravity is more than expansive soil (under study). The specific gravity is 3.215. The details of engineering properties of dolochar are reported in Table 1.

3. Preparation of blended samples and their engineering properties

Fly ash and dolochar were added to the virgin expansive soil in different percentages by dry weight of expansive soil at 5% increment till 30%. In this way, six fly ash blended samples and six dolochar blended samples were prepared. All the blended samples were tested to determine their engineering properties. The effects of engineering properties of expansive soil followed by the addition of fly ash and dolochar are discussed as below.

3.1 Addition of fly ash

Fly ash was added to the virgin expansive soil in different percentages by dry weight of expansive soil at 5% interval till 30%.

3.1.1 Consistency characteristics

Fig. 6 shows the effect of fly ash on consistency limits and plastic characteristics of expansive soil. With increase in fly ash content, the liquid limit of soil-mix decreased and simultaneously plastic limit increased. It is observed that the plasticity index is decreased with the increase in fly ash content.

The expansive soil is highly plastic (Plasticity Index 28%) with clay content of 40%, whereas fly ash is non-plastic with clay content 7.5%. When fly ash was mixed with expansive soil, the particle size of the blended samples is increased. Due the increasing of particle size, the surface area of particles is decreased. Again the quantities of clay mineral decreased with the increase of fly ash content in the blended samples. As a result the water holding capacity of blended samples is decreased with the increase in percentage of fly ash content in the blended samples. So the

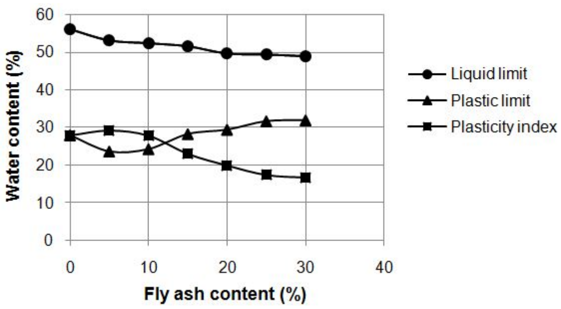


Fig. 6 Variation of consistency limits with percentage of fly ash content

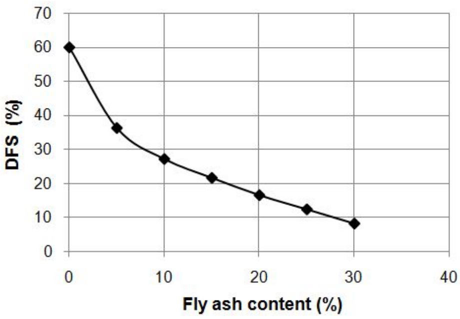


Fig. 7 Variation of differential free swelling properties with percentage of fly ash content

liquid limit of blended samples is gradually decreased with the increase in fly ash content. The non-plastic characteristics of blended samples are increased with the increase in fly ash content. As a result plastic limit is gradually increased, whereas plasticity index is gradually decreased.

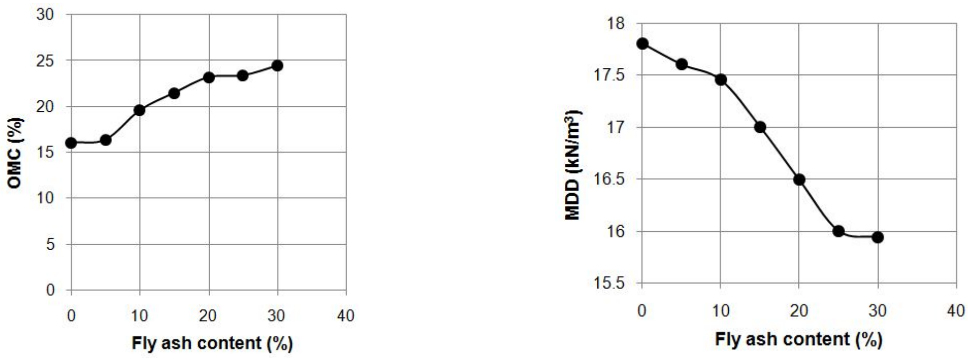
3.1.2 Expansive characteristics

The differential free swell of virgin expansive soil sample was found to be 60% (Highly expansive) and for fly ash it was 0% (Non expansive). The presence of clay mineral decreased with the increase of fly ash content in the blended samples. As fly ash is non-expansive in characteristics, the expansiveness of expansive soil gradually decreased with the increase of fly ash content in it. Fig. 7 shows the variation of differential free swelling with increase in fly ash content.

