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GEOTECHNICAL CHARACTERIZATION OF BLACK COTTON SOIL BLENDED WITH FLY ASH

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ABSTRACT:
Expansive soils are a worldwide problem that poses several challenges for civil engineers. They are considered a potential natural hazard, which can cause extensive damage to structures if not adequately treated. Such soils can be effectively and economically treated with the addition of stabilizing agents such as lime or fly ash. In this study, a high plastic soil was stabilized using fly ash (obtained from NSPCL, Bhilai, CG). The geo-engineering properties such as Atterberg limits, grain size distribution, compaction characteristics, unconfined compressive strength (UCS) and California Bearing Ratio (CBR) value of virgin soil and treated with fly ash were evaluated and reported. The soil was stabilized with the various proportion of fly ash i.e. at 0, 15, 20, 25, and 30 %. Plasticity index of soil-fly ash mixes decreases with increase in fly ash content. Thus with the addition of fly ash-soil makes less plastic and increases its workability by colloidal reaction and changing its grain size. The variation of optimum moisture content (OMC) observed with the increasing trend of maximum dry density (MDD) up to 20% of fly ash content, thereafter it gets decreases with the further addition of ash content. Unconfined compressive strength of soil-fly ash mixes is found to be decreased with increasing fly ash contents. The CBR values of soil-fly ash mixes, tested under un-soaked conditions, shows peaks at 30% and 70% ash content. Hence, it is concluded that the fly ash has a good potential to be used as an additive for improving the engineering properties of soil.
Keywords – fly ash, soil stabilization, unconfined compressive strength, California Bearing Ratio.

INTRODUCTION:
Expansive soils cover a considerable part of various countries including India. It is mostly found in Maharashtra, Madhya Pradesh, Chhattisgarh, Gujarat, Tamilnadu, Andhra Pradesh, Karnataka and some region of other states of India and covers almost 22 % of the total land cover of the country. These soils are also commonly known as soil or 'regur' which is consists of high iron, hummus and magnesium minerals derived from trap or basalt and a variety of minerals such as montmorillonite, kaolinite, and illite [1]. Swelling and shrinkage are the key characteristics of these soils which cause defects to the foundations, structures, roadways, railways, and various other lifelines. These swelling and shrinkage depend upon the percentage of montmorillonite and illite minerals and the moisture content presents in the soil. Due to such kind of behavior of soil, it becomes compressible and it leads to decreases in strength or unstable. Since these types of soil are very destructive in nature so great precaution should be taken before any construction, so that the risk will be minimum. There are several methods/ways that have been used to minimize or eliminate the harmful effects of expansive soils on structures. A most common method is to tackle the problematic expansive soil/soil and remove the soil or refill with non-problematic soil or improve the properties of the existing soil. The characteristics of the problematic soil can be improved by

pozzolanic stabilization using rice husk ash or coal ashes, chemical stabilization, lime and cement stabilization, etc.
Several research studies have demonstrated the successful utilization of low calcium-based stabilizers, such as fly ash to improve the soil characteristics [2-10]. According to the research carried out the stability or the characteristics of the soil was improved at a significant level so that it can be used as a construction material. Fly ash is one of the residues generated in the combustion of coal and comprises the fine particles that rise with the flue gases. The fly ash generally contains a high amount of silicon dioxide (SiO_2), and aluminum oxide (Al_2O_3) and other basic mineral oxides which necessary for forming pozzolanic compounds. Fly ash is classified as either class C or F based on the available CaO content present. According to the American Society for Testing Materials (ASTM C 618-15), fly ash can be classified as class C if the CaO content about 20% and the sum of SiO_2, Al_2O_3 and Fe_2O_3 is less than 70%. If the sum of SiO_2, Al_2O_3, and Fe_2O_3 is more than 70% can be classified as a class F. Presently, India produces nearly 169.25 million metric tons of coal ash; that is expected to double in the next 10 years. Where the relative utilization very less nearly 107.10 million metric tons i.e. 63.28 % [11]. It has potential impacts on the environment that suggest the need for proper disposal of fly ash and maximize utilization of fly ash. In this context, extensive research is needed to understand the mechanism and geo-engineering properties of soil stabilized with fly ash. Considering this in the present work an attempt has been made to evaluate the geotechnical characteristics of the soil blended with fly ash such as plasticity, grain size distribution, compaction parameters, unconfined compression test, California Bearing Ratio (CBR).

