Interface Frictional Properties of Geogrid-Reinforced Pond Ash

Mogili Sudhakar, M. Heeralal, G. Kalyan Kumar

Abstract*: The performance of any reinforced soil (RS) structure mainly depends on the soil-geosynthetic interface friction mechanism. Nowadays, due to the non-availability of conventional backfill materials and unsuitability of locally available soils, the exploration has started to find an alternative material for backfilling. One of such materials is pond ash, generated as a waste by-product from thermal power plants. In this regard, the present work is aimed to find the interfacial frictional characteristics of geogrid reinforced pond ash in terms of coefficient of interface friction (C_i) and pullout frictional factor (f*) by conducting large direct shear test and pullout tests using two biaxial geogrids (GG1 and GG2) of different stiffnesses. From the experimental results, it was observed that the coefficient of interface friction (C_i) values were in the range of 0.84 to 0.66 and pullout frictional factor (f*) values were in the range of 0.43 to 0.28 for the applied normal stresses of 50 kPa, 100 kPa and 150 kPa respectively. Further, GG1 shows higher frictional characteristics compared to GG2 because of its structural geometry and stiffness characteristics.

***Index Terms*: Pond ash, Geogrid; Interface friction, Pullout resistance.**

I. INTRODUCTION

The "Reinforced Earth" technology was invented by Henry Vidal during 1960s and constructed many reinforced soil (RS) structures such as walls, slopes, embankments, abutments etc. The construction of these RS structures have benefits of simplicity in construction phase, flexibility, cost-effective, ability to tolerate large deformations in vertical as well as horizontal directions when compared to conventional classical retaining structures like gravity walls [1], [2]. In addition, with great advent and wide applications of geosynthetics in civil engineering practices, a new era has started in this technology. Even though the design and performance of these structures appear to be simple, its internal friction mechanism development for stability and serviceability point of view is unique, which mainly depends on the interactive forces between soil and reinforcement [3], [4]. The development of these forces further relies on the nature of backfill soil and reinforcement characteristics. In the design of RS structures, sliding (direct shear) and pullout of reinforcement (pullout failure) are the commonly considered failure conditions which causes instability or failure to the structures (Fig. 1).

Therefore, it is significant to identify the mode of failure, so that the optimized design can be carried out.

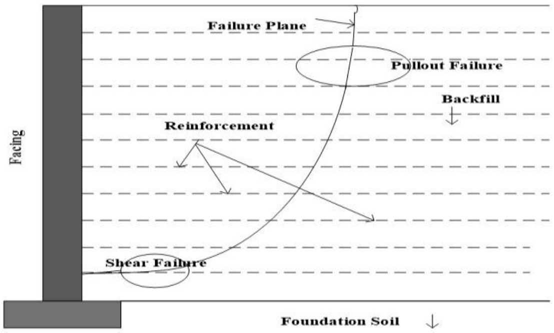

Fig. 1. Schematic diagram of model RS structure

There are numerous studies available to explain the development of interface friction mechanism and its significant contribution in the performance of RS structures with conventional granular frictional backfill soils and geosynthetics [5]-[7]. However, due to the non-availability of such conventional backfill materials at many construction sites, people have started using locally available soils (like clayey soils, marginal soils, etc.) as backfill materials. Further, its undesirable engineering behaviour was reported during lifespan of the structures in the form of pore water pressure development, insufficient frictional stresses, and corrosion of reinforcement [3], [8]. In order to overcome such problems, few researchers have suggested electro-kinetic geosynthetic drainage, preloading techniques, etc. Nevertheless, these techniques involve high quality control and technical difficulties. Hence, there arises a need to find alternative sustainable material for backfilling purpose. One of such materials is pond ash, generated from coal-based thermal power plants as a waste material in huge quantities (180 MMT/year). The production of this coal ash demands huge area of land for disposal, creates environmental hazard problems, and makes an ecological imbalance [9]. Therefore, utilization of these ashes in huge quantity for construction purpose is essential to overcome the problems.

Later, in several investigations, researchers have confirmed the suitability of coal ash as a construction material, especially for geotechnical applications because of its desirable engineering properties such as low specific gravity, good drainage, insensitive to water during compaction, low compressibility, and good frictional characteristics [10], [11].

