Staged Pullout Testing of Extensible and Inextensible Reinforcements

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Dedicated to

My Family

Abstract

Disposal of waste material like pond ash is a major concern to environment. One of the possible applications of this type of waste material is to utilize them as backfill material in reinforced earth structures. To proper design of any reinforced earth structure, soil reinforcement interactions are important where shear and pullout are the most common internal failure modes. Pullout parameters have an important role in design of reinforced earth structure and to determine these parameters pullout test has been carried out at different samples.

In this study it is proposed to use pond ash and sand as a backfill material so, this study is carried out to determine the axial pullout resistance of smooth metal strip reinforcement and geogrids. Pond ash from Narla Tarato thermal plant, Vijaywada, Andhra Pradesh has been used. Here, a new test method has been developed named as staged pullout test (SPOT) where a model ground can be tested for two or more than two normal stress conditions. SPOT has advantage over conventional pullout test (CPOT) because CPOT requires three or more model ground to get the pullout properties and it is very difficult to maintain same properties for each model ground while for SPOT only one ground has been used to get the pullout properties. In the SPOT, normal loads are in staged condition or changing the normal load after stopping the test when pullout displacement reaches to 20 mm. In order to investigate the SPOT method, both CPOT and SPOT have been performed on the same model ground and results have been compared. From the comparison, SPOT results of smooth metal strip reinforcement were found to be closer with CPOT results for 17 kPa and 52 kPa while for 87 kPa SPOT results can be used with a factor of safety of 1.2. It has been also observed that SPOT results produce comparable results with CPOT for first 20 mm displacement irrespective of the reinforcement. For geogrids, logarithmic fitted test results are differ by less than 10% for first 20 mm displacement and 15-20% for remaining displacement up to 60 mm. The percentage change for logarithmic fitted results is going to higher when moving to higher normal stress conditions. So, SPOT method could be used instead of CPOT with a factor of safety of 1.2 to 1.3. From the results, SPOT has a probability to be used as a new pullout test method instead of CPOT.

Nomenclature

CEA – Central Electricity Authority

FA – Fly ash

SP – Poorly graded sand

HDPE – High density polythene

SW-SM – Well graded sand with silt and gravel

OMC – Optimum moisture content

COV – Coefficient of variation

CPOT – Conventional pullout test

SPOT – Staged pullout test

δ – Axial displacement

P – Axial pullout force

m, n – Hyperbolic constants

IS – Indian standard

USCS – Unified soil classification system

Cu – Coefficient of uniformity

Cc – Coefficient of curvature

Gs – Specific gravity

MD – Machine direction

CMD – Cross machine direction

LVDT – Linear variable differential transformers

DAQ – Data acquisition system

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Chapter 1

Introduction

1.1 Overview

The most abundant material that is available everywhere in the world is sand which consists of crystalline silica (quartz). With the vast utilization of sand for different activities, sand has become as one of the fast extinct materials. Sand can be defined as a coarse grained soil which consists of particle size ranging between 0.075mm to 4.75mm. The basic property that makes it suitable for construction is abundant in rocks, comparatively hard, insoluble in water and does not decompose. It is a major ingredient of mortar, concrete, and plaster etc. It can also be used in various construction activities like construction of embankment, retaining wall construction and brick manufacture, glass and electronics industry, etc. From the recent studies, sand is the most extracted material in the world (by weight), thereby we can say that in near future the world will find sand to be a scarce material. For example, in Vietnam, domestic demand for sand exceeds the country's total reserves. If this mismatch continues, world may run out of construction using sand in near future. Sand mining also has serious impacts on environment as well as people's livelihoods. At the same time, we have to think about alternative materials for sand that can be used for engineering applications and fulfill the requirements.

Pond ash is one of the most useful waste materials which is easily available and can be used in engineering applications. Pond ash is a mixture of fine fly ash and bottom ash. Fly ash is generated when coal is burnt to heat the water thereby generating the steam, which is a common process in coal-based thermal power plants. It contains metal oxides, siliceous materials, aluminous materials, and sulphur which have less pozzolonic properties. Heavy ash particles deposit near the boilers, and are termed as bottom ash. The fly ash from the electrostatic precipitators (ESPs) mixed with the bottom ash is disposed into large ponds using wet disposal method and is termed as pond ash.

According to the report published by Central Electricity Authority, New Delhi, India, (2016-17) Indian coal has high amount of ash content of order 30-45% which generates large quantity of fly ash at thermal power plants. The generation of fly ash has increased from 68.88 million-ton in 1996-97 to a level of 169.25 million-ton in 2016-17 and at the same time the percentage of utilized fly ash has increased from 9.6% to 63.3%. The amount of fly ash that was generated in 2016-17 contains 33.2% ash content. For the year 1996-97, the utilization of fly ash was 6.6 million-ton which has increased to a level of 107.1 million-ton in 2016-17. Out of this for the year 2016-17, nearly 64% fly ash has been utilized. As per Central Electricity Authority 2016-17 report, the major utilization of fly ash (Fig. 1.1) in cement industry was 14.0% and 8.8% in bricks and tiles industry, 7.0% in ash dyke raising, 6.9% in mine filling, 6.5% in reclamation of low lying area, and rest about 10% are in roads, agriculture, concrete, and hydro power sectors.

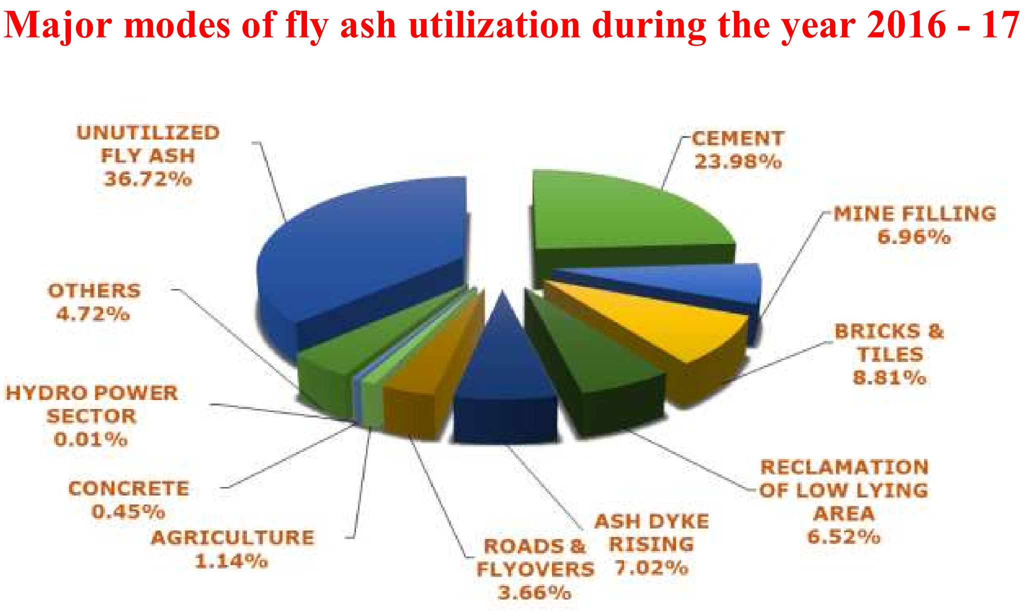


Fig 1.1 Major modes of fly ash utilization during the year 2016-17(Central Electricity Authority, 2016-17)