MATERIAL AND METHOD:
This research presents laboratory investigation to study the characteristics of soil blended with fly ash in terms of grain size distribution, Atterberg limits, specific gravity, compaction characteristics, unconfined compressive strength and California bearing ratio as per relevant IS code.
Soil- For the laboratory investigation, low plastic soil were used, which collected from near to Amaleshwar, Mahadeo Ghat, Raipur, Chhattisgarh India, From the top surface of the ground. The soil preliminary allows to dry for 2 days period and thoroughly grinded. Its engineering and index properties are shown in Table 1.

Table 1 Basic properties of soil

Sr. No.	**Properties**	**Value**
1.	Color	Blackish Gray
2.	Specific Gravity	2.61
3.	Liquid Limit (%)	58
4.	Plastic Limit (%)	20
5.	IS classification of soil	CH
6.	MDD (kN/m^3)	16
7.	OMC (%)	16.8
8.	UCS (kN/m^2)	1739.02
9.	CBR (%)	6.06

Fly ash – The fly ash is procured from NSPCL, Bhilai. The followings are the chemical components of fly ash. The specific gravity (Gs) of the fly ash sample was 1.44 obtained by using glass density bottle. The chemical compositions of the fly ash sample are shown in Table 2. From Table 2, it can be observed that the sum of major oxides i.e., SiO_2, Al_2O_3, Fe_2O_3 is more than 70 %, hence the fly ash is Class F fly ash according to ASTM C 618 (1996) standard.

Table 2 Chemical Compositions of Fly Ash

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Constituents	Percentage Range (%)	Obtained values
Silica (SiO_2)	49-67	63.78
Alumina (Al_2O_3)	16-29	24.44
Iron Oxide (Fe_2O_3)	4-10	5.01
Calcium Oxide (CaO)	1-4	1.94
Magnesium Oxide (MgO)	0.2-2	0.48

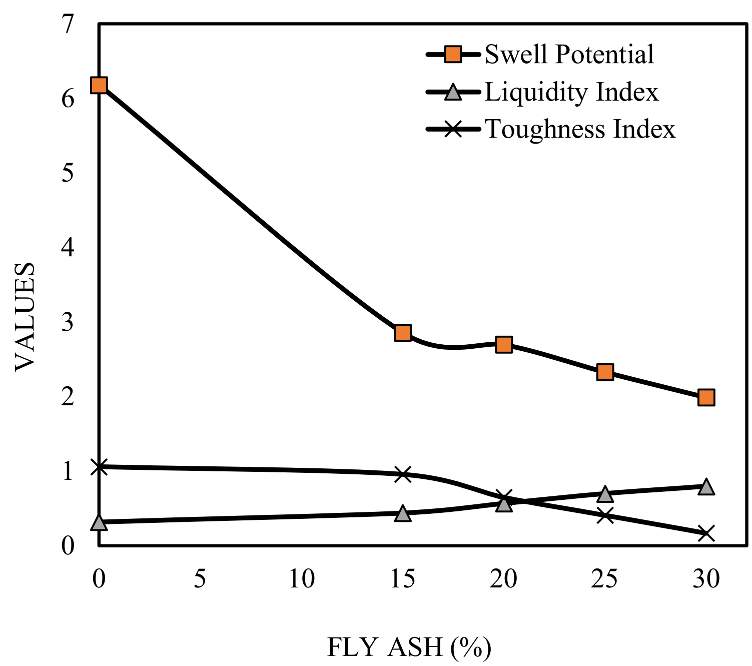
RESULTS AND DISCUSSION:

The soil sample was collected from the field and dried for 2 days, then the soil was thoroughly grinded. The various proportion of fly ash is mixed with soil as 0, 15, 20, 25, and 30% and its effect on soil were evaluated in terms of engineering and index properties of the mixture.

Atterberg Limits- Atterberg limit is very important for the characterization of soil which indicates the plastic nature of the soil. The variations of liquid limit and plastic limit with varying percentages of fly ash are shown in Table 3.

