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An Assessment of Geotextiles' Effectiveness as an Earthen Reinforcement in Soil Structures

Ravi Ande[1*], Akshay Rathod[2*], Miral Gajjar[3], Varteeka Punja[4], Kalpana Singh[5]
[1]Department of Fabric and Apparel Sciences, Lady Irwin College, University of Delhi, New Delhi, 110001, India, ravi.ande@lic.du.ac.in
[2*]Department of Civil Engineering, GTU Institute of Technology and Research, Mevad, Mehsana, 384460, India.
[3]Geologist, Water Resource Department, Gujarat Water Resource Resource Developmeny Corporation, Gandhinagar, India.
[4]Research Scholar, Department of Civil Engineering, Institute of Engineering and Technology, Lucknow, U.P. -22602, India
[5]Department of Computer Science Engineering, Rajkiya Engineering College, Sonbhadra, UttarPradesh - 231206, India

Abstract
The California Bearing Ratio (CBR) values showed a consistent increase for both clay–fly ash and clay–fly ash–geotextile matrices. Geotextiles contribute to this improvement through their key characteristics: mechanical strength, filtration ability, and chemical resistance. These properties arise from the physical structure of polymer fibers, their processing during textile manufacturing, and the inherent chemical composition of the polymers. Reinforced soil refers to soil strengthened with materials capable of withstanding tensile forces while interacting with the soil through adhesion and/or friction. CBR test results for both matrices reflect the benefits of such reinforcement. In the clay–fly ash matrix, CBR values increased from 11.64% to 14.29% and then to 17.21% as the thickness ratio increased from 1:2 to 1:1 and then to 2:1. Similarly, for the clay–fly ash–geotextile matrix under Standard Proctor compaction energy, CBR values improved from 12.00% to 14.50% and finally to 18.50% for the same thickness ratio progression. However, when the moulding moisture content increased from 16.00% to 34.00% at a 2:1 thickness ratio, the CBR value dropped from 17.21% to 6.77%. Conversely, increasing the compaction energy (Standard Proctor) led to a rise in CBR value from 17.21% to 32.73% for the clay–fly ash matrix at the same thickness ratio. These results highlight the combined effect of thickness ratio, moisture content, and compaction energy on the strength behavior of reinforced soils.
Keywords: *Geotextiles, polymer fibers, Reinforced soil, tensile stresses, shear test, Sampling techniques*

INTRODUCTION

A nation's social and economic development is reflected in the quality of its road system. In case the sub-grade made of clay is of poor, due to its low strength and high compressibility, the sub-grade calls for improvement of its strength in terms of California bearing ratio. Research has been carried out for last few decades in this field in search of alternative suitable construction materials for this purpose [1]. Researches have shown that fly ash which is the most abundant by product of Thermal Power Plants can effectively improve the subgrade strength. Also, reinforcements in the form of Geotextile layers or other fabrics or fibre can improve the subgrade strength considerably [2]. According to research, India currently produces around 100 million tonnes of fly ash a year, which presents two issues: disposal and environmental contamination [3]. If fly ash could be utilised to increase the California bearing ratio of subgrade clay, it might help reduce the current global disposal issue while also boosting subgrade strength. Using fly ash to improve subgrade, especially for soft alluvial deposits, is incredibly economical and efficient. platform. Further advantage occurs with fly ash due considering its low weight, a lower surcharge load is applied than with other building materials [4]. Because fly ash embankments may be compacted throughout a broad range of moisture content, their density varies less as the moisture content varies. Because the material is lightweight and non-plastic, it is portable and easy to handle. Fly ash gives the subgrade more strength since it has a higher California bearing ratio than clay [5]. Fly ash's pozzolanic characteristic gives the subgrade even more strength. Since fly ash is free at thermal power plants, the only expenses required are for rolling, laying and transportation. Given all of these benefits, efforts may be undertaken to use fly ash to build the flexible pavement's subgrade [6-7]. Therefore, when fly ash is employed as fill material and is accessible nearby, economy can be directly realized. It appears from their work that the California bearing ratio of subgrade clay rises when fly ash is applied on top of it or when fly ash and other materials are combined. Further it has been found that geotextile helps the subgrade in rapid strengthening process as well as in drainage [8-9]. While coming across the researches on the subgrade improvement it appears that the study on the behavior of subgrade with overlying compacted fly ash with geotextile at interface, has not been well addressed by the previous researchers [10-11].. In light of this, the current work aims to investigate how applying overlying compacted fly ash and geotextiles at the interface can increase the California bearing ratio and clay behavior [12].

This has been done through california bearing ratio tests carried out on clay, clay-fly ash and clay-fly ash-geotextile matrices together with model studies of embankments made of these matrices (Amalendu Ghosh and Ambarish Ghosh., 2009). The results of model embankment tests have been supplemented further with appropriate numerical study by employing Plaxis 2D software and the finite element approach. The outcomes of the experiment and numerical studies have been analysed from load settlement curves [13].

The following are the study's objectives: To investigate how the original clay's California bearing ratio can be improved by overlaying fly ash on top of soft clay sub-grade at varying thickness ratios (that is, the thickness of compacted fly ash to that of soft clay [14]. To compare the improved California bearing ratio of the original clay to that of the soft clay sub-grade covered in fly ash at varying thickness ratios and a At the interface, a single layer of woven geotextile [15]. To investigate, by experimental and numerical modelling, the enhancement of embankment behaviour with fly ash and geotextile through load settlement behaviour of model embankments composed of three compacted clay, clay-fly ash, and clay-fly ash-geotextile matrices. Creating a statistical model to evaluate the embankment's maximum load-bearing capability with or without geotextile at the interface and a layer of compacted fly ash on top [16].

MATERIALS

In the present investigation geometry and loading do not vary significantly in the longitudinal direction so this problem may be referred to as plain strain problem [17]. Clay system has been discretized as shown in figure 1. Each node of the element has been considered to have displacement v in the vertical direction (y) and displacement u in the horizontal direction (x) with two degrees of freedom [18]. The shape function matrix [N] establishes a relationship between the nodal displacement vector (q) and the generalised displacement vector (u) at a location within an element.

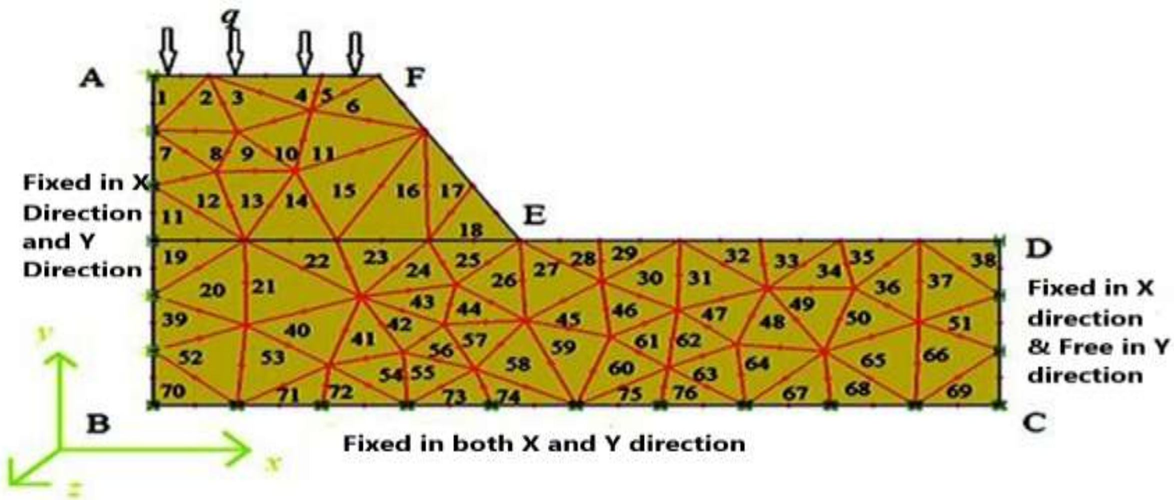

Fig. 1 : Finite element mesh with triangular elements

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$$u = \alpha1L12 + \alpha2L22 + \alpha3L32 + \alpha4L1L2 + \alpha5\ L2\ L3 + \alpha6L3L1 \quad (1)$$

Where u is the displacement vector at a location inside an element; the generalised coordinates, denoted by $\alpha1$, $\alpha2$, $\alpha3$, $\alpha4$, and so on, are unknown coefficients. L_1, L_2 and L_3 are the line elements. It may be noted that all the terms in the above polynomial are quadratic since any term which is not quadratic can be made so by proper multiplication of $L_1+L_2+L_3$ whose magnitude is equal to unity [19].

Salient features of plaxis 2d

Different salient features of Plaxis 2D Software in relation to the modelling done for the present study have been discussed in this section. Two-dimensional finite element analyses have been performed using Plaxis version 8 (figure 2). Plane strain is the model parameter's default setting in Plaxis 2D [20].