Pond ash can be used for various purposes, i.e., land and mine filling, manufacturing of bricks and blocks, to improve the acidic land, road construction, embankments and flyovers, raw material for cement and various geotechnical applications as a substitute of earth dust.

This study involves the use of sand and pond ash as a backfill material for reinforced earth structures. Reinforced earth is a combination of earth (soil) and linear reinforcement that are capable of resisting tensile stresses. First reinforced earth was patented by French engineer Henry Vidal in 1963. Later on, first reinforced earth structure was constructed in United States in 1971 and in India first reinforced earth structure (retaining wall) was constructed in 1986 using fly ash as a backfill material. Inclusion of reinforcement in the soil improves the interfacial bond resistance between soil and reinforcement as well as passive resistance. Some of the applications of reinforced earth structures are retaining wall, marine wall, bridge abutments, embankments, etc. (Fig. 1.2).

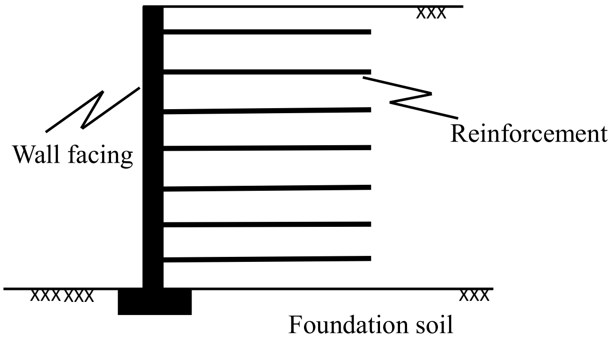


Fig 1.2 Typical reinforced soil retaining wall

Design of any reinforced earth structures considers three types of failures like external failure (base sliding, overturning and bearing capacity failure), internal failure (pullout and internal sliding failure) and facing failure (connection, column shear and topping failure) are required. Out of the three types of failures, in the present study, pullout failure (Fig 1.3) and sliding failure (Fig 1.4) are studied by performing axial pullout test and direct shear test respectively.

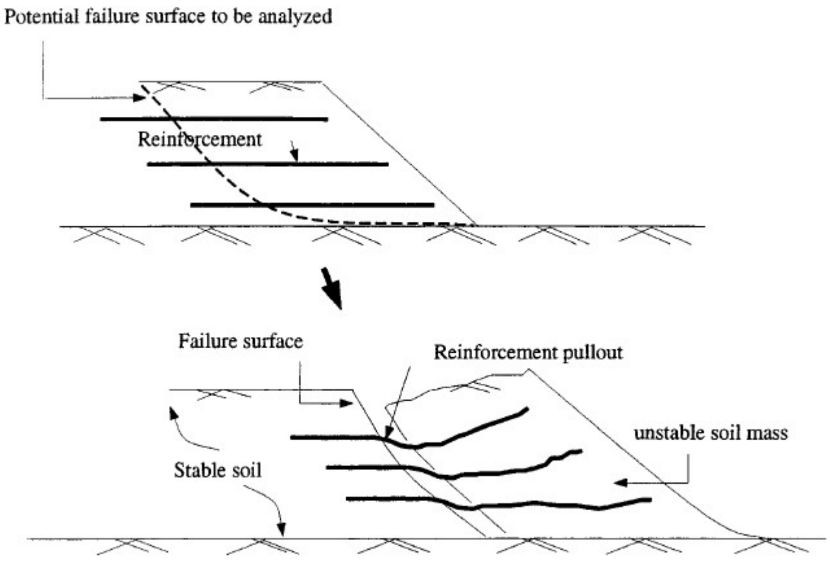


Fig 1.3 Typical sketch of Pullout failure (Mallick et al.,1996)

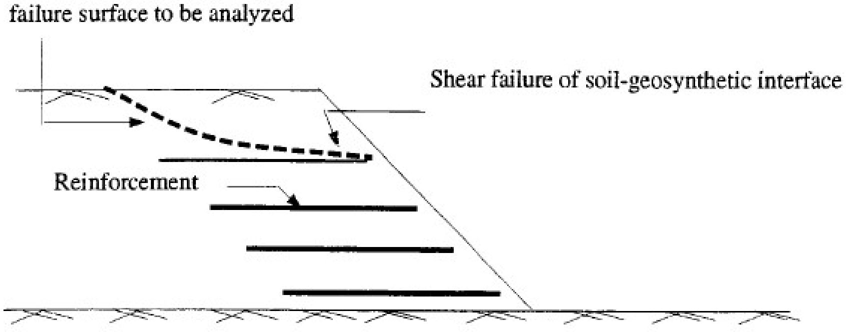


Fig 1.4 Typical sketch of sliding failure (Mallick et al.,1996)

Direct shear test is used to obtain the interface shear strength between reinforcement and backfill material (ASTM D5321) while pullout test is used to obtain the resistance offered by reinforcement due to axial pullout force (ASTM D6706). Axial pullout resistance factors are commonly considered in the design of mechanically stabilized earth walls. It is customary to perform minimum of three number of tests to develop the pullout factors considering the change in the overburden stress on the reinforcement at different levels. It is also difficult to prepare identical samples to perform pullout tests at different normal stress conditions. The practice of conducting three different tests consumes time and as well as enormous effort (manhours). The studies that are available in literature have focused only on the conventional pullout testing (where different test has to be performed for different normal stress conditions) but very limited studies were found in the literature on staged pullout testing (Ju 2004). Accordingly in the present study, staged pullout tests were conducted on smooth metal strip reinforcements and different types of geogrid embedded in sand and pond ash.

Finally, the experimental results of staged pullout testing on smooth metal strip reinforcements and geogrids were found to be in close agreement with the conventional pullout tests under the normal stresses considered in this study. The axial pullout load for higher stress condition in staged testing is slightly different from the conventional testing because of pre shearing at reinforcement-soil interface due to repetitive loading and breakage of the bond between reinforcement material and the fill material during the application of initial normal stress conditions.