Table 3 Atterberg limits of fly ash-soil composite

% Soil	% FA	Liquid Limit %	Plastic Limit %	Plasticity Index %	Type of Soil	Liquidity Index %	Toughness Index %	Swell Potential % (Chen, 1988)
100	0	58	20	38	CH	0.32	1.06	6.18
85	15	48	19.18	28.82	CI	0.44	0.96	2.86
80	20	44	15.9	28.1	CI	0.57	0.65	2.70
75	25	40	13.62	26.38	CI	0.70	0.41	2.33
70	30	37	12.53	24.47	CI	0.80	0.17	1.99



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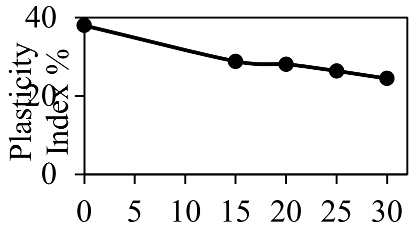


Figure 1: Variations of plasticity index

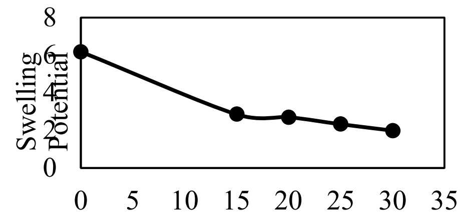


Figure 2: Variation of swelling potential

As it was observed that plasticity index reduced with increasing fly ash content (Figure 1) which may be attributed to cations exchange or pozzolanic reaction occurred between soil and fly ash. A similar trend of results was observed by [1, 3, 12-16]. Liquid limit of the fly ash-soil mixes decreases with increasing the fly ash content which indicates that higher will be the dry strength and toughness while permeability and compressibility get decreases [17]. Liquidity index of the mixes ranges in between 0 to 1 so it indicating that the consistency of the soil is plastic, which is softer with an increasing percentage of fly ash. Toughness index indicates that the shear strength at the plastic limit which lies in between 0 to 3 for most of the soils. In this case, with the addition of the fly ash in soil toughness of the soil, get reduces. The swelling potential of the soil-fly ash mixes was calculated by the indirect method by Chen 1988, which shows that reduction in the swelling characteristics of the soil (Figure 2).

Specific gravity- Specific gravity of various mixing parentage was estimated according to the IS: 2720 (Part 3) – 1985. It can be seen that the addition of the fly ash with soil reduces the specific gravity of the soil mixes (Table 4). The reason for the reduction of the specific gravity is due to the light weight of fly ash. The same result was reported by [3, 13, 18 -19].

Table 4 Specific Gravity of fly ash-soil composite

% Soil	% FA	Specific Gravity
100	0	2.61
85	15	2.46
80	20	2.48
75	25	2.37
70	30	2.35

Grain Size Distribution- the grain size distribution test were conducted as per IS: 2720 (Part 4)-1985. Figure 3. shows the grain size distribution curve for soil blended with fly ash at various proportions of 0, 15, 20, 25 and 30%.

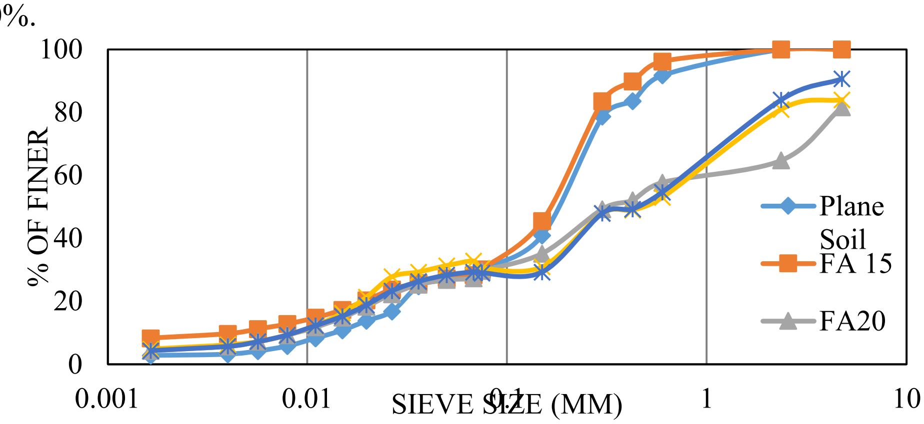


Figure 3: Grain size distribution curve for soil-fly ash mixes

Grain size distribution indicates the gradation of the material well graded, poorly graded, uniformly graded, fine or course. Here, the blended soil was altered by the addition of fly ash. The shifting of the grain size distribution of soil to the coarser side as silt and sand fractions increased whereas the clay fraction decreases with an increasing amount of fly ash. Also formation of flocculation of clay particle due to some chemical reaction or cation exchange between fly ash and soil. Similar results were noted by [3, 12].