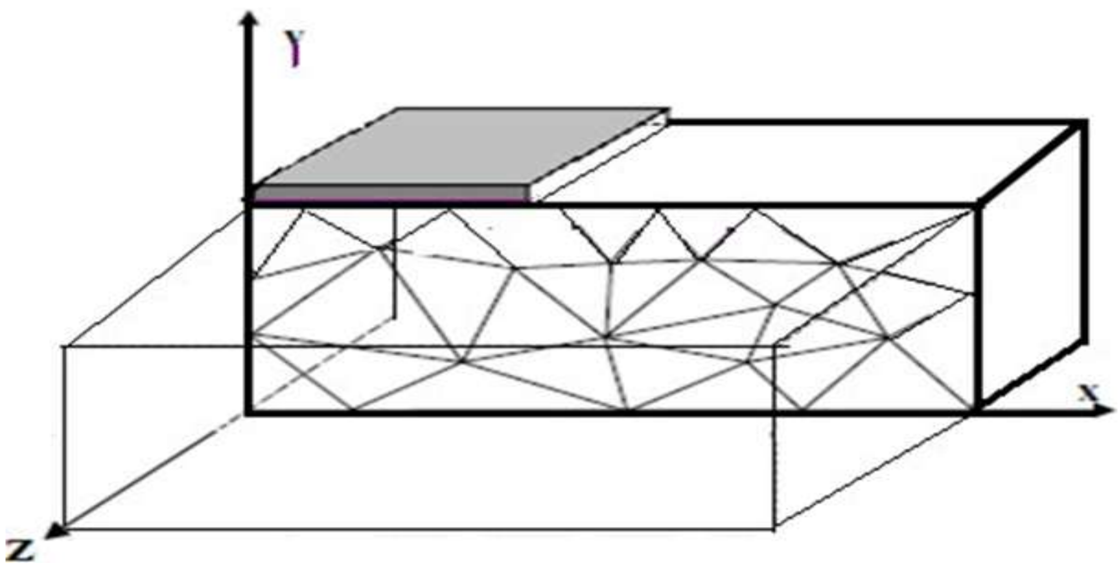

Fig. 2 : Model for plane strain condition

Interface Behaviour Parameters

In the event that interface elements are situated in the matching clay layer, the data set additionally includes parameters to extract interface attributes from the clay model parameters. The third tab sheet of the Material data set window contains the strength reduction factor Rinter, which is the primary interface parameter [21]. The behaviour of interfaces is described using an elastic-perfectly-plastic model in order to model the interaction between clay and structure. The Coulomb criterion is used to differentiate between plastic interface behaviour, which may result in permanent slippage, and elastic behaviour, which allows for minor displacements inside the interface [22].

The Geosynthetics' roles in functions in construction of dams

The uses of geosynthetics in dams are similar to those of geosynthetics in all additional geotechnical and civil engineering applications. Surface erosion, protection, strengthening, separation, planar drainage (transmission), and fluid (gas or liquid) barrier management are among the roles played by geosynthetics [23]. Construction and maintenance of dams have made use of all these features. Although confinement (for soil and sediments) is recognised as an eighth function by the International Geosynthetics Society (IGS), dam building does not use this function. Table 1 lists the functions that will be covered in more detail in this section along with typical geosynthetic examples that are utilized to fulfil each purpose in design [**24**].

Table 1. The Geosynthetics' roles in functions of the dams

Functions of Geo-synthetics	**Uses of Typical Geo-synthetics**	**References**
Particle Filtration from Soils	Nonwoven Geotextile Woven Geotextile Knitted Geotextile	Bera, Ashis Kumar (2010)

Dissimilar Material Separation	Geotextile Nonwoven Geotextile Woven Geo-composite	Huan-Lin Luoa . (2007)
Planar Drainage	The Geomat Nonwoven Geotextile The Geomat geocomposite Geomembrane with Structure (drain)	Dey, Utpal (2009)
The Reinforcement	The Nonwoven Geotextile The Woven Geotextile The Geogrid The Geo-composite	Rijnish Shrivastava (2012)
The Fluid Barrier	The geomembrane GCL in limited Geomembrane-containing geocomposite	Dygku Salma Awg Ismail (2010)
The Protection	The Nonwoven Geotextile The geocomposite	Kumar Sandeep and Mahla R.P. (2015)
Control of Surface Erosion	Controlled Erosion Geocomposites The geocells The geomat	Kumar S. P. and Rajkumar R. (2012)

METHODOLOGY

In this present research work three materials namely, locally available silty clay, Class F fly ash and woven polypropylene geotextile have been used and they are detailedbelow: Clay: Locally available soft clay (silty clay) This study employed data that was gathered from a marshy area in Anandapuri, Barrackpore, West Bengal, India [25]. Fly ash: The Titagarh Thermal Power Plant in West Bengal, India, provided the fly ash sample used in this investigation. For the current study, pond ash has been gathered and utilized (Kumar S. P. and Rajkumar R., 2012) Geotextile: The experiment employed 100% polypropylene, a commercially available high strength woven geotextile, as reinforcement material. The characteristics of these materials have been determined by conducting relevant tests [26].

Data Collection

To find out the properties of individual material the experiments have been carried out table 2 presents the names of the laboratory tests and relevant codes used for carrying out the tests. Apparent opening size of geotextile. Geotextile opening size tester (Dry Sieving) has been done in the laboratory as per ASTM D4751 By passing glass beads through the geotextile sample, the apparent opening size (AOS) of the geotextile was measured [29]. Sized glass beads were inserted on the geotextile's surface after the specimen was put in a sieve frame. To cause the beads to jar and allow them to pass through the test specimen, the geotextile and frame were shaken laterally [30]. Until the apparent opening size was established, the process was repeated on the same specimen using glass beads of varying sizes. Five tests has been conducted to establish the true opening size. The sieve diameter of 200 mm has been used for the test. Shaking time has been maintained as ten minutes for each test [31].

EXPERIMENTAL STUDIES

It frequently becomes crucial to accurately estimate the frictional resistance between soil and geotextile in problems involving their interaction. Although the fundamental concept of friction appears straightforward, it has been an issue for many years. Although friction is a problem in all engineering domains, there is currently no theory that addresses soils and geotextiles [32].. There has been some advancement in the theory of skin friction between solid materials, and some of the findings may be applicable to friction between solids and soils. Direct shear testing was used to measure the interface friction angle between geotextile-wrapped cement mortar specimens and four different soil types (sand, gravel, fine sand, and clayey sand)

[33]. Additionally, the behaviour of the cement mortar-soil contact and the geotextile-soil interface were compared. Additional expense may be required to do this, and the relationship between cost and performance is important when selecting the material. Ageotextile can enhance the mechanical and/or hydraulic behaviour of the structure it is included into by carrying out one or more tasks. The physical and engineering characteristics of the soil found in nature vary greatly [34]. This kind of investigation necessitates restricting the examination to particular soil types. For the studies on the soil-geotextile matrix, fine sandy soil (gathered from Tisaiyanvilai, Tirunelveli District, Tamil Nadu) is chosen. In a similar vein, Just five types of geotextiles glass geotextiles (GG), carbon geotextiles (CG), basalt geotextiles (BG), aramid geotextiles (AG), and polypropylene geotextiles (PG) were chosen for this study from among the many varieties that are available. These types are anticipated to be more appropriate for use in roads and embankments [35]. . All of the chosen soils' pertinent characteristics were ascertained in the lab using the most recent Bureau of Indian Standard Specifications. The goal of this study is to increase soft soil's bearing capacity using geotextile reinforcement. Its primary goal was to raise fine sandy soil's CBR value. This Paper provides an overview of the laboratory testing of these materials' characteristics [36].

Geotextiles

A soil that has been strengthened with a substance that can withstand tensile loads and interacts with the soil through adhesion and/or friction is known as reinforced soil. Permeable textiles called geotextiles are used to strengthen soil. It can separate, filter, fortify, protect, or drain when applied to soil. The idea of using geotextiles for reinforcement is not new [37]. One of the earliest instances of the use of soil reinforcement is the almost 3,000-year-old ziggurats discovered in Iraq. The Romans built reed-reinforced earth levees along the Tiber River. The creation of reinforced earth retaining walls and the geotextile stabilisation of access and haul roads in the 1960s marked the beginning of the current applications of soil reinforcement [38]. Geotextiles are utilised to strengthen soil. It has been used to stabilise thin soil and repair failing slopes locally. Another fiber-based reinforcement technique, unlike geosynthetics, is used by randomly spreading the fibre. Fiber-reinforced soil has effects that are comparatively comparable to those of geosynthetic-reinforced soil for both coarse grained and fine-grained soils, including boosting soil strength and bearing capability [39]. .