1.2 Research Objectives and scope

In this thesis, we study the pullout resistance of different types of reinforcements-smooth metal strip and geogrids- embedded in sand and pond ash and the pullout resistance obtained from the experiments are helpful to design the reinforced earth structures.

The main objective of the present study is to develop a staged pullout test method to determine the axial pullout resistance of geosynthetic reinforcements. Same sample is made to subject to different normal stresses for limited axial displacements, thereby minimizing the time and manual power involved in performing the conventional pullout test. The resulted axial pullout resistances from the staged pullout testing are compared with the conventional pullout testing and factors are proposed.

1.3 Thesis Outline

Chapter 2 presents the literature available on the different factors that can affect the conventional pullout testing as well as staged pullout testing and method available in literature for staged pullout testing.

Chapter 3 provides detailed overview pullout test equipment, different properties of materials that we use for testing, details of sample preparation and method to perform staged pullout testing.

Chapter 4 presents the results of staged pullout testing and staged direct shear testing for smooth metal strip reinforcements and geogrids and also presents the comparison between conventional pullout testing and staged pullout testing.

Chapter 5 covers the conclusions made from this study.

Chapter 2

1. Literature Review

2.1 Overview

In the past few years, construction of reinforced earth structures has become popular because it has a number of advantages over concrete structures in terms of bearing capacity, differential settlement, built heights, cost of construction, the speed of construction and resistance to earthquake loading etc. In any type of reinforced earth structures, external and internal failures can happen wherein an external failure (Overturning, Sliding and Bearing failure) entire structure considered as a unit whiles in an internal failure (Shear and Pullout failure) each part of the structure studied separately. So, to design of any reinforced earth structure, pullout resistance of reinforcement is one important parameter needed to design. Most of the research studies available in literature have focused on conventional pullout testing of reinforcement (different test for different normal stress condition) but a few studies are available on staged pullout testing (single sample can be tested for two or more than two normal stress conditions at a time). In the axial pullout testing, reinforced is subjected to axial pull to get to know the soil-reinforcement interaction behavior. Different types of backfill materials can be used in the construction of reinforced earth structures. In this study, our main focus is to develop pond ash as a backfill material for reinforced earth structures.

2.2 Pond ash production

Now days, entire world is facing the problem of collection and disposal of the residues such as fly ash and sludge from the various industry. Fly ash is one of the most generated residues in thermal plants at the time of combustion. Fly ash is also known as flue ash because it comprises the micron size fine particles that rise with flue gases. The ash that cannot fly can be collected from the bottom of the furnace and termed as bottom ash. This fly ash with bottom ash is known as pond ash (Kim et al. 2005).

Nearly 73% of India's total installed power generation capacity is thermal, of which coal based generation is 90% - the remaining comprising diesel, wind, gas and steam (Pandey and Agrawal 2002). The ash content of the Indian coal contributes the large amount of fly ash. Hence, there is a need to effectively use fly ash. Therefore, the various application of fly ash is fire bricks, ceramic tiles, roads and embankments etc. Using fly ash as a backfill material can be another application in the construction of reinforced earth structures.

The thermal power plant in India consumes more than 300 million-tons of coal and generated nearly 100,000 MW power. This produces fly ash around 163.56 million-tons out of which only 61.37% is being utilized. These fly ash particles are spherical in shape and size ranges from 0.5 to 100 µm. This fly ash composed of Si, Al, Fe, Ca, C, Mg, K, Na, S, Ti, P and Mn (Ahmad et al. 2014). Fig. 2.1 shows the production and utilization of fly ash in India.

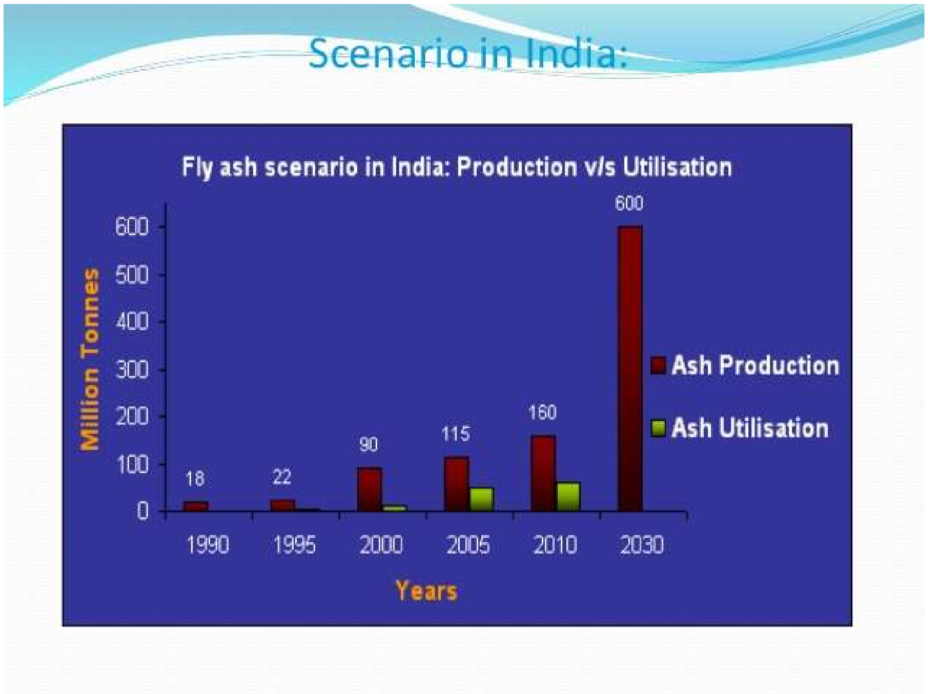


Figure 1.1 Fly ash scenario in India

2.3 Pullout resistance of reinforcement

Many research studies have done on the pullout behavior of reinforcement. These researchers have used different types of reinforcements with different backfill materials. Pullout test apparatus was designed to determine the pullout behavior of reinforcement. This test apparatus consists of a test chamber, pullout setup and loading frame etc. and reinforcement has been placed between the compacted backfill materials. Normal load has been applied through the loading device and pullout resistance has been measured. Pullout behavior of reinforcement depends on the many factors like size and shape of backfill material, test procedure, type of reinforcement etc. Significant research studies are available on conventional pullout behavior of reinforcement but a few studies are available on staged pullout behavior of reinforcement. Some of the research studies are presented in the following paragraphs:

ASTM 6706 – 01 gives the standard test method for measuring geosynthetic pullout resistance in soil. It gives the rectangular or square box of standard size with 610mm long by 460mm wide by 305mm deep. It has also given the minimum depth above and below the geosynthetics and this minimum depth is 150mm. Fig. 3.2 shows the experimental set-up for pullout test.