Table 5 Percentage of Particle size of fly ash-soil composite

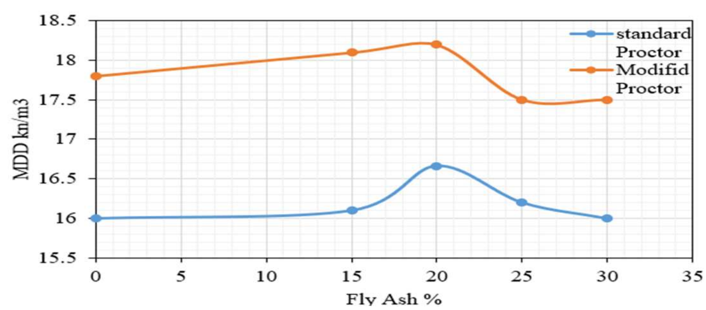
Sr. No.	Soil	FA %	Clay Content %	Silt content %
1.	100	0	2.84	27.00
2.	90	10	8.34	20.49
3.	85	15	4.34	23.92
4.	80	20	4.84	24.32
5.	75	25	4.34	23.26

Compaction characteristics- the standard compaction test and modified proctor test were carried out to understand the tendency of density-moisture curve. The Table 6 shows variation of MDD and OMC, in standard proctor test and in Modified Proctor test with increasing percentage of fly ash initially MDD increase up to 20% of fly ash content thereafter its starts falling down, Similar behaviour in OMC and MDD were observed when fly ash or industrial wastes were used as stabilizing agents [7, 20]. Initial increments in MDD and OMC is due to fine particles of the fly ash occupy the void space of soil mass which gives resistant to compactive efforts also due to less quantity of the fly ash as compared to soil in soil mixes. Beyond 20 % of the fly ash decrements in MDD where noted as due to fly ash has low specific gravity as compared to soil. The OMC of soil increases this may attribute to progressive hydration of fly ash which consume some moisture inside the voids.

Table 6 Compaction test results of fly ash soil composite

Sr. No.	Fly ash%	BC Soil %	Standard Proctor Test		Modified Proctor Test	
			OMC%	MDD (kN/m^3)	OMC%	MDD (kN/m^3)
1.	0	100	16.8	16	15.5	17.8
2.	15	85	16.6	16.1	16.2	18.1
3.	20	80	15.8	16.66	16.2	18.2
4.	25	75	14.8	16.2	16.9	17.5
5.	30	70	17	16	16	17.5

Figure 4: Result of Standard Proctor and Modified Proctor test



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Unconfined Compression Strength (UCS) - UCS test performed on both treated and non-treated soil, the results shows in table addition of fly ash UCS decreases rapidly may be because of breaking of cohesive bond between soil particles which loose the soil strength. The UCS value also get reduces with increasing curing days this may due to fly ash soil mix does not form any binding material with respect to time.

Table 7 UCS results of fly ash soil composite

BC Soil%	FA%	UCS (kN/m^2)
100	0	1739.02
85	15	702.89
80	20	683.75
75	25	438.74
70	30	450.02

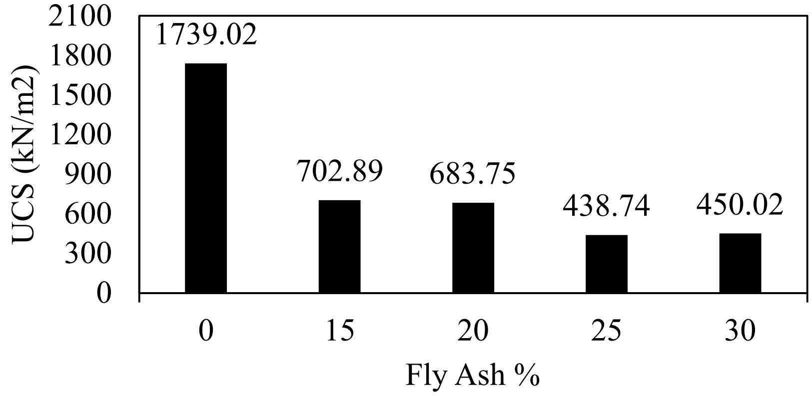

Figure 5: UCS results of soil fly ash mixes

California Bearing Ratio (CBR) :