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Some other investigations on the use of coal ash in engineering practices, either by itself or blended with other soils/admixtures/inclusions reported the improvement in strength and stiffness characteristics [12]-[14]. Some researchers have studied the interfacial frictional characteristics of geosynthetic reinforced coal ashes (especially fly ash) used as structural backfill [15]. However, very limited work is available on the use of pond ash as backfill material.

Hence, this study is aimed to assess the interface frictional properties of pond ash reinforced with biaxial geogrid reinforcement for backfilling applications.

II. MATERIALS

A. Pond ash

The pond ash used in this study is collected from Kakatiya Thermal Power Plant (KTPP) Bhupalpalle, Telangana, India. The physical properties of pond ash are shown in Table. 1 and its grain size distribution curve is shown in Fig. 2. The CaO content in pond ash is less than 15% and hence, according to the ASTM (C-618-98), it can be categorized to class F.

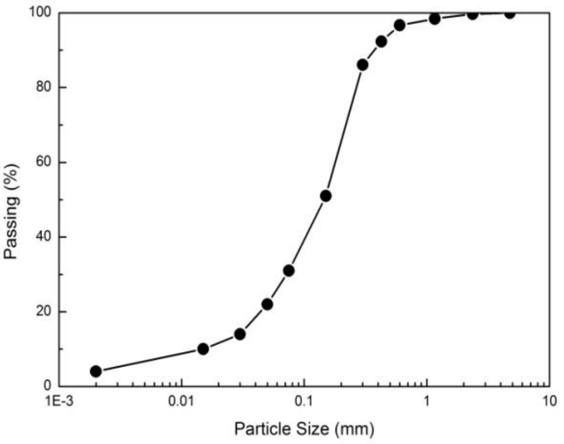

Fig. 2. Grain size distribution of Pond ash

Table 1. Physical properties of Pond ash

S. No	*Property*	*Value*
1	Specific gravity	1.83
2	Plasticity Index	NP
3	Grain Size Distribution % Gravel % Sand % Fines	 0 70 30
4	Maximum dry density, MDD (g/cc)	1.05
5	Optimum moisture content, OMC (%)	38.1
6	Angle of Internal Friction(φ°)	35.1
7	Permeability, k (cm/s)	6.3×10^{-4}
8	Compression Index, C_c	0.0847

B. Reinforcement

Two geogrid type reinforcements were used in the present study represented with GG1 and GG2 as shown in Fig. 3. The configuration of meshes of GG1 and GG2 are rectangular with thickness of 1.0 mm each and internal opening sizes of 26.5 mm x 25 mm and 30 mm x 30 mm respectively. The tensile strengths of GG1 and GG2 were determined using wide width specimens and was found to be 26 kN/m and 14 kN/m with maximum elongation at break of 15% and 9.8% respectively. The testing was done in accordance with ASTM D5035 at a pulling rate of 5 mm/min.

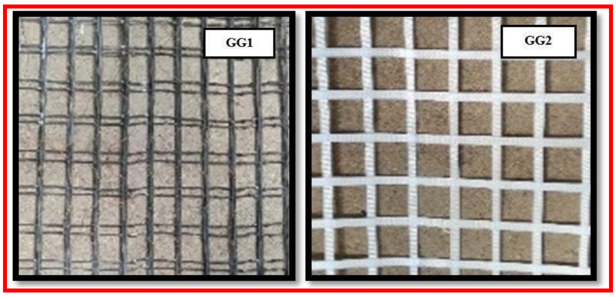

Fig. 3. Geogrid materials used in the study

III. METHODOLOGY

In the present work, large direct shear tests as well as geosynthetic pullout tests were performed to assess the interface frictional characteristics of pond ash and pond ash-geogrid reinforcement in terms of interface friction coefficient (C_i) and pullout resistance frictional factor (f*).