Geotextiles made of basalt

The very fine fibres of basalt, which is made up of the minerals olivine, pyroxene, and plagioclase, are used to make basalt geotextile. It has a similar chemical makeup to glass geotextile fibre, but it is stronger and, in contrast to most glass geotextile fibres, it is far more resistant to salt, acid, and alkali assault, which makes it an ideal choice for coastline and concrete structures [40]. The tensile strength of basalt geotextile fibre is between 2800 and 4800 N/mm2. It has a wider range of applications than carbon and aramid geotextile fibres, including a temperature range of 452°F to 1200°F, greater resistance to oxidation and radiation, stronger compression strength, and high shear strength [41].

Geotextiles Made of Carbon

Carbon crystals aligned along a long axis make up carbon geotextile fibre. The ribbon is strong throughout its long axis because of its crystal structure. The grain orientation affects the strength of the carbon geotextile fibres. High-tensile carbon geotextile fibre, also known as whisker, is created by heating petroleum wastes, rayon, or polyacrylonitrile fibres to the proper temperatures. Carbon geotextile fibres are more than 90% carbonised and can have a diameter of 7 to 8 microns. Among all the fibres used in geotechnical and structural applications, carbon geotextile fibre offers the broadest range of strength and stiffness [42].

Glass Geotextiles

Glass geotextiles are the most predominant geotextiles used in the reinforced polymer industry and among the most versatile. Glass geotextile fibre has high tensile strength of about 1020 to 4080N/mm^2. Glass composites are used where the higher stiffness of carbon or aramid geotextiles are not required and do not need the high chemical and alkali resistance of basalt geotextile fibre. Glass geotextile fibres are useful thermal insulators because of their high ratio of surface area to weight. However, the increased surface area makes them much more susceptible to chemical attack. In contrast to carbon geotextile fibre, glass can undergo more elongation before it breaks [43].

Polypropylene Geotextiles

Polypropylene geotextile fibre is the most common synthetic fibre used as a reinforcement material for the soil reinforcement and concrete. Polypropylene is found to be suitable to increase the impact strength. Polypropylene geotextile fibre possesses very high tensile strength, but due to its low modulus of elasticity and high elongation they do not contribute to the flexural strength. Polypropylene geotextile fibre has properties of hydrophobic, non-corrosive resistance over chemicals, alkalis and chlorides. Reinforcing soil with polypropylene fibre can increase unconfined compressive strength and shear strength [44].

Geotextiles made of glass

Glass geotextiles are among the most versatile and widely used geotextiles in the reinforced polymer sector. The high tensile strength of glass geotextile fibre ranges from 1020 to 4080 N/mm². When the greater rigidity of carbon or aramid geotextiles is not needed, or when the excellent chemical and alkali resistance of basalt geotextile fibre is not needed, glass composites are utilised. Glass geotextile fibres' high surface area to weight ratio makes them effective thermal insulators. But because of their larger surface area, they are far more vulnerable to chemical attack. Glass can withstand more elongation before breaking than carbon geotextile fibre [45].

The geotextiles made of polypropylene

The most popular synthetic fibre used as a reinforcement material for concrete and soil reinforcement is polypropylene geotextile fibre. It has been discovered that polypropylene works well for boosting impact strength. Although polypropylene geotextile fibre has a very high tensile strength, its high elongation and low modulus of elasticity prevent it from contributing to flexural strength [17-18]. The hydrophobic and non-corrosive qualities of polypropylene geotextile fibre make it resistant to chemicals, alkalis, and chlorides. Polypropylene fibre reinforcement of soil can improve its unconfined compressive and shear strengths (Figure 3) [19-20].

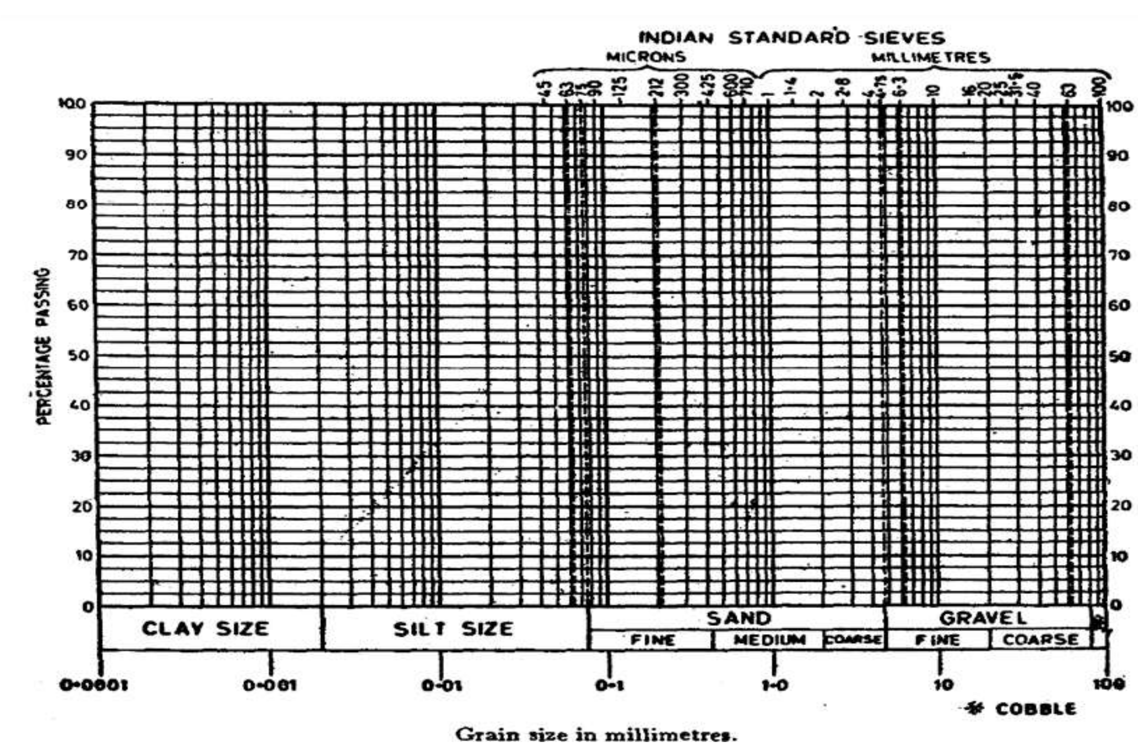

Fig 3. Grain Size Distribution Chart IS 2720.

Analysis of Sieves

A set of common sieves was used to do the sieve analysis. Two pairs of wires were woven at right angles to each other to create sieves. The restriction that is provided by the square holes that are thus created between the wires. The process of sieving was carried out by stacking the several sieves one on top of the other according to the mesh openings; the pan was placed beneath the finest sieve, and the coarsest sieve was kept at the top. The entire assembly was preserved with a receiver at the bottom and a cover at the top. The entire system was mounted on a sieve-shaking machine, with the soil sample placed on the upper sieve [21-22]. Establishes the dimensions of the particles that are retained on a specific sieve. A series of sieves that produce equal grain size intervals on a logarithmic scale is typically used. Using a nest of sieves, with each sieve having an aperture around half the size of the coarser sieve above it in the nest, allows for a proper spacing of soil particle diameters on the grain size distribution curve (Figure 4 & Table 2). The process of sieving was carried out by stacking the several sieves one on top of the other according to the mesh openings; the pan was placed beneath the finest sieve, and the coarsest sieve was kept at the top [23-24].

Table 2: Analysis of Sieves Relationship

IS. Sieve Size	Weight Retained in gms	% of Weight Retained	% of Cumulative Weight Retained	% of Passing
4.75mm	0	0.0	0.0	100.00
2.36mm	0	0.0	0.0	100.00
1.18mm	5	1.0	1.00	99.00
600µ	60	12.0	13.00	87.00
300µ	175	35.0	48.00	52.00
150µ	160	32.0	80.00	20.00
75µ	45.00	9.0	89.00	11.00
pan	55.00	11.0	100.00	0.00