A major application area for fly ash utilization is its use as a sub-base material in the construction of pavements. For the design of pavement CBR method is used widely. The CBR values of different mixes of fly ash and soil were determined as per IS 2720, Part 16. The specimens were prepared at their respective modified proctor MDD and OMC for unsoaked condtion and respective value were evaluated. The results shows in Table 8 the improvements in the CBR value with increasing fly ash content. Many researcher reported the samillar trend of improvement of CBR value, [12, 21]. Figure 6 shows the variation of CBR value with varring fly ash conent, as 30% of fly ash content shows maximum CBR value. It may be mentioned here that the fly ash used out here consists essentially of sandy and silt size fraction with a small amount of clay-size fraction. The fly ash also a non-plastic material with addition of the soil the cohesion increases giving higher CBR value. Also, at 30 % of fly ash showing better packing with all size particles.

Table 8 CBR results of fly ash soil composite

Sr. No.	BC Soil%	FA%	CBR%
1.	100	0	6.06
2.	85	15	6.13
3.	80	20	6.86
4.	75	25	7.36
5.	70	30	11.04

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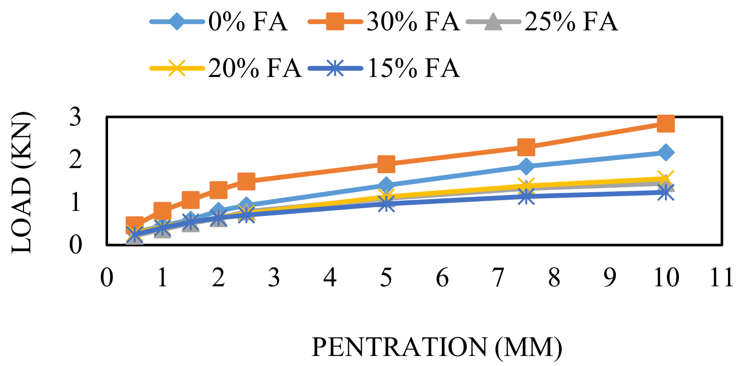

Figure 6: Unsoaked CBR results with soil blended with fly ash

CONCLUSION:

In this study, Soil was stabilized with fly ash with different proportions and their performance was evaluated using a series of laboratory investigations. The following some important conclusions were drawn from obtained results.

1. Addition of the fly ash content plasticity characteristics of soil reduces, the liquid limit, plastic limit, plasticity index decreases.
2. The indirect swelling potential of soil also get reduces drastically with increasing fly ash content.
3. Grain size of the particles alters to courser side on addition of fly ash.
4. MDD of soil mixes increases with fly ash content, up to 20% of fly ash in both standard proctor test and modified proctor test. Whereas OMC goes on increasing with fly ash percentage.
5. The strength of soil fly ash composite enhanced with addition of 30% fly ash. Therefore fly ash found to be good binder up to certain proportion which help to solve the disposal problem of fly ash in environment friendly manner.

REFERENCES :

1. Shukla, R. P.; Parihar, N. S.; Tiwari, R. P.; Agrawal, B. K. Black cotton soil modification using sea salt. Electronic Journal of Geotechnical Engineering. 2014, 19(Y), 8807–8816.
2. Bhuvaneshwari, S.; Robinson, R. G.; Gandhi, S. R. Stabilization of Expansive Soils Using Flyash and Murrum. International Journal of Innovative Research in Science, Engineering and Technology. 2014, 1–10.
3. Cokca, E. Use Class C fly Ashes for the Stabilization of an Expansive Soil. Journal of Geotechnical and Geoenvironmental Engineering. 2001, 127, 568–573.
4. Kaniraj, S. R.; Gayathri, V. Factors influencing the strength of cement fly ash base courses. Journal of Transportation Engineering. 2003, 129(5), 538–548. https://doi.org/10.1061/(ASCE)0733-947X(2003)129:5(538)
5. Moghal, A. A. B. State-of-the-Art Review on the Role of Fly Ashes in Geotechnical and Geoenvironmental Applications. Journal of Materials in Civil Engineering. 2017, 29(8), 04017072. https://doi.org/10.1061/(asce)mt.1943-5533.0001897
6. Mohanty, S. Stabilization of Expansive Soil Using Industrial Waste: Fly Ash. Civil Engineering Research Journal. 2018, 3(2), 0–9. https://doi.org/10.19080/cerj.2018.03.555606
7. Phani Kumar, B. R.; Sharma, R. S. Effect of fly ash on engineering properties of expansive soils. Journal of Geotechnical and Geoenvironmental Engineering. 2004a, 130(7), 764–767.