3.1.3 Compaction characteristics

The optimum moisture content (OMC) and maximum dry density (MDD) of virgin expansive soil sample was determined as 16.1% and 17.8 kN/m^3 respectively, whereas the optimum moisture content and maximum dry density of fly ash was 35% and 12.2 kN/m^3 respectively. But with increase in fly ash content in the blended soil sample by decreasing the same percentage of expansive soil, the maximum dry density of blended soil sample decreased and optimum moisture content followed a reverse trend. The variation of OMC and MDD are shown in Figs. 8(a)-(b).

Fly ash is lighter than the virgin expansive soil, when the percentages of fly ash content is increased in the virgin expansive soil, the weight per unit volume of blended samples decreased. As a result MDD of blended samples decreased with the increase of fly ash content. The OMC of



(a) Variation in OMC (b) Variation in MDD

Fig. 8 Effect of fly ash on compaction characteristics

fly ash is 35% and that of virgin expansive soil is 16.1%. When the percentages of fly ash increased in virgin expansive soil (Blended samples), the OMC of blended samples increased.

3.1.4 Strength characteristics (*California Bearing Ratio*)

Fig. 9 shows the variation of CBR of the blended sample with increase in fly ash content. The un-soaked CBR of soil sample as 16.99%, but it gradually decreased and then increased with increase in fly ash content in blended samples. At 5% addition of fly ash with expansive soil, there was no remarkable improvement. It may be due to the nearly same MDD and OMC. But with addition of 10% fly ash to soil sample, its un-soaked CBR suddenly decreased to 7.62%. It may be due to the increase in OMC (19.6%) by 3.5% and decrease of MDD (17.45 kN/m^3) by 0.35 kN/m^3. Then further addition of 10% to 30% fly ash to soil sample, the un-soaked CBR gradually increased. It may be due to re-arrangement of fly ash particle with the fines of the soil sample making the mix more stable with compactness. In case of soaked CBR (4 days soaking in water), the CBR value gradually increased with increase of fly ash content, which may be due to virgin expansive soil and fly ash mix becoming more stable with addition of fly ash.

3.1.5 Strength characteristics (*Un-confined compressive strength*)

Fig. 10 shows the variation in unconfined compressive strength with increase in fly ash content

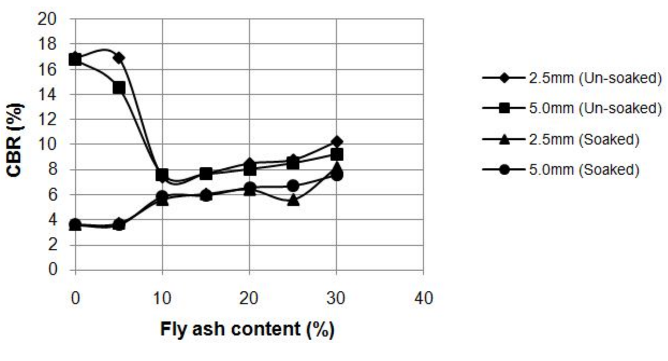


Fig. 9 Effect of fly ash on California Bearing Ratio in both un-soaked and soaked condition

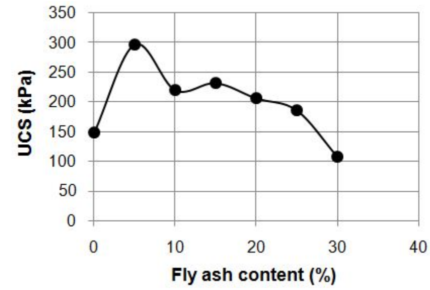


Fig. 10 Variation of unconfined compressive strength with fly ash content

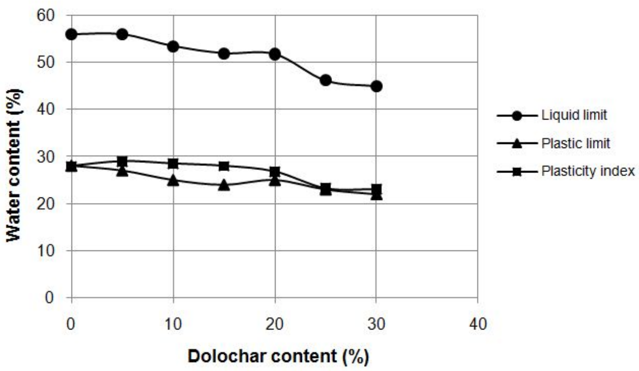


Fig. 11 Variation of consistency limits with percentage of dolochar content

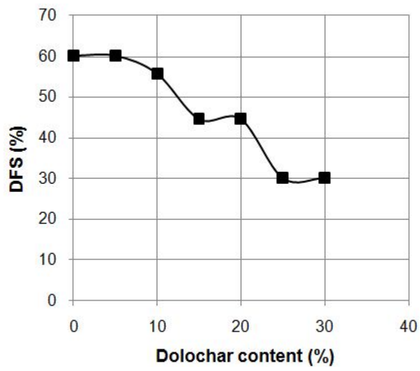


Fig. 12 Variation in DFS with dolochar content

in the blended sample. From Fig. 10 it is observed that the UCS of virgin expansive soil sample is maximum at 5% fly ash content. With further increase in fly ash content, UCS gradually decreased. It is seen that the UCS of the blended sample with 25% of fly ash content has more UCS value than the virgin expansive soil. It may be due to the bond between soil particle and fly ash particle is stronger than the bond between soil particles only. But beyond 25% fly ash content, UCS decreased and shows less UCS than that of the virgin expansive soil. This may be due to the non-plastic and non-cohesive characteristics of fly ash making the mix less cohesive.