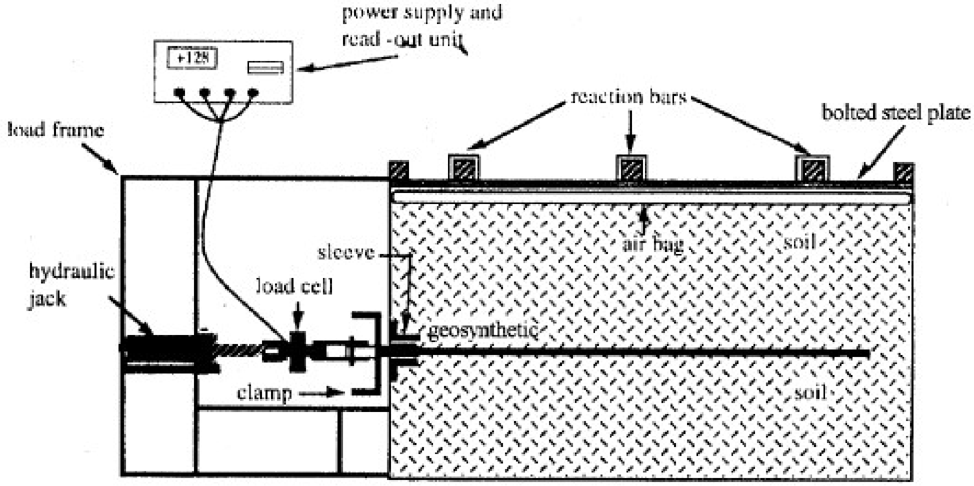


Figure 1.2 Experimental Pullout test set-up

According to ASTM, to remove the side wall friction high density polyethylene geomembrane should be bonded to the inside surface of pullout box or a lubricant can be spread on the side walls of the box or a minimum 150mm distance should be provided between the specimen and side wall. This box must allow at least 610mm embedded length beyond the load transfer sleeve. This metal sleeves transfer the force into the soil to a sufficient horizontal distance so the stress on the door of the box can be reduced by a significant amount.

Farrag et al. (1993) studied the axial pullout behavior of Tensar SR2 and Conwed-9027 geogrid reinforcements embedded in locally available blasting sand and characterized as poorly-graded sand. The minimum and maximum densities equal to 15.6 kN/m^3 and 17.4 kN/m^3 respectively. A large scale pullout box of dimensions equal to 1.52m x 0.90m x 0.76m (in length x width x height) was used and the sample was prepared by pouring the sand through a flexible outlet from the elevated hopper. Results showed that the pullout resistance of the reinforcement increased with the width of reinforcement. The author also suggested that, to minimize the side wall effect on the test results, a minimum distance of 15 cm between the edge of the geogrid specimen and the test box is required. The geosynthetic decrease the effects with an increase in the thickness of the soil layer above the reinforcement. Test results indicated that the minimum thickness of soil above and below of the reinforcement should be equal to 30 cm to minimize the effect of rigid boundaries of the test box, otherwise the boundaries have an effect on the interaction mechanism between the soil and the reinforcement. The pullout resistance of the reinforcement was found to increase with the soil density because of interaction between soil and reinforcement becomes higher. Also, test results showed that the pullout resistance is a combination of frictional resistance by longitudinal ribs as well as transverse ribs and passive resistance by transverse ribs.

Nejad et al. (2005) conducted pullout tests on geogrid reinforcement and studied the interface properties between the reinforcement and two types of soils. To determine the axial pullout resistance, a large scale pullout box of size equal to 0.3m x 0.265m x 0.370m (length x width x height) was used. Two types of soils, first silica sand classified as poorly-graded sand (SP) and the other crushed aggregate of basaltic origin were used. Test results showed that the pullout resistance of the geogrid reinforcement is the combination of frictional resistance between longitudinal and transverse ribs with soil, and bearing resistance against transverse ribs. Also, the results obtained from the pullout tests are much higher compared to the direct shear results because of mobilization of passive resistance against the transverse ribs.

Balunaini et al. (2010) studied the axial pullout behavior of ribbed metal strip reinforcement embedded in Ottawa sand and tire shred- sand mixtures. To determine the axial pullout resistance, a large scale pullout box of size equal to 1.0m x 0.38 m x 0.47m (length x width x height) was used and a pneumatically operated piston compactor was used to prepare the sample inside the test chamber. The pullout behavior was obtained for three different normal stresses equal to 40 kPa, 65 kPa and 90 kPa. The pullout force increased with displacement and peak force was noticed for all the normal stresses considered in the study. The initial shear stiffness of sand-metal strip was also found to increase with the increase in the normal stress. This is because as the normal stress increases on the surface of reinforcement, the relative displacement of reinforcement and soil decreases leading to higher interface shear stiffness.

Minazek et al. (2013) studied the soil and reinforcement interaction mechanism in reinforced soil by pullout test. Fig. 2.4 shows the possible mechanism of internal collapse in the reinforced soil embankment where zone A shows the shear in the plane of soil and reinforcement tested by direct shear test, zone B shows the lateral movement of soil and reinforcement tested by ensile test, zone C shows the direct shear test with inclined reinforcement, zone D shows the pullout of reinforcement from soil tested by pullout test. A large scale pullout box of size 1.9m x 0.9m x 1.2m (length x width x height) has been developed and a sleeve of 30cm width has also provided to reduce the impact on the front wall. The sample has prepared by vibro-compactor and test are carried out at a displacement rate of 2mm/min The pullout test results are significantly affect by the boundary conditions, clamping system, method of soil installation, compaction technique, reinforcement type and dimensions etc. Soil and reinforcement interaction mechanism depends on the grain size distribution, shear strength, grain shape, degree of compaction, density of soil and type of reinforcement, aperture size of geogrid, surface roughness and stiffness of reinforcement. It has been also reported that interaction mechanism is a combination of friction of soil particles over the reinforcement, soil interlocking in grid apertures and passive soil resistance to the grid transverse ribs.