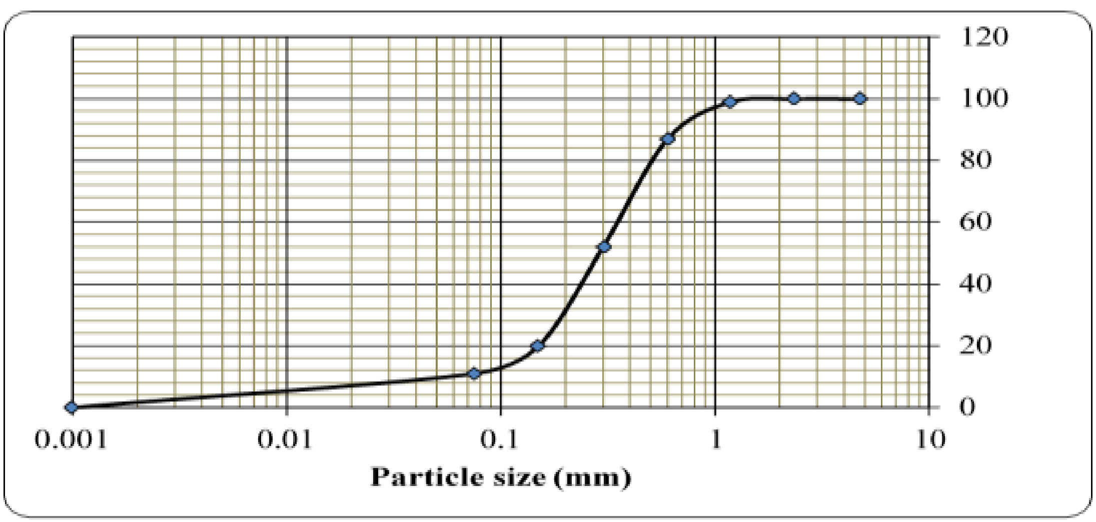

Fig 4. Distribution Curve of Grain Size

Soil Specific Gravity Test

The ratio of the unit weight of soil solids to that of water is known as the specific gravity of soil. Numerous techniques are used to determine it, and they are. The density bottle approach The Pycnometer method the gas jar method the shrinkage limit technique. The flask method of measurement. The Pycnometer method and the density bottle method are straightforward and widely used techniques. The Pycnometer method is used in this study to determine the specific gravity of the soil. Empty weight (M1), empty + dry soil (M2), empty + water + dry soil (M3), and Pycnometer filled with water (M4) at room temperature were the four scenarios in which it was weighed using the Pycnometer method. The formula below calculates the specific gravity of these four masses (equation 1) [25].

$$G = \frac{(M2 - M1)}{(M2 - M1) - (M3 - M4)} \tag{1}$$

Test of Proctor Compaction

The Proctor test is another name for this soil compaction test. The mass of dry soil per cubic metre is calculated using it. The maximum dry density at the ideal moisture content is obtained when the soil is compacted over a range of moisture levels. As a result, this test gives the compaction properties of several soils with varying moisture contents. This is accomplished by decreasing the air gaps in the soil, which densifies it. The dry density of the soil is used to estimate the degree. At the ideal water content, the dry density reaches its maximum [26]. The purpose of Proctor's test is to ascertain the soil's compaction properties. Compaction is simply the process of densifying the soil to reduce air gaps. The dry density of the soil is used to quantify the degree of compaction. The Proctor test mould with hammer is depicted in Figure 3 & 4 [27-28].

Study of California bearing ratio of different matrices

California bearing ratio (california bearing ratio) tests have been conducted in accordance with IS: 2720 for both light and heavy compaction for clay, fly ash, and matrices of clay-fly ash and clay-fly ash-geotextile in order to examine the improvement of the California bearing ratio of clay-fly ash matrix and clay-fly ash-geotextile matrix in comparison to that of only clay [29]. Different moulding moisture contents (16%, 22%, 28%, 34% for Standard Proctor compaction and 12%, 18%, 24%, and 36% for Modified Proctor compaction) and thickness ratios (1:2, 1:1, and 2:1), which are defined as the ratio of fly ash to clay thickness, were used in the tests for the matrices [30]. The moulding moisture contents have been increased to find the effect of softening of clay as its moisture contents approach to liquid limit. This data deals with the test programmes and presentation of test results for California bearing ratio of clay, fly ash as well as different matrices of clay, fly ash and geotextile [31].

RESULTS AND DISCUSSION

California bearing ratio of clay of the test programme Proctor energy

Accordingly, these materials consist of a membrane, which often indicates something thin and flexible and is mainly employed for liquid containment or waterproofing. Flexible Membrane Liners (FMLs), pond liners, synthetic liners, or just plastic liners are all referred to by the previous terms. In any case, the main application was for liquid containment or for waterproofing a structure [32]. Table 3 presents the test program for fly ash, clay, clay, clay-fly ash composite matrix, and clay-fly ash-geotextile matrix using standard and modified Proctor energy, respectively. Eight Penetrated California bearing ratio tests (Table 3 and Figure 5) were performed on clay, with the sample height being kept at 127 mm and the moulding moisture content of the clay varied .The remaining four digits had modified Proctor compaction energy, while the other four had conventional Proctor compaction energy. According to SATU, geomembranes are "essentially impermeable geosynthetics composed of one or more synthetic sheets [33].

Table 3: Test Programme Proctor energy for penetrated california bearing ratio of clay

Sl. No.	Ht. of clay (h_s)	Moulding water content of clay (%)	
		Standard Proctor energy	Modified Proctor energy
1	127	16	12
2	127	22	18
3	127	28	24
4	127	34	30

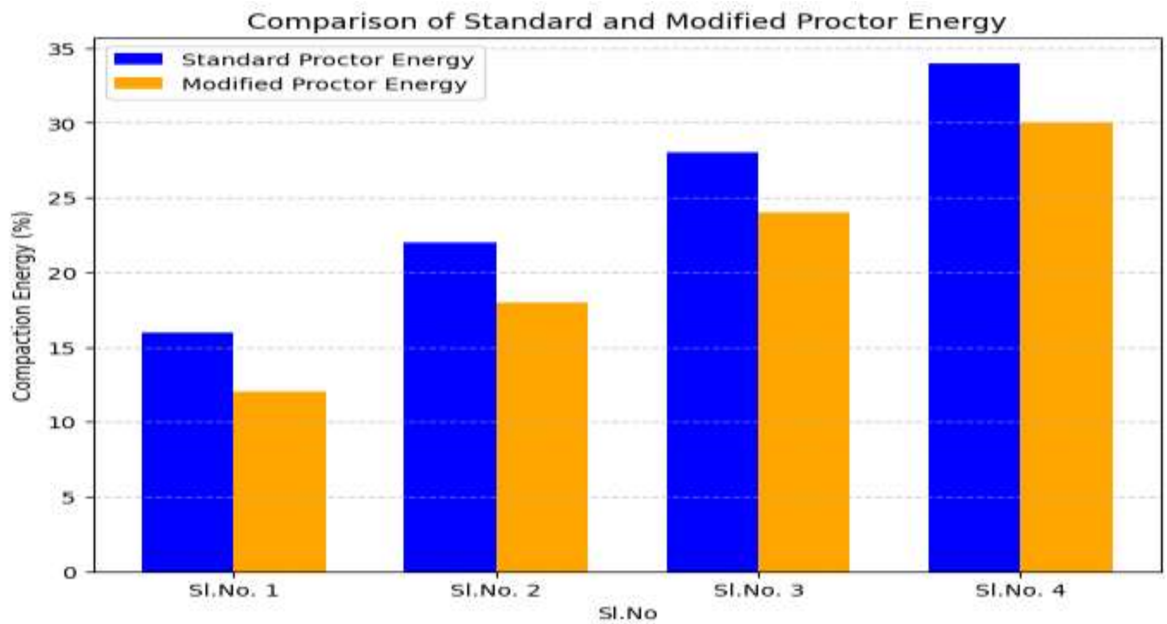

Fig.5: Comparison between the standard and modified Proctor Energy

Test programme for penetrated california bearing ratio of fly ash

For fly ash, total two numbers of penetrated California bearing ratio tests (Table 4) among which one test with standard Proctor compaction energy and the remaining one with modofied Proctor compaction energy, have been conducted varying the moulding moisture content of fly ash and maintaining the sample height as 127mm. From fabric overlap, seam joining with pins or staples, heat sealing, or fixing seams with adhesives, geotextiles have developed into sewed seams [34]. The stitching of seam junctions is the finest option. Sewn seams can save labour expenses, speed up the installation process, and produce better outcomes by doing away with the needless overlapping of cloth [35]. It is decided to sew seams together; however, the type of seam and stitch must be chosen. For geotextile field stitching, there are three main types of seams that can be utilised. The single-thread chainstitch and the two-thread chainstitch are the only two stitch types that work well for field sewing geotextiles. and penetrated California bearing ratio of fly ash (figure 6) [36].