https://doi.org/10.1061/(ASCE)1090-0241(2004)130:7(764)
8. Rajak, T. K.; Yadu, L.; Pal, S. K. Analysis of slope stability of fly ash stabilized soil slope. In Lecture Notes in Civil Engineering. 2019, (Vol. 13), 5-13. https://doi.org/10.1007/978-981-13-0368
9. Sivapullaiah, P. V.; Prashanath, J. P.; Sridharan, A. Effect of Fly ash on the Index Properties of Black Cotton Soil. Soils and Foundations. 1996, 36(1), 97–103. Retrieved from https://www.jstage.jst.go.jp/article/bpb1993/17/11/17_11_1460/_pdf/-char/ja
10. Turkane, S. D.; Chouksey, S. K. Partial replacement of moorum with fly ash in embankment. Lecture Notes in Civil Engineering. 2021, 77, 381–391. https://doi.org/10.1007/978-981-15-5195-6_30
11. Central Electricity Authority (n.d.). Report on Fly ash Generation at Coal/lignite based Thermal Power Stations and Its Utilization in the Country for the year 2017-18.
12. Bose, B. Geo-engineering properties of expansive soil stabilized with fly ash. Electronic Journal of Geotechnical Engineering. 2012, 17 (2004), 1339–1353.
13. Kolay, P. K.; Ramesh, K. C. Reduction of Expansive Index, Swelling and Compression Behavior of Kaolinite and Bentonite Clay with Sand and Class C Fly Ash. Geotechnical and Geological Engineering. 2016, 34(1), 87–101. https://doi.org/10.1007/s10706-015-9930-4
14. Lekha, B. M.; Sarang, G.; Shankar, A. U. R. Effect of Electrolyte Lignin and Fly Ash in Stabilizing Black Cotton Soil. Transportation Infrastructure Geotechnology. 2015, 2(2), 87–101. https://doi.org/10.1007/s40515-015-0020-0
15. Phani Kumar, B. R.; Sharma, R. S. Effect of Fly Ash on Engineering Properties of Expansive Soils. Journal of Geotechnical and Geoenvironmental Engineering. 2004b, 130(7), 764–767. https://doi.org/10.1061/(asce)1090-0241(2004)130:7(764)
16. Shukla, R. P.; Parihar, N. S. Stabilization of Black Cotton Soil Using Micro-fine Slag. Journal of The Institution of Engineers (India): Series A. 2016, 97(3), 299–306. https://doi.org/10.1007/s40030-016-0171-1
17. Ranjan, G.; Rao, A. S. R. Basic and Applied Soil Mechanics. In New Age International Publishers, New Delhi. 2005.
18. Kate, J. M. Strength and volume change behavior of expansive soils treated with fly ash. Geotechnical Special Publication. 2005, (130–142), 1851–1865.
19. Yadu, L.;Tripathi, R. K.; Singh, D. Comparison of fly ash and rice husk ash htabilized black cotton soil. International Journal of Earth Sciences and Engineering. 2011, 4(6), 42-45.
20. Sharma, A. K.; Sivapullaiah, P. V. Ground granulated blast furnace slag amended fly ash as an expansive soil stabilizer. Soils and Foundations. 2016, 56(2), 205–212. https://doi.org/10.1016/j.sandf.2016.02.004
21. Petersen, D.; Link, R.; Pandian, N.; Krishna, K.; Sridharan, A. California Bearing Ratio Behavior of Soil/Fly Ash Mixtures. Journal of Testing and Evaluation. 2001, 29(2), 220. https://doi.org/10.1520/jte12249j

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