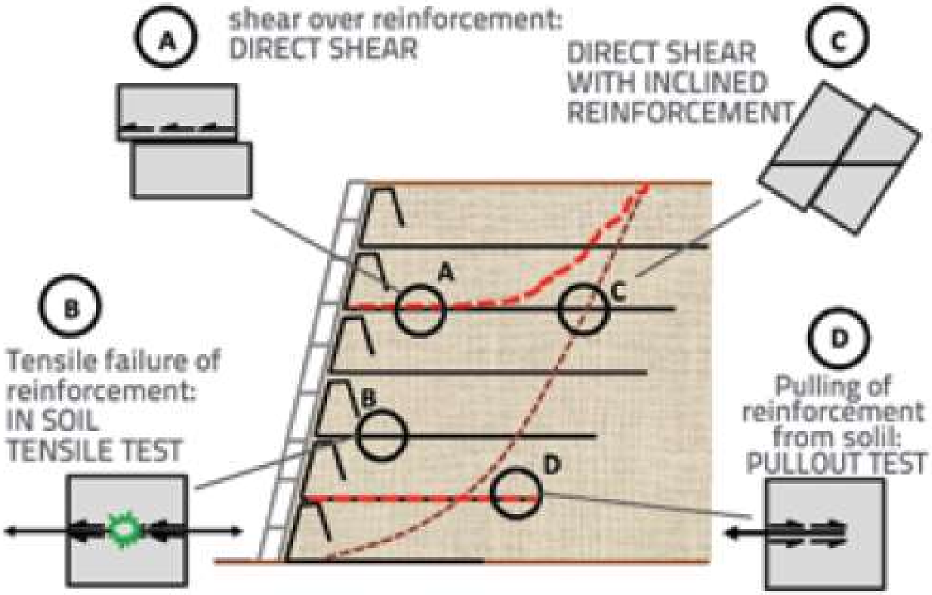


Figure 1.3 Cross section of embankment of reinforced soil with failure mechanism and tests that correspond to a particular failure mechanism

Balunaini et al. (2014) studied the axial pullout behavior of uniaxial geogrid reinforcements embedded in Ottawa sand and tire shred-sand mixtures. To determine the axial pullout resistance, a large scale pullout box of size equal to 1.0m x 0.38 m x 0.47m (length x width x height) was used and plate vibrator method was used to prepare the sample inside the test chamber. The pullout behavior was obtained for three different normal stresses equal to 40kPa, 70kPa and 100kPa. The pullout resistance of reinforcement increased with displacement and reached a critical state. Pullout resistance factors were calculated and values were found to be in the range of 0.30-0.49 for the normal stresses varying from 40kPa to 100kPa.

Ferreira et al. (2015) studied the axial pullout behavior of uniaxial geogrid reinforcement manufactured from HDPE embedded in granite residual soil and this soil was classified as SW-SM (well graded sand with silt and gravel). The minimum and maximum unit weight of soil was 13.4kN/m^3 and 18.9kN/m^3 respectively. The water content of soil was 11.5%. They have also given the influence of soil moisture content and density on the interface behavior during the pullout movement by adopting three values of soil moisture content i.e. dry half of optimum moisture (OMC) content and optimum moisture content and two values of dry unit weight (15.3kN/m^3 and 17.3kN/m^3). To determine this they have developed a large scale pullout box (Fig. 2.3) of size 1.53m x 1.0m x 0.8m (length x width x height) and to minimize the friction 0.20m long sleeve has been provided inside the box. Test results are recorded by data acquisition system and size of the geogrid was 0.33m wide and 1.0m long.

Figure 1.4 Pullout test set-up (Ferreira et al., 2015)

Pullout test was conducted under 25kPa normal stress with 2mm/minute displacement rate. From the results, it can be concluded that pullout resistance increased 56% for the dry soil, 25% for the soil at half of moisture content and 95% at moisture content when dry weight increases from 15.3kN/m3 to 17.3kN/m3. So, failure mode was highly dependent on soil density and failure caused by lack of tensile strength of the geogrid and the pullout interaction coefficient for soil-geogrid ranged from 0.33 to 0.58. For looser soil, pullout resistance at half of moisture content is higher than other moisture content and for denser soil; the influence of moisture content on pullout resistance was almost negligible.

Hariprasad et al. (2016) studied about the effect of relative density on the sand specimen during large scale laboratory testing. In this study, to compact the soil they have used two techniques named as pluviation technique and vibration technique. Indian standard Ennore sand of Grade II and III was used for the sample preparation and soil was classified as poorly graded sand (SP). To develop a full scale pluviation device, a scale-down pluviation device of 300mm x 300mm was first fabricated and calibration studies have done. Based on the calibration studies full scale pluviation device of plan dimensions equal to 890mm x 890mm (Fig. 3.12) has been developed to prepare the sample. It has been noted that drop height of sand and opening width of sieves significantly affect the relative density and with increase in height of fall relative density also increases while relative density decreases with increase in the opening width of bottom plate. For IS Grade II, if height of fall increases from 5 to 50mm relative density increased by 52 and 55% for opening width of 2mm and 4mm respectively. Similarly, for IS Grade III, relative density increased by 27 and 28% for the same height of fall and opening width. Same soil was compacted with the help of impact type piston vibrator (Fig. 3.14a) of 18kg with a rate of 15 sec per pass. When time of compaction increase from 15 to 90 sec, relative density increased by 50% and 35% for IS Grade II and 25% and 16% for IS Grade III with corresponding pressure equal to 100 and 200 kPa respectively. The COV in relative density was found to be less than about 7% in case of pluviation and less than 4% in case of vibration. Hence, vibrator method can be used for preparation of sand particles at low pneumatic pressure.

2.4 Staged pullout resistance of reinforcement

Ju et al. (2004) conducted staged pullout test on geogrid reinforcement embedded in sand and also given a estimated curve using hyperbolic function. The minimum and maximum density of sand was 1.398 gm/cm^3 and 1.654 gm/cm^3 respectively. To determine the axial pullout resistance, a large scale pullout box of size equal to 0.6m x 0.4m x 0.19m (length x width x height) was used. The model ground which has 90% relative density was tested for 20 kPa, 50 kPa and 80 kPa normal stress conditions using staged pullout test method and the results were compared with conventional pullout test method for the same normal stress conditions. Here, pullout test were performed by changing the normal stress after stopping a test if reaching about 20mm axial displacement. Hyperbolic function has been used to estimating the entire pullout curve which is:

$$P_d = \frac{\delta}{m + n\delta}$$

Where, δ = Axial displacement, P_d = Pullout force, m, n = Hyperbolic constants

To get the hyperbolic constant values, plot the curve between δ vs. δ/P where the slope and y-axis intercept of this curve give the constant values. In this method only one model ground is needed so it is a very convenient test method.