Table 4 : Test programme for penetrated California bearing ratio of fly ash

*Moulding water content of clay (%)	
Standard Proctor energy	Modified Proctor energy

41	28

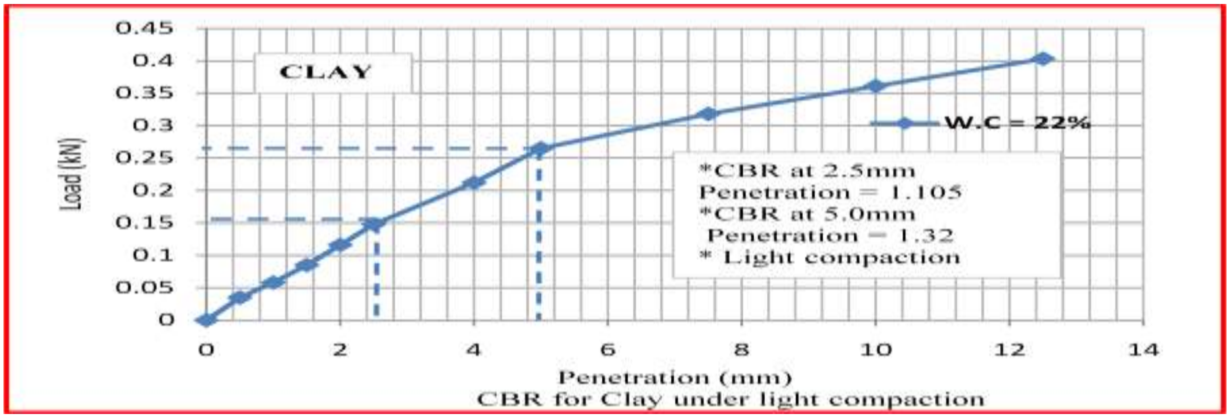

Fig.6: Penetrated California bearing ratio for Clay under light Compaction

The fly ash-clay composite matrix wet California bearing ratio without geotextile

According to Adams and Collin (1997), geosynthetic clay liners (GCLs) are geocomposites utilised as a low permeability liquid barrier, typically in conjunction with a geomembrane (i.e., composite liner system in landfills). For clay–fly ash composite matrix, total twenty-seven numbers of California bearing tests (Table 5) were conducted, with varying parameters such as moulding moisture content and sample thickness of clay and fly ash and maintaining the total sample height of 127mm. Among these tests, twelve were 15 of them had Modified Proctor compaction energy while the remaining 15 had Standard Proctor compaction energy. "A manufactured hydraulic barrier consisting of clay bonded to a layer or layers of geosynthetic materials" is how ASTM defines a GCL. According to A.K. Choudhary (2010), the clay layer is typically a 0.2 to 0.4 inch (5 to 10 mm) thick layer of sodium bentonite that is adhered to a geomembrane or sandwiched between two geotextiles. The final mat is often stitched together by needlepunching if it is made from two geotextiles. The GCL offers a low permeability barrier once it is hydrated and subjected to normal load, which is typically at least three feet of soil. GCLs come in rolls up to 16 feet (4.9 meters) wide, and when under load, the overlaps are "seamed" using granular bentonite to create a seal (figure 7) [37].

Table 5 :Test programme for fly ash-clay composite matrix wet california bearing ratio without geotextile

Sl. No.	Ht. of fly ash (h_f) (mm)	Ht. of clay (h_s) (mm)	fly ash: clay (h_f/h_s)	*Moulding water Content of Clay (%)	
				Standard Proctor energy	Modified Proctor energy
1	84.0	43.0	1:2	12	16
2	63.5	63.5	1:1	12	16
3	43.0	84.0	2:1	12	16
4	84.0	43.0	1:2	18	22
5	63.5	63.5	1:1	18	22
6	43.0	84.0	2:1	18	22
7	84.0	43.0	1:2	24	28
8	63.5	63.5	1:1	24	28
9	43.0	84.0	2:1	24	28
10	84.0	43.0	1:2	30	34
11	63.5	63.5	1:1	30	34
12	43.0	84.0	2:1	30	34
13	84.0	43.0	1:2	36	-

14	63.5	63.5	1:1	36	-
15	84.0	43.0	2:1	36	16

* The fly ash's moulding water content (MWC) has remained at 41%.

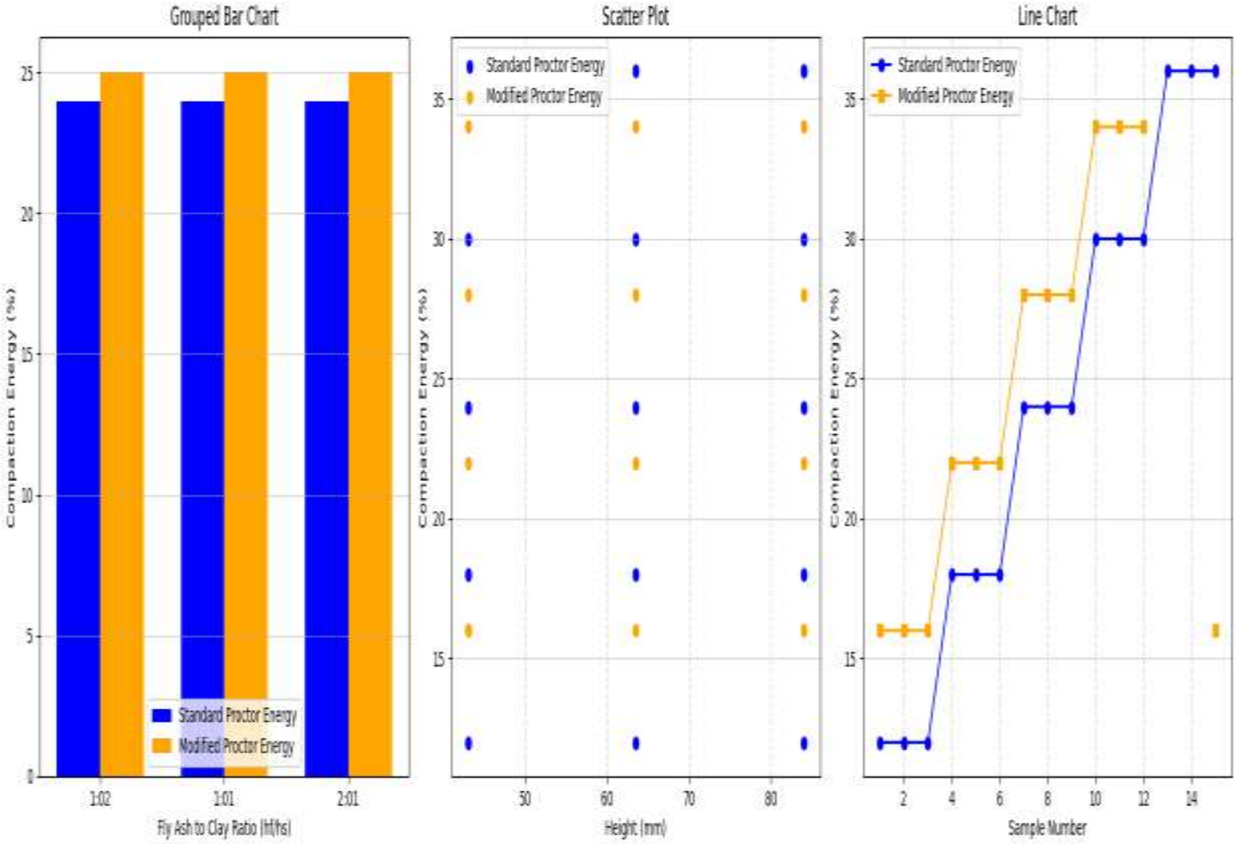

Fig.7: The California bearing ratio without geotextile of fly ash-clay composite matrix wet between the standard and modified Proctor Energy

California bearing ratio of fly ash, clay, and geotextile composite matrix at the interface.

The total of twenty-seven California bearing ratio experiments were conducted on the clay–fly ash–geotextile composite matrix. (Table 6) have been conducted varying different parameters such as moulding moisture content and sample thickness of clay and fly ash and maintaining the sample height fixed as 127mm**.** **A**mong these, twelve numbers were for the remaining fifteen values' Standard Proctor compaction energy and Modified Proctor compaction energy, respectively [38]. To check for repeatability, every test was run twice. Results can vary by up to ±0.5%, with an average value being used to determine the outcome of each test. Tests for Penetrated california bearing ratio have been performed on every sample (Table 6 & figure 8). after soaking each sample for four days as per IS 2270[39].

Table 6: Fly ash-clay composite matrix with geotextile at the interface penetrated the California bearing ratio.

Sl. No.	Fly ash height (hf) (mm)	Clay's height (hs) (mm)	fly ash: clay (h_f/h_s)	*Clay's moulding water content (%)	
				Standard Proctor energy	Proctor energy modified
17	84.0	43.0	1:2	12	16
18	63.5	63.5	1:1	12	16

19	43.0	84.0	2:1	12	16
20	84.0	43.0	1:2	18	22
21	63.5	63.5	1:1	18	22
22	43.0	84.0	2:1	18	22
23	84.0	43.0	1:2	24	28
24	63.5	63.5	1:1	24	28
25	43.0	84.0	2:1	24	28
26	84.0	43.0	1:2	30	34
27	63.5	63.5	1:1	30	34
28	43.0	84.0	2:1	30	34
29	84.0	43.0	1:2	36	-
30	63.5	63.5	1:1	36	-
31	43.0	84.0	2:1	36	-

* The fly ash's moulding water content (MWC) has remained constant at 41% across all instances.