3.2 Addition of dolochar

Six samples were prepared by adding dolochar up to 30% at an increment of 5%. The engineering properties of all the six samples are determined which are summarized in Fig. 11 to Fig. 15.

3.2.1 Consistency characteristics

Fig. 11 shows the effect of dolochar on consistency limits and plastic characteristics of expansive soil. When the dolochar content increased in blended samples by decreasing the same percentage of soil, the liquid limit and plasticity index simultaneously decreased. A slight increase was observed at 15% dolochar content.

The virgin expansive soil is highly plastic (Plasticity Index 28%) with clay content 40%, whereas dolochar is non-plastic with clay content 0%. When dolochar was mixed with the virgin expansive soil, the particle size of the blended samples increased. Due the increase in particle size, the surface area of particles decreased. Again the quantities of clay mineral decreased with the increasing of dolochar content in the blended samples. As a result the water holding capacity of blended samples decreased with increase in percentage of dolochar content in the blended samples. So liquid limit and plastic limit of blended samples are gradually decreased with the increase in dolochar content. The non-plastic characteristics of blended samples are increased with the increase of dolochar content. As a result plasticity index is gradually decreased.

3.2.2 Expansive characteristics

The Differential Free Swell (DFS) of virgin expansive soil sample was found to be 60% and dolochar as 0%.With addition of dolochar, the DFS of the blended samples decreased to 50% of the virgin expansive soil. Fig. 12 shows the decrease in DFS with increase of dolochar content. When the percentage of dolochar content is increased, the DFS of blended samples gradually decreased. It is due to the presence of dolochar which is non-expansive in nature.

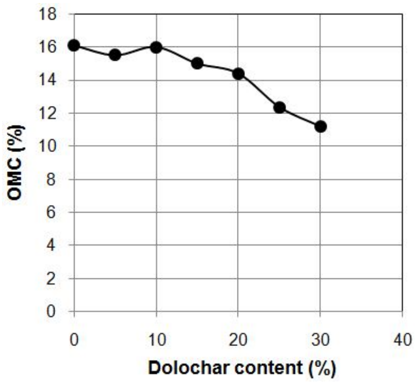
3.2.3 Compaction characteristics

Fig. 13(a)-(b) shows the variation of Optimum Moisture Content (OMC) and Max Dry Density (MDD) with addition of dolochar to virgin expansive soil.

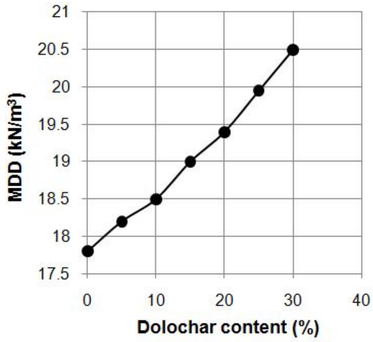
The OMC and MDD of the virgin expansive soil sample were determined as 16.1% and 17.8 kN/m^3 respectively, whereas the OMC and MDD of dolochar were 6.7% and 26.34 kN/m^3 respectively. Dolochar is a by-product of sponge iron and it is heavier than the virgin expansive soil. When the percentage of dolochar content is increased in the blended sample by decreasing the same percentage of soil by weight, the weight per unit volume of blended sample is increased. As a result MDD of blended samples are increased with the increase in dolochar content. Again the water holding capacity of dolochar (OMC = 6.7%) is less than that of the virgin expansive soil (16.1%). As a result, the OMC of blended sample is less than that of the virgin expansive soil and it is decreased with the increase in percentage of dolochar content.

3.2.4 Strength characteristics (*California Bearing Ratio*)

For CBR test, samples were remoulded at their OMC and MDD condition. The un-soaked CBR of soil sample was determined to be 16.99, whereas the un-soaked CBR of dolochar sample as 40.05%. When dolochar was added to soil sample, the un-soaked CBR of soil sample initially decreased at 5% dolochar content, then increased with the increase of percentage of dolochar content in expansive soil sample which can be observed from Fig. 14. Similarly soaked CBR (4



(a) Variation in OMC



(b) Variation in MDD

Fig. 13 Effect of dolochar on compaction characteristics

days soaking in water) of soil sample also increased with the increase in dolochar content in soil sample. The increase in CBR value of blended samples is due to the re-arrangement of coarser particles of dolochar with the fines of the expansive soil making the matrix more stable and compact.