Chapter 3

2. Experimental work

3.1 Overview

The experimental program of this study consists of large scale laboratory pullout testing and direct shear testing on various types of reinforcements (metal strips and geogrids) embedded in sand and pond ash. The main objective of the laboratory testing was to find a new backfill material for retaining earth structures and develop a modified pullout test method called staged pullout test (SPOT) to overcome the problems (to minimize the time and manual power) in conventional pullout test (CPOT). Total four tests were performed on a single type of reinforcement (three conventional pullout tests at different normal stress condition and one staged pullout test). The conventional pullout tests were performed under three normal conditions, viz., 17, 52 and 87 kPa to simulate overburden pressure at depths equal to about 1, 3 and 5m respectively. The unit weight of sand was considered as 17.1 kN/m^3. Variables monitored during the test were axial pullout force, axial displacement and time at different normal stress conditions. This chapter primarily describes the pullout test set-up, direct shear test set-up, materials used in the study, sample preparation and method to conduct staged pullout testing.

3.2 Materials used

The materials that are used in the study include Vijayawada pond ash and sand as a backfill material and metal strip and geogrid as reinforcement.

3.2.1 Sand

Indian standard (IS) sand (passing through 1mm sieve and retained on 0.5mm sieve), known as Ennore sand (IS 650:1991) of grade II was used as a backfill material. Table 3.1 provides the properties of the sand used in the study. Grain-size distribution, specific gravity, the maximum and the minimum density of sand were obtained according to ASTM D422 (2007), ASTM D854 (2014), ASTM D4253 (2006), and ASTM D4254 (2006) respectively (Hariprasad et al., 2016). Fig.3.1**Error! Reference source not found.** shows the grain-size distribution curve of the sand used in the study (Hariprasad et al., 2016). As per Unified Soil Classification System (USCS) soil was classified as poorly-graded sand (SP).

Table 3.1: Physical properties of sand

Parameter	Value
Coefficient of uniformity, Cu	1.89
Coefficient of curvature, Cc	1.13
Specific gravity, Gs	2.65
Minimum density (g/cc)	1.53
Maximum density (g/cc)	1.68
Chemical composition (silica) % (http://www.tamingranites.com)	99.3
Sand classification	SP
Colour	Greyish white

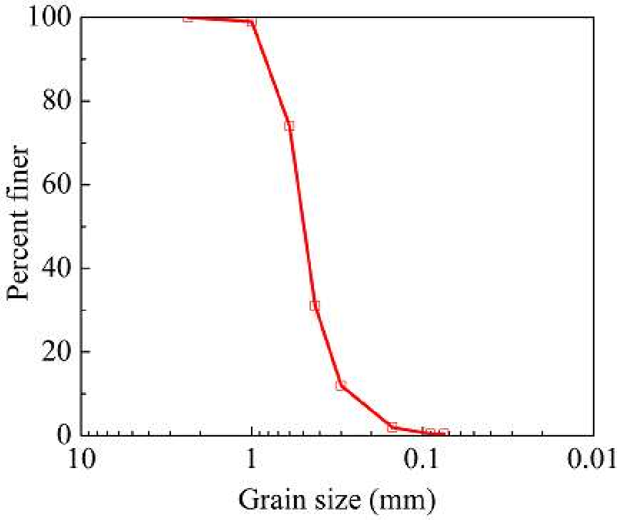


Figure 2.1 Grain-size distribution curve of sand (Hariprasad et al., 2016)

3.2.2 Pond ash

Pond ash used in the present study was collected from the Narla Tatarao thermal power plant ash pond, Vijayawada, Andhra Pradesh. The generated fly ash collected at electrostatic precipitators and bottom ash collected near the boilers were mixed and dumped in the ash ponds. The mixture of fine fly ash and bottom ash, collectively called as pond ash. Ash sample of nearly 4 tons was shipped from ash pond to IIT Hyderabad laboratories and filled in air tight bags.

Figure 2.2 Vijayawada pond ash (site view)

Figure 2.3 Collected pond ash from Vijayawada

Table 3.2: Physical properties of sand

Parameter	Value
Coefficient of uniformity, Cu	3.07
Coefficient of curvature, Cc	1.30
Specific gravity, Gs	2.36
Sand Classification	SP
Percentage of fines	9.63%
Percentage of gravels	2.5%

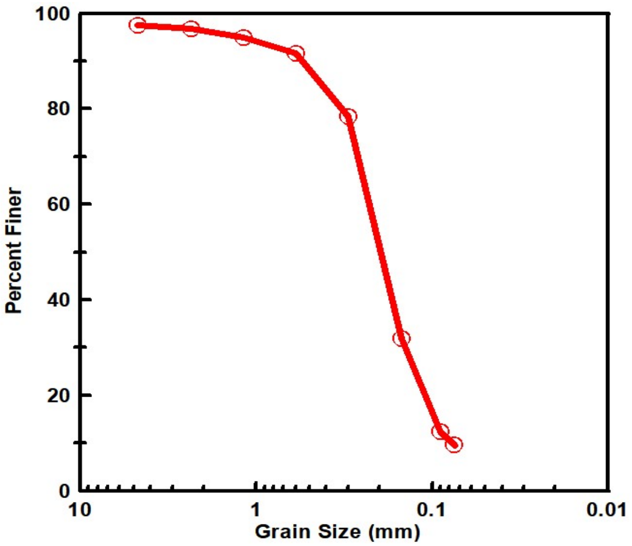
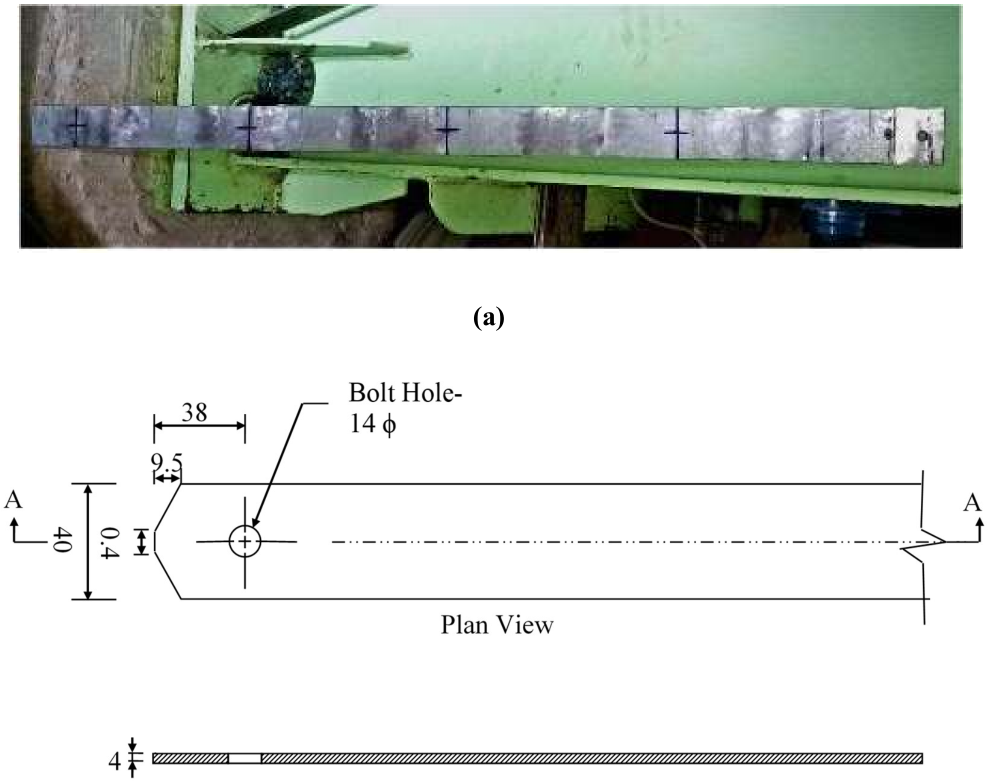