A. Large direct shear test

To conduct the direct shear tests, a box of size 300 mm x 300 mm x 200 mm was used. The test set up consists of a horizontal load cell with 30 kN capacity and a dial gauge extensometer (with least count of 0.01 mm / div) to measure horizontal deformations during the shearing stage. Each test was carried out with pond ash and reinforced pond ash compacted to a density of 90% of MDD at OMC condition. The reinforcement was placed at the interface between lower and upper box and gripped tightly with lower box using gripping system. The reinforcement size used in the present study was same as that of plan area of shear box. The tests were performed by considering three normal stress levels of 50 kPa, 100 kPa, and 150 kPa. Further, with a maximum shear displacement of 30 mm, the shear force was applied at a rate of 1 mm per minute. All the tests were performed as per ASTM D5321. The direct shear test setup used in this study is shown in Fig. 4.

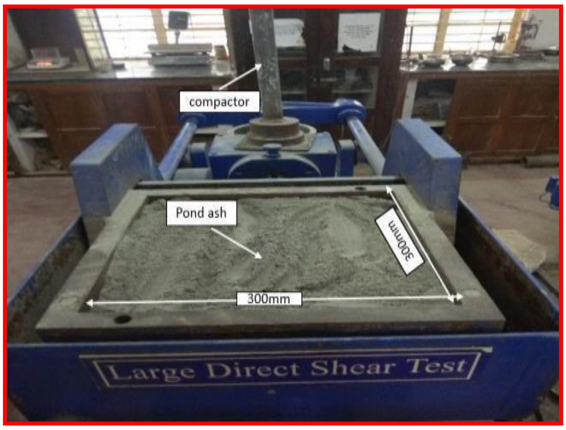

Fig. 4. Large direct shear test set up

B. Geosynthetic pullout test

The geosynthetic pullout tests were performed in a prefabricated pullout test equipment with a pullout box size of 610 mm X 460 mm X 380 mm. The box must allow the maximum embedded length of 600 mm beyond the sleeve with a minimum width of 175 mm. The pond ash sample was compacted in pullout box with a relative density of 90% MDD at its OMC. In order to know the pullout behaviour of reinforced pond ash, three normal stress levels of 37 kPa, 72 kPa, and 110 kPa were applied to the specimens. During test, the pullout load was applied with a constant rate of 4.5 mm/min until pullout failure or maximum load was recorded. The application of load was noted with the help of a proving ring of capacity 100 kN. The horizontal displacement of geosynthetic was measured at the entrance of pull out box with dial gauge extensometer. In the test procedure, to begin with, the bottom half of the pullout box was filled in layers with pond ash and compacted to required density of 90% MDD at OMC condition. Then, the geogrid was placed on the pond ash, and drawn between the sleeves, and fixed to the clamping device. Subsequently, pond ash was placed in top half, and compacted in the same manner as that of the bottom half of the test box. Finally, the test box was closed with the top plate and equipped with the necessary measuring devices. The procedure followed this test is as per ASTM D6707. The geosynthetic pullout apparatus used in the study is shown in Fig. 5.

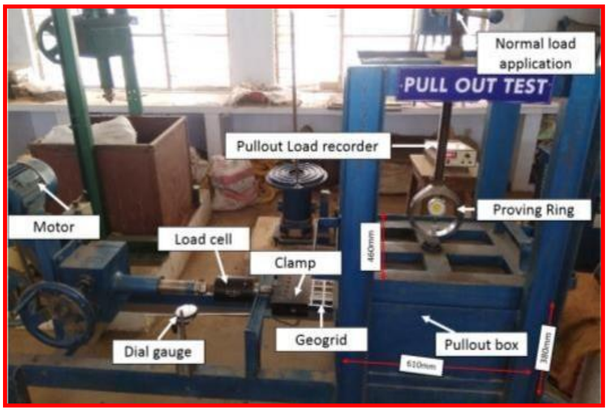

Fig. 5. Geosynthetic Pullout test apparatus

IV. RESULTS AND DISCUSSIONS

A. Shear strength of pond ash

The shear strength of pond ash was determined by conducting direct shear test (DST). The variation of shear stresses with the horizontal deformation at three normal stress levels are shown in Fig. 6, and its corresponding shear strength envelop is shown in Fig. 7. It can be observed that the peak shear stresses of corresponding normal stresses were observed at horizontal deformation of 5 to 8 mm, while the critical/residual stresses (at large displacement) were observed at horizontal displacement of almost 13 mm. From Mohr-Coulomb envelop, the peak and critical values of shear strength parameters (i.e., C and φ°) were found to be 2 kPa and 35.1°, and 2.7 kPa and 33.3° respectively. From the test results, it can be seen that with the increase in normal stresses, there is an increase in the shear strength of pond ash, due to interlocking action between pond ash particles [11].