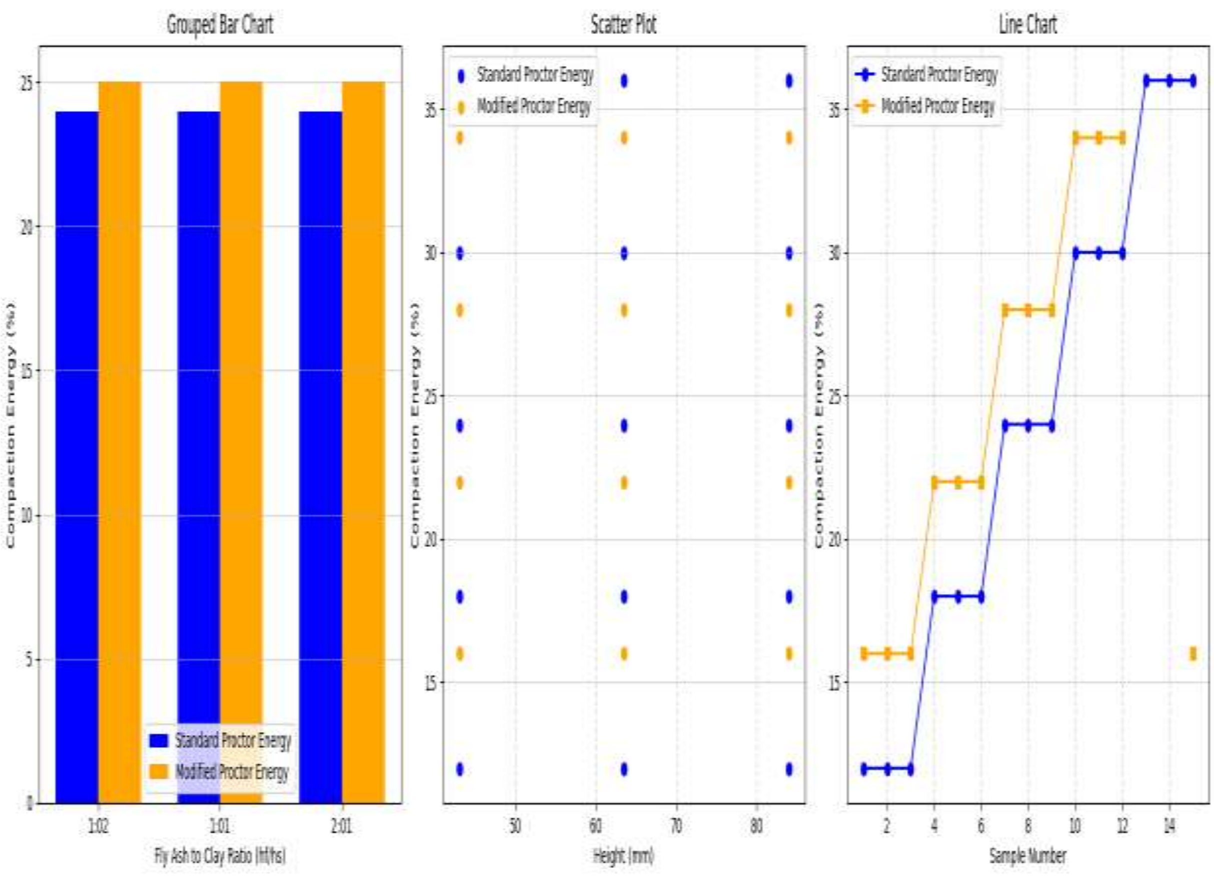

Fig.8: The California bearing ratio without geotextile of fly ash-clay composite matrix wet between the standard and modified Proctor Energy

4.5 Clay and fly ash carrying ratio value for California

The penetrated california bearing ratio values for clay, California bearing ratio tests were conducted using the test schedule displayed in Table 7 to acquire fly ash, clay-fly ash, and clay-fly ash-geotextile matrices. According to Long V. P. and Lee C. H. (1994), geotextiles are directly related to technical textiles or common textile industry goods. To investigate how different matrices (clay-fly ash and clay-fly ash geotextiles) improve the bearing ratio for California in comparison to clay alone, the California bearing ratio values of clay have been studied at OMC and also at other moulding water contents [40]. Further compaction properties of fly ash are also necessary as it has been used as a component of different matrices. Hence load-penetration curves of clay and fly ash have been obtained by relevant california bearing ratio tests and the curves for clay have been presented and that for fly ash in figure 9 and the results are summarised in Tables 7 for Standard and Modied Proctor energy respectively [41].

Table 7 : The Fly ash and clay's penetrated california bearing ratio values (%).

Type	Depth (mm)	Moulding water content (MWC)				
		(34%)	(41%)	(16%)	(22%)	(28%)
Clay	127	0.24	-	3.24	1.32	0.39
Fly ash	127	-	20.10	-	-	-

*Samples made with compaction energy measured by Standard Proctor.

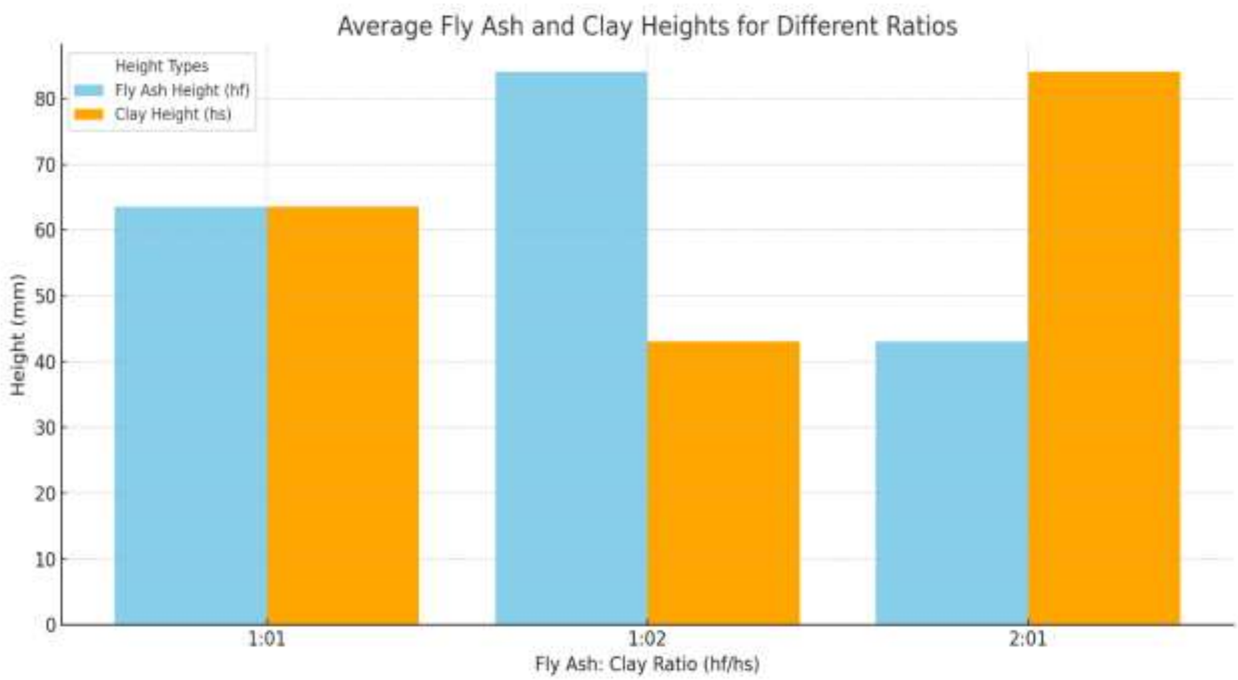

Fig. 9: The Fly ash and clay's penetrated California bearing ratio values of Ratios

Data for the penetrated California carrying ratios of fly ash and clay

Bearing ratio for California To find the soaking California bearing ratio values for clay, fly ash, clay-fly ash, and clay-fly ash-geotextile matrices, experiments were carried out using the test schedule shown in table 8 and figure 10. Geotextiles are directly related to technical textiles or common textile industry goods. The clay's California bearing ratio values have been investigated at OMC and at various moulding water contents in order to examine how the bearing ratio for California is improved by various matrices (clay-fly ash and clay-fly ash geotextiles) in comparison to that of simply clay [42].

Table 8: Fly ash and clay's penetrated California bearing ratio values (%).