Figure 2.4 Grain-size distribution curve of pond ash

3.2.3 Smooth metal strip reinforcement

The metal strip that is used in the study was manufactured and supplied by The Reinforced Earth Company. The steel used in the fabrication of the metal strip conforms to ASTM A-572 Grade 65 (AASHTO M-223). The strips were galvanized with zinc coating to account for reinforcement corrosion under service conditions. Fig. 3.5 shows the photograph and schematic view of smooth metal strip reinforcement used during axial pullout testing. The dimensions of metal strips used for testing were 850mm long, 40mm wide and 4mm thick. Smooth metal strip can resist only frictional resistance during pullout.



(a)

(b)

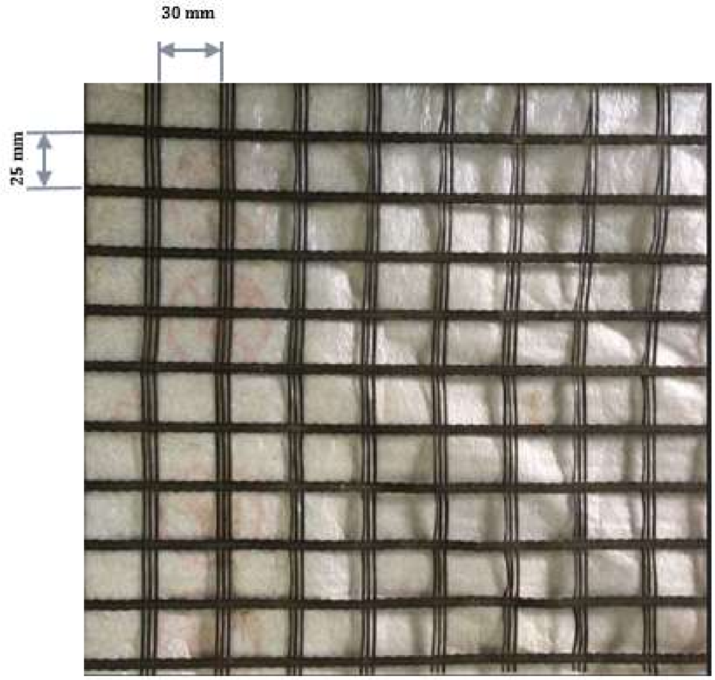
Figure 2.5 (a) Photograph of smooth metal strip reinforcement (b) Plan and sectional view of smooth metal strip reinforcement

3.2.4 Geogrid reinforcement

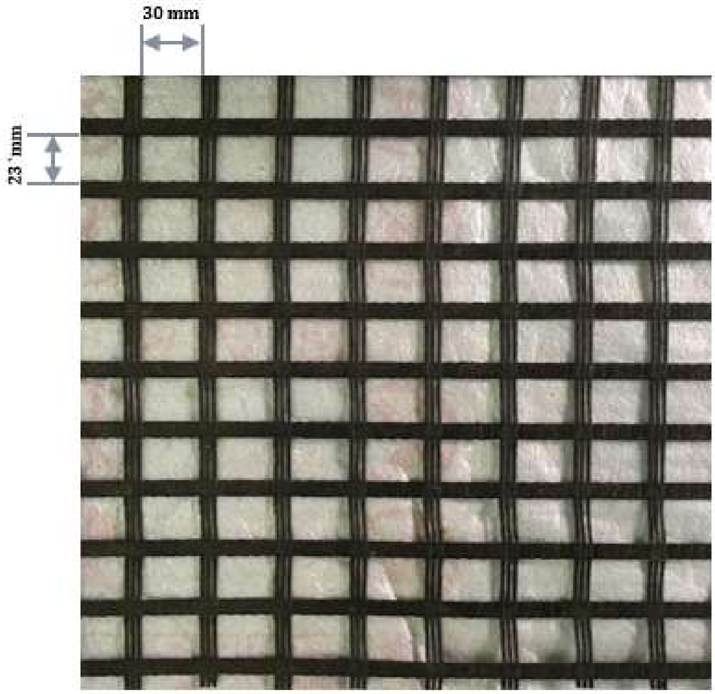
Various types of geosynthetic materials available in the market, viz., geogrids, geocells, geomembranes, geotextiles, etc. have different functions in the field. In this study, geogrids of different strengths were used for pullout testing. Commercially available uniaxial geogrid reinforcement manufactured by Techfab India and Strata Geosystems Pvt. Ltd., were used in the study. These high performance grids are uniaxial knitted polyester geogrids with a protective polymeric coating to fulfill the geotechnical requirements. These grids are mechanically and chemically durable in harsh construction installation phase and in the aggressive soil environments. Fig. 3.6 shows the photograph of different types of geogrid reinforcements used during axial pullout testing. The dimensions of geogrid used for testing were 850mm long and 330mm wide. Table 3.3 shows the different properties of geogrids.