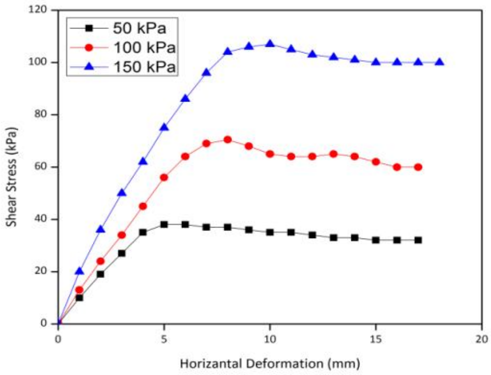

Fig. 6. Direct shear test on pond ash at different normal stress levels

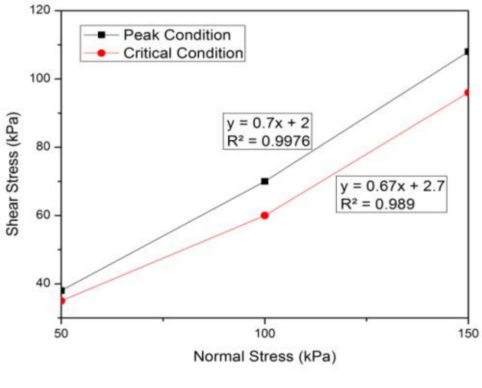

Fig. 7. Shear envelop of pond ash

B. Interface friction between pond ash and geogrid

The interface shear stresses vs horizontal deformation plots at different normal stress levels are shown in Figs. 8 and 9 for both geogrids GG1 and GG2 respectively. The shear parameters were considered under both peak and critical conditions. From Fig. 8, the resulting peak shear strength parameters for GG1 were calculated as C_a = 4.0 kPa and δ = 28.45°, whereas for critical condition C_a = 3.5 kPa and δ = 27.5°. From Fig.

9, the interface shear stresses between pond ash and GG2 at both peak and critical states were $C_a = 4.0$ kPa, $\delta = 26.10°$, and $C_a = 2.0$ kPa, $\delta = 24.7°$ respectively. From the test results, it can be observed that with an increase in normal stress, the shear strength of reinforced sample increases. This is due to the interlocking of the pond ash particles present in the apertures of geogrid, and restrained forces developed by apertures of geogrid reinforcement against shear failure [8]. In addition, the stiffness of reinforced pond ash increases with an increase in normal stresses, which can be observed by the steep slope of stress-strain curves (Fig. 8 and 9). However, the internal friction of pond ash is higher than the mobilized interaction between pond ash and reinforcement, which is almost in the range of 68 to 80 percent of the frictional angle of pond ash [16]. The summary of shear strength parameters of reinforced pondash are shown in Table 2.

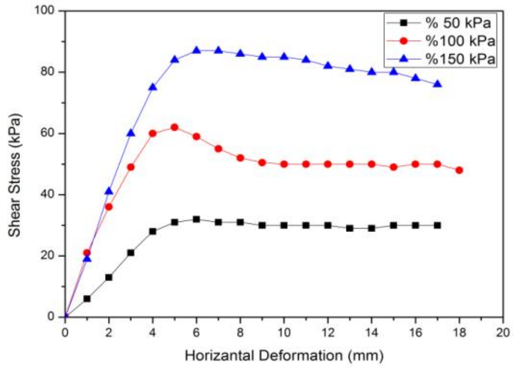

Fig. 8. Shear stress vs horizontal deformation of envelop of Pond ash reinforced with GG1 at different normal stress levels

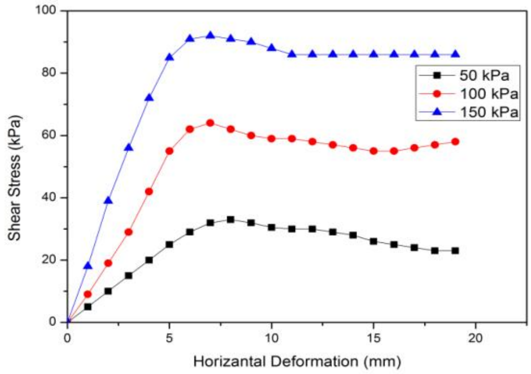

Fig. 9. Shear stress vs horizontal deformation of envelop of Pond ash reinforced with GG2 at different normal stress levels