Type	Depth (mm)	Moulding water content (MWC)				
		(28%)	(30%)	(12%)	(18%)	(24%)
Clay	127	-	0.22	3.87	2.16	0.51
Fly ash	127	25.93	20.10	-	-	-

** The samples were made with compaction energy derived from Modified Proctor.

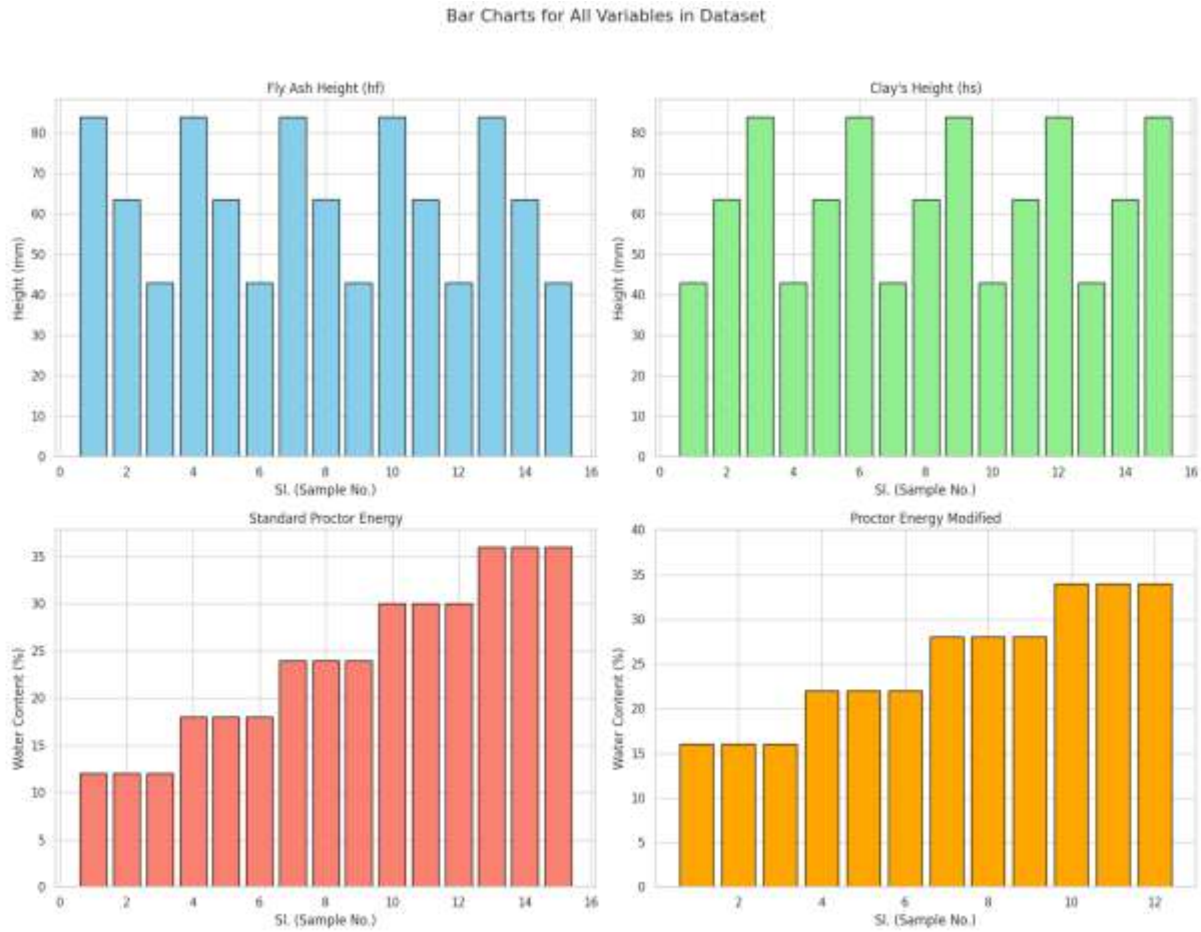

Fig. 10 : Fly ash and clay's penetrated California bearing ratio values

California bearing ratio values (%) of a composite matrix made of fly ash and clay without geotextile

Penetrated California bearing ratio tests of clay-fly ash matrices have been conducted maintaining different thickness ratios of fly ash to clay as 1:2, 1:1 and 2:1 and varying moulding water contents of clay at 16%, 22%, 28% and 34% using light compaction and 12%, 18%, 24%, 30% and 36% using heavy compaction [43]. The water content of fly ash for the tests have been maintained as 41% in all this cases i.e., at OMC of fly ash for light compaction. Load-penetration curves for all these tests have been presented in figure 11 and figure 12. Each test has been repeated twice for ensuring the repeatability and average california bearing ratio value for each test has been summarized in Table 9 &10 for both conventional and modified Proctor compaction energy, as a result. Improvement factor (IF) regression model for a non-dimensional parameter [44]. The development of a regression model to evaluate the ultimate load carrying capability of embankment matrices with a compacted fly ash layer on top and with or without geotextile at the fly ash and clay interface has been attempted. Tables 9 and 10 define the non-dimensional parameter if as follows [45].

Table 9: used the Standard Proctor compaction energy to penetrate the California bearing ratio test findings for the clay-fly ash matrix without geotextile at the interface..

Test no.	Fly ash clay	Clay's water content (%)	Water content of fly ash (%)	At 2.5mm penetration, the California bearing ratio (%)	At 5.0mm penetration, the California bearing ratio (%)	California bearing ratio calculated as a percentage	average California bearing ratio taken (%)
1.	1:2	16	41	11.645	11.545	11.645	11.64
2.	1:2	16	41	11.630	11.515	11.630	
3.	1:1	16	41	12.991	14.338	14.338	14.29
4.	1:1	16	41	13.678	14.233	14.233	
5.	2:1	16	41	17.448	17.113	17.448	17.21
6.	2:1	16	41	16.971	16.757	16.971	
7.	1:2	22	41	4.106	2.685	4.106	4.50
8.	1:2	22	41	4.896	3.369	4.896	
9.	1:1	22	41	7.580	7.645	7.645	7.97
10.	1:1	22	41	8.292	8.213	8.292	
11.	2:1	22	41	11.256	12.216	12.216	11.94
12.	2:1	22	41	11.123	11.673	11.673	
13.	1:2	28	41	3.632	1.648	3.632	3.71
14.	1:2	28	41	3.790	1.842	3.790	
15.	1:1	28	41	6.318	4.686	6.318	6.20
16.	1:1	28	41	6.081	5.686	6.081	
17.	2:1	28	41	10.420	9.565	10.420	10.15
18.	2:1	28	41	9.872	9.372	9.872	
19.	1:2	34	41	2.290	0.789	2.290	2.53
20.	1:2	34	41	2.760	1.053	2.760	
21.	1:1	34	41	4.343	1.158	4.343	5.33
22.	1:1	34	41	6.318	3.422	6.318	
23.	2:1	34	41	6.318	6.318	6.318	6.77
24.	2:1	34	41	6.476	7.213	7.213	

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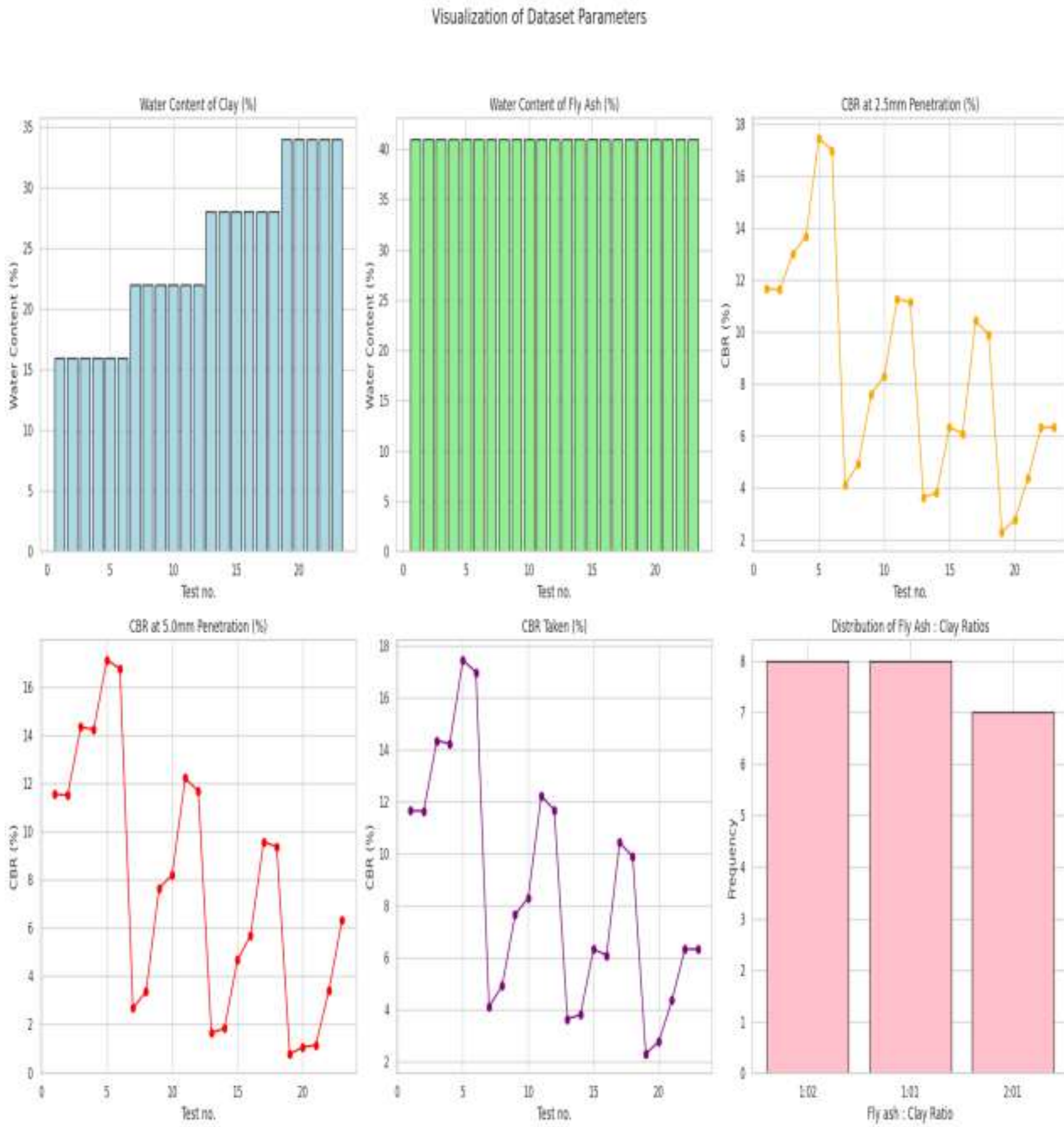

Fig. 11 :The california bearing ratio test for clay-fly ash matrix without geotextile at interface

Table 10: Penetrated California bearing ratio test results for clay-fly ash matrix without Using Modified Proctor compaction energy at the interface for geotextile.