Table 3.3: Properties of geogrids

Name of the grid	Tensile strength in Machine direction (MD)	Tensile strength in Cross Machine direction (CMD)	Aperture size (mm x mm)
TechGrid 60x30	60 kN/m	30 kN/m	30x25
TechGrid 120x30	120 kN/m	30 kN/m	30x23
TechGrid 250x30	250 kN/m	30 kN/m	30x23
StrataGrid 200x30	200 kN/m	30 kN/m	63x22



(a)



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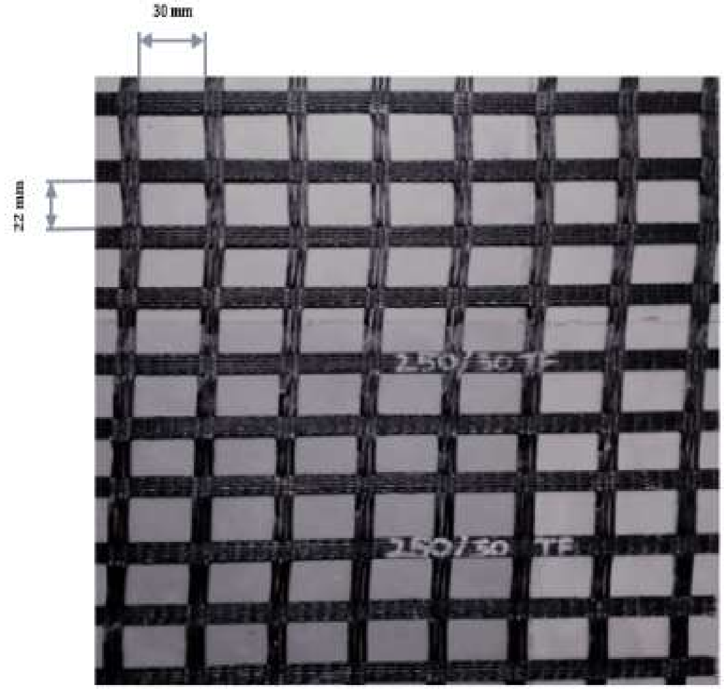

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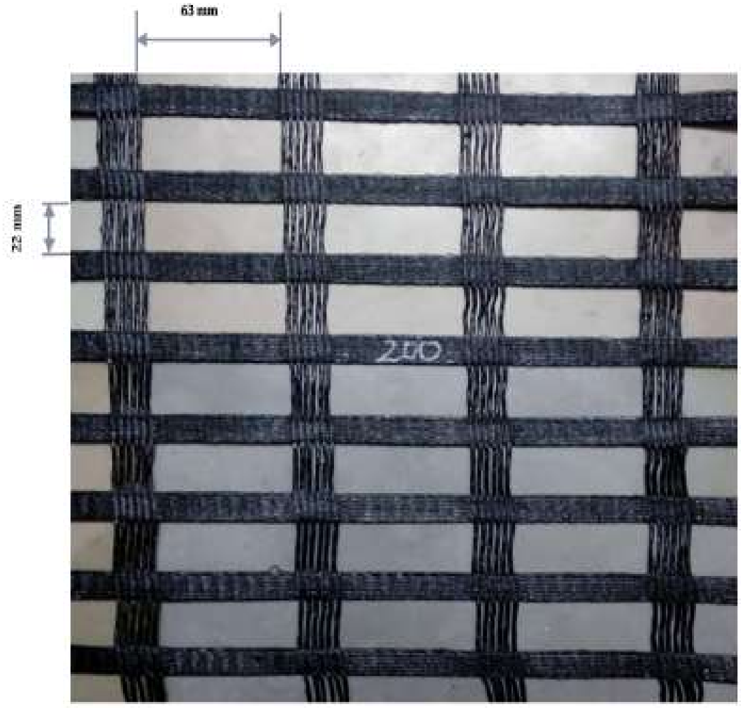


(d)

Figure 2.6 Photograph of geogrid specimens (a)Techfab India 60x30 (B)Techfab India 120x30 (C)Techfab India 250x30 (D) Strata Geosystems 200x30

3.3 Experimental setup

To study the pullout mode of failure in reinforced earth structures, axial pullout test setup is used. The following section details of pullout test setup used in the present study.

The test frame used in the study, was formerly designed to perform transverse pullout test to measure the resistance offered by the reinforcements when it is subjected to a vertical pull. Later, axial pullout setup is built in the same frame to test the axial pullout resistance for different reinforcements. The main components of the axial pullout setup are hydraulic cylinder, loading plate, guide rods, clamping plate, sleeves, load cells, DAQ (Data acquisition system), etc. Fig. 3.10 shows the photograph of axial pullout test setup. The setup was used to perform axial pullout testing on smooth metal strip and geogrid reinforcement embedded in sand and pond ash.

Figure 2.7 Photograph showing axial pullout test setup

3.3.1 Test chamber

The test chamber of size 900mm x 900mm x 1000mm (in length x width x depth) (Fig. 3.10) was used for the axial pullout testing. At a height of 520mm from the bottom of the test chamber, a slot of 400mm width and 20mm height was made on the right side wall of test chamber to allow the movement of reinforcement in axial direction during application of axial pullout force.

3.3.2 Hydraulic cylinder

Hydraulic cylinder with bore diameter of 125mm was used in the setup to pull the reinforcement sample connected to it. Oil was pumped from the hydraulic pack to hydraulic cylinder to apply the desired load.

3.3.3 Rigid plate

A steel rigid plate of size 890mm x 890mm x 24mm (in length x width x thickness) was used to apply the normal load on the sample.

3.3.4 Guide rods

Four guide rods (Fig. 3.10) are provided to make sure the uniform movement of rigid plate and also to avoid the tilting and bending of rigid plate during the application of normal load or its downward movement.

3.3.5 Load cells

Load cell of 90 kN capacity was connected between the top hydraulic cylinder and the extension rod to the application of normal load while the load cell of 100 kN capacity was connected between bottom hydraulic cylinder and clamping plate to measure the axial pullout force.

3.3.6 Control panel

The movements of the hydraulic cylinders in the setup were controlled by control panel. It helps during the application and removal of normal stress from the sample (see fig. 3.11b).

3.3.7 Sleeves

L-angles of leg width 40mm were used as sleeves in the silt for the movement of the reinforcement material. Sleeves transfer the point of application of the pullout force away from the front wall and into the interior of soil mass and reduce the stress on the door of the box.

3.3.8 Clamping system

Clamping plate (Fig. 3.11a) was used to allow the pullout force to be distributed evenly throughout the width of the reinforcement. It also connects the reinforcement with the pullout force system to prevent slipping. It must allow the reinforcement to remain horizontal throughout the testing.


(a) (b)

Figure 2.8 (a) Closer view of clamping plate (b) Control panel

3.3.9 Data acquisition system (DAQ system)

The data acquisition system (Fig. 3.12) processes the data and converts analog signals into digital values. The DAQ used in this study was manufactured and supplied by HBM Test and