Table 2. Summary of shear strength parameters results

Material combination	Peak stress condition		Critical stress condition	
	Cohesion (kPa)	Friction (φ°)	Cohesion (kPa)	Friction (φ°)
PA	2	35.1	2.7	33.3
PA + GG1	4	28.45	3.5	27.5
PA + GG2	4	26.1	2	24.7

C. Interface friction coefficient (C_i)

The interface friction coefficient (C_i) between backfill material and reinforcement is calculated by using Eq. (1) [1], [3].

$$\begin{aligned} C_i &= [\tau_{\text{pond ash- geogrid}} \;/\; \tau_{\text{pond ash}}] \\ &= [C_a + \sigma \tan\delta_a \,/\, C + \sigma \tan_{\varphi}] \end{aligned} \tag{1}$$

The C_i of pond ash with geogrid reinforcements GG1 and GG2 are shown in Table 3. The variation of C_i with respect to normal stresses are shown in Figs. 10 and 11. The C_i values obtained from the direct shear test under both peak and critical conditions for corresponding normal stresses of 50 kPa to 150 kPa were in the range of 0.84 to 0.79 & 0.78 to 0.75 for GG1; 0.76 to 0.71 & 0.70 to 0.66 for GG2 respectively. From the test results, it is observed that with an increase in normal stresses, the C_i of pond ash–geogrid reinforcement decreases because of progressive failure against shearing. Further, it was observed that the interfacial frictional strength of GG1 was found to be higher than GG2. This can be attributed to the higher stiffness, availability of number of transverse ribs (which offers restrain stresses in the form of passive resistance) and surface roughness characteristics of GG1 [4], [11], [13].

Table 3. Coefficient of interface friction of pond ash with geogrid reinforcements

Normal Stresses (kPa)	(Pond ash + GG1)		(Pond ash + GG2)	
	Peak state	Critical state	Peak state	Critical state
50	0.84	0.78	0.76	0.7
100	0.82	0.76	0.73	0.68
150	0.79	0.75	0.71	0.66

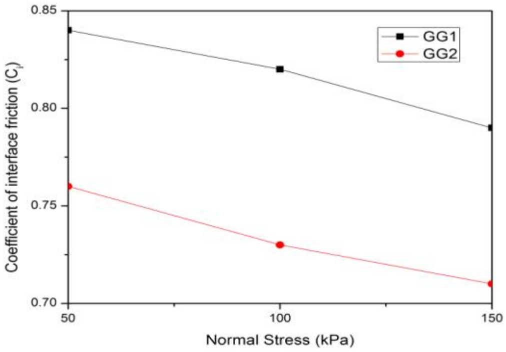

Fig. 10. Interface friction coefficient of reinforced pond ash at peak condition

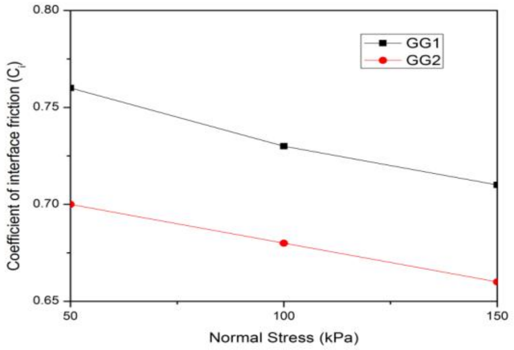

Fig. 11. Interface friction coefficient of reinforced pond ash at critical condition