3.2.5 Strength characteristics (*Un-confined compressive strength*)

For Un-confined compressive strength (UCS) test, samples were remoulded at their OMC and MDD condition and then saturated by soaking in water for 9 days. Fig. 15 shows the effect of dolochar on unconfined compressive strength of the blended samples (virgin expansive soil with dolochar). UCS of soil sample increased with increase in dolochar content and it was found optimum at 10% dolochar content. Beyond 10% dolochar content, UCS decreased with increase in dolochar content. Initially fine particles of virgin expansive soil are re-arranged by the coarser particles of dolochar up to 15% of dolochar content and make the mix more stable. As a result the UCS of the blended samples up to 15% increased. But when the percentage of dolochar content increased beyond 15% in the blended samples, the cohesiveness of blended samples decreased and its stability (stiffness) decreased. As a result the UCS gradually decreased.

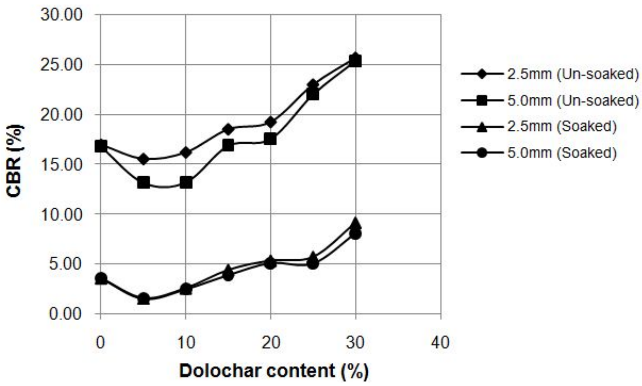


Fig. 14 Effect of dolochar on California Bearing Ratio in both un-soaked and soaked conditions

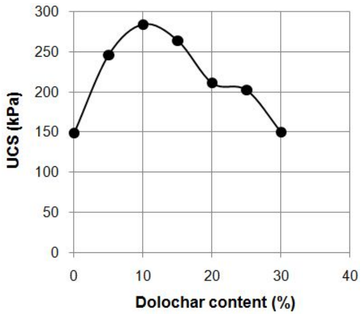


Fig. 15 Effect of dolochar on unconfined compressive strength

4. Conclusions

The effect of addition of fly ash and dolochar in different proportions to the locally available expansive soil in improving its mechanical properties is presented in this technical paper. Fly ash and dolochar were added up to 30% at an increment of 5% by dry weight of virgin expansive soil as per existing practice. Based on the test results obtained from the study the following conclusions have been drawn.

4.1 Addition of fly ash

- With increase in fly ash content, Liquid Limit (LL) and Plasticity Index (PI) of the virgin expansive were found to decrease. At 30% fly ash content, Liquid Limit was found to decrease by 12.95% and plasticity index decreased by 40%.
- At 30% fly ash content the swelling potential of the virgin expansive soil decreased by around 86%.
- Maximum Dry Density (MDD) was found to decrease with increase of fly ash content whereas Optimum Moisture Content (OMC) followed a reverse trend.
- With initial drastic decrease (around 55% till 10% fly ash content) the un-soaked California bearing ratio (CBR) was found to gradually increase with further addition of fly ash till 30% fly ash content.
- Soaked California bearing ratio (CBR) was found to gradually increase with increase in fly ash content. It was 126% more in comparison to virgin expansive soil at 30% fly ash content.
- With addition of fly ash, un-confined compressive strength (UCS) initially increased. At 5% fly ash content, UCS was found to be maximum. Then with increase in fly ash content, UCS gradually decreased.

4.2 Addition of dolochar

- Liquid limit gradually decreased with increase in dolochar content. The decrease was around 20% at 30% dolochar content. Similarly the plasticity index decreased by around 18% at this dolochar content.
- Swelling potential gradually decreased with addition of dolochar to the virgin expansive soil. The decrease was around 50% at 30% dolochar content.

- MDD increased with increase in dolochar content and OMC simultaneously decreased.
- Both un-soaked and soaked CBR was found to increase gradually with increase in dolochar content in the mix. The increase was around 154% at 30% dolochar content.
- With gradual increase till 10% dolochar content, UCS was found to decrease thereafter.

4.3 Recommendation

The expansive soil of eastern India (Balasore district) stabilized with the addition of 30% of either fly ash or dolochar can be used in the construction of roads, pavements and foundations which will reduce the disposal problem of industrial wastes leading to environmental hazards.

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