Test No.	Fly ash : clay	Water content of clay (%)	Water content of fly ash (%)	California bearing ratio 2.5 mm penetration percentage	California bearing ratio 5.0 mm penetration percentage	California bearing ratio Taken (%)	Average California bearing ratio Taken (%)
25.	1:2	12	28	11.138	15.183	15.183	15.71

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26.	1:2	12	28	13.557	16.237	16.237	
27.	1:1	12	28	26.340	24.920	26.340	26.26
28.	1:1	12	28	25.050	26.183	26.183	
29.	2:1	12	28	30.449	32.570	32.570	32.73
30.	2:1	12	28	29.811	32.887	32.887	
31.	1:2	18	28	8.371	8.687	8.687	8.57
32.	1:2	18	28	8.450	7.634	8.450	
33.	1:1	18	28	8.450	12.320	12.320	12.90
34.	1:1	18	28	11.452	13.478	13.478	
35.	2:1	18	28	15.953	23.430	23.430	26.06
36.	2:1	18	28	15.400	28.695	28.695	
37.	1:2	24	28	4.343	3.159	4.343	4.07
38.	1:2	24	28	3.790	2.632	3.790	
39.	1:1	24	28	8.292	9.635	9.635	9.98
40.	1:1	24	28	8.371	10.319	10.319	

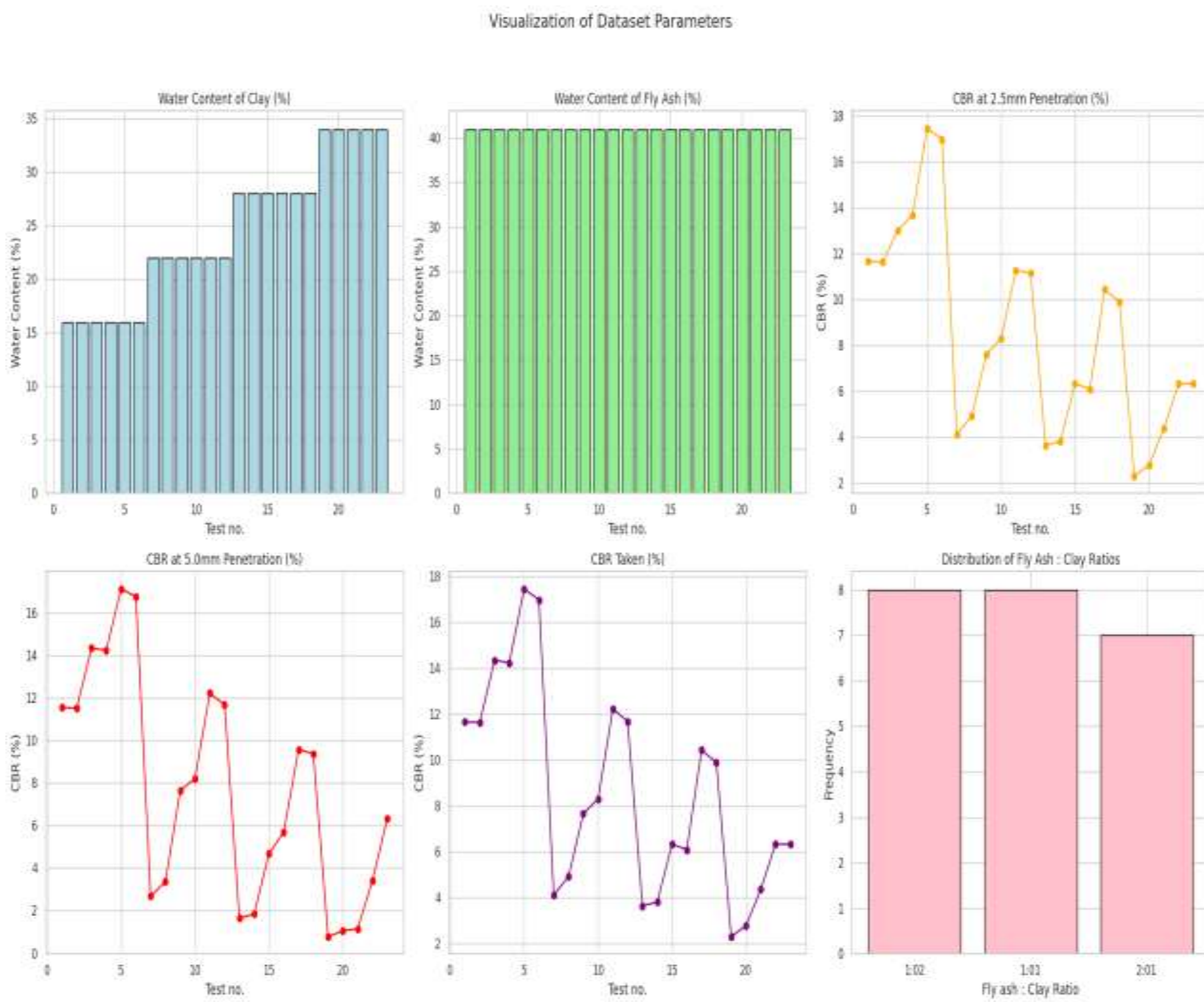

Fig. 12: The california bearing ratio test for clay-fly ash matrix without geotextile at interface

5. CONCLUSION

Several conclusions have been reached based on the findings of the California bearing ratio test as well as the experimental and numerical model studies that are reported in this paper. These conclusions are detailed individually for the California bearing ratio tests and model embankment studies below. Regarding the California bearing ratio tests on clay-flyash and clay-fly ash-geotextile matrices, the following findings can be made. The value of the California bearing ratio rises from 11.64% to 14.29% and then to 17.21% for clay-fly ash matrix with increase of thickness ratio from 1:2 to 1:1 and then further to 2:1 .In case of clay-fly ash geotextile matrix the california bearing ratio value increases from 12.00% to 14.50% and then to 18.50% for similar changes in thickness ratio for Standard Proctor compaction energy. For both matrices, there is a similar trend in the growth of the california bearing ratio value with the thickness ratio when the Proctor compaction energy is adjusted. This suggests that for both matrices, the thickness ratio significantly affects the california bearing ratio value. The California bearing ratio value is at its highest. When the moulding moisture level in a clay-fly ash matrix approaches the clay's liquid limit, compared to the corresponding OMC, the California bearing ratio drastically decreases. The California bearing ratio figure for Standard Proctor energy rose from 17.21% to 6.77% for a 2:1 thickness ratio, while the moulding moisture content rose from 16.00% to 34.00%. In comparison, the California bearing ratio value decreased from 32.73% to 8.40% for the same thickness ratio when the moulding moisture content increased from 12% to 36% in the case of Modified Proctor energy. For the clay, fly ash, and geotextile matrix, a comparable pattern has been observed, with a corresponding variation in the moulding water content. The California bearing ratio value increases for all thickness ratios and moulding moisture percentages for the clay-fly ash and clay-fly ash-geotextile matrices. as compaction energy increases. Furthermore, it is shown that the increase in compaction energy from Standard to Modified Proctor compaction energy at OMC increases from 17.21% to 32.73% with a thickness ratio of 2:1 and a clay-fly ash matrix california bearing ratio. Similar trend of increasing california bearing ratio value was observed for clay-fly ash-geotextile matrix also. This indicates that increase in compaction energy has appreciable effect of increase in california bearing ratio value for both the matrices.

Ethical Approval

Our institution does not require ethical approval for reporting individual cases or case series.

-Consent to Participate

Informed consent was obtained from all individual participants included in the study. Verbal informed consent was obtained prior to the interview.

Consent to Publish

The participant has consented to the submission of the case report to the journal.

Funding: No funding was obtained for this study.

Competing Interests: The study provided in this publication, according to the authors, was unaffected by any of their known financial conflicts or personal relationships.

Data availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.ravi.ande@lic.du.ac.in

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