D. Pullout frictional characteristics between Pond ash and Geogrid

The pullout force vs horizontal deformation behaviour of geogrid reinforced pond ash at different normal stress levels (37, 72 and 110 kPa) are presented in Figs. 12 and 13. From the test results, it can be observed that pullout resistance forces have increased with an increase in normal stresses from 37 to 110 kPa, and all the maximum pullout forces were achieved within the deformation range of 50 to 80 mm. Beyond this, the pullout resistance forces were observed to be decreased because of particles rearrangement among themselves and followed by reinforcement pullout [17]. The improvement in pullout resistance against normal load is due to the development of passive resistance of transverse reinforcement. Thereafter, the test results were analyzed to evaluate the interface frictional bond strength between pond ash and reinforcement in terms of pullout friction factor (f*) by using Eq. (2) [4], [26]. The summary of the pullout test results is shown in Table 4. In each case, all the reinforced specimens failed under pullout mode only. However, the present study assumes that the nonlinear stress reduction along the embedded length of the reinforcement is 0.8 for all test specimens on account of scale effect correction factor (α) [4].

$$\begin{aligned} P_r &= 2\, L_e\, .\, B.\ \sigma_v.\ \alpha.\ \tan\phi \\ &= 2\, L_e\, .\, B.\ \sigma_v.\alpha.\ \tan\delta \qquad (2) \\ &= 2\, L_e\, .B.\ \sigma_v.\ \alpha.\ f^* \end{aligned}$$

Where P_r = pullout resistance, L_e = length of embedded reinforcement, B = reinforcement width, σ_v = vertical overburden pressure, α = scale effect correction factor, tanδ = f* = pullout frictional factor.

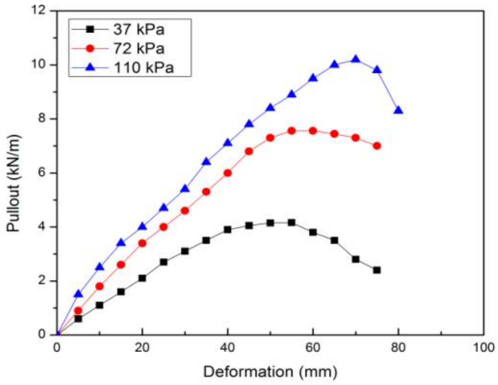

Fig. 12. Pullout force vs Deformation of pond ash reinforced with GG1 at different normal stress levels

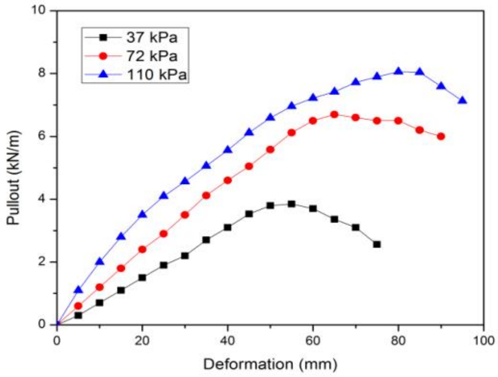

Fig. 13. Pullout force vs Deformation of pond ash reinforced with GG2 at different normal stress levels

E. Pullout friction factor (f*)

In geogrid reinforced pond ash, the friction factor values decreased with the increase of normal loads, varying from 0.43 to 0.35 for GG1 and 0.42 to 0.28 for GG2. The reason for this decrease can be attributed to the development of non-linear stress distribution along the embedded length of reinforcement. A similar trend was observed in earlier studies [6], [7], [13]. From Table. 4, it is noticed that GG1specimen showed higher pullout resistance than GG2 specimen because of higher stiffness, presence more transverse ribs (which offers passive resistance) and its surface roughness characteristics with the pond ash (which results in higher interaction values).

Table 4. Geosynthetic pullout test results

Test fill and reinforcement	Normal Stress (kPa)	Max Pullout resistance (kN/m)	Pullout resistance factor (f*)
Pond ash + GG1	37	4.15	0.43
	72	7.56	0.41
	110	10	0.35
Pond ash + GG2	37	4.01	0.42
	72	6.82	0.37
	110	8.06	0.28

V. CONCLUSIONS

The purpose of the study is to determine the interfacial frictional characteristics in terms of shear and pullout between pond ash and geogrid reinforcement by conducting the large direct shear test and pullout test. The following conclusions were drawn from the experimental study:

- With increase in normal stress levels, the shear resistance force increases due to interlocking action between pond ash particles against shear failure, and interface friction coefficient (C_i) decreases due to progressive failure nature while shearing.
- The mobilized interfacial friction angles of geogrid reinforced pond ash are nearly 68 to 80 percent of the angle of internal friction of pond ash.
- With increase in normal stress levels, the pullout resistance force (P_r) increases due to development of passive resistance, and the resistance factor (f*) decreases due to non-linear stress distribution along the length of reinforcement.
- Due to the presence of more transverse ribs, higher stiffness, and surface roughness, the interface friction characteristics (in terms of shear and pullout) of GG1 are higher than GG2.

REFERENCES

1. D. T. Bergado, J. C. Chai, H. O. Abiera, M. C. Alfaro, A. S. Balasubramaniam, “Interaction between cohesive-frictional soil and various grid reinforcements”, *Geotextiles and Geomembranes*, Vol. 12, No. 4, pp. 327-349, 1993.
2. R. D. Holtz, “46th Terzaghi lecture: geosynthetic reinforced soil: from the experimental to the familiar”, Doctoral dissertation, American Society of Civil Engineers, 2017.
3. BSI “Code of Practice for Strengthened/reinforced soils and others fills, *BSI Standards Publication*”, 2010.
4. R. R.Berg, B. R. Christopher, N. C. Samtani, “Design and construction of mechanically stabilized earth walls and reinforced soil slopes”, US Department of Transportation, *Federal Highway Administration, National Highway Institute (FHWA)*, 2009.
5. C. N. Liu, J. G. Zornberg, T. C. Chen, Y. H. Ho, B. H. Lin, “Behavior of geogrid-sand interface in direct shear mode”, *Journal of Geotechnical and Geoenvironmental Engineering* (ASCE), Vol. 135, No. 12, pp. 1863-1871, 2009.
6. P. W. Jayawickrama, W. D. Lawson, T. A. Wood, J. G. Surles, “Pullout resistance factors for steel MSE reinforcements embedded in Gravelly backfill”, *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 141, No. 2, pp. 1-9, 2014.
7. A. Hegde, R. A. Roy, “Comparative Numerical Study on Soil–Geosynthetic Interactions Using Large Scale Direct Shear Test and Pullout Test”, *International Journal of Geosynthetics and Ground Engineering*, Vol. 4, No. 1, pp. 1-12, 2018.
8. S. Mallick, H. Zhai, S. Adanur, D. Elton, “Pullout and direct shear testing of geosynthetic reinforcement: a state-of-the-art report”, *Journal of the Transportation Research Board*, vol. 1534, pp. 80-90, 1996.
9. CEA “Fly ash generation at coal/lignite based thermal power stations and its utilization in the country for the year 2016-2017”, New Delhi: *Central Electricity Authority*, 2017.
10. B. Indraratna, P. Nutalaya, K. Koo, N. Kuganenthira, “Engineering behaviour of a low carbon, pozzolanic fly ash and its potential as a construction fill”, *Canadian Geotechnical Journal*, Vol. 28, No. 4, pp. 542-555, 1991.
11. R. S. Jakka, G. V. Ramana, M. Datta, “Shear behaviour of loose and compacted pond ash”, *Geotechnical and Geological Engineering*, Vol. 28, No. 6, pp. 763-778, 2010.
12. B. A. Mir, A. Sridharan, “Physical and compaction behaviour of clay soil–fly ash mixtures”, *Geotechnical and Geological Engineering*, Vol. 31, No. 4, pp. 1059-1072, 2013.
13. M. A. Pando, R. H. Swan, Jr, Y. Park, S. Sheridan, “Experimental study of bottom coal ash-geogrid interaction”, In Geo-Congress 2014: *Geo-characterization and Modeling for Sustainability*, pp. 316-325, 2014.
14. B. R. R. Lal, J. N. Mandal, “Model studies on cellular reinforced fly ash walls”, *International Journal of Geotechnical Engineering*, Vol. 9, No. 3, pp. 289-297, 2015.
15. A. Pant, M. Datta, G.V. Ramana, “Bottom ash as a backfill material in reinforced soil structures”. *Geotextiles and Geomembranes*, 2019. (Accepted manuscript).
16. R. M. Koerner., “Designing with geosynthetics”, (5th edition) Prentice Hall, 2005.
17. J. B. Park, D. Kim, S. B. Yang, J. H. Kim, “Pullout Characteristics of Geosynthetics Reinforced Earth Using Multilayer Spreading Pullout Test”, *Advances in Materials Science and Engineering*, 2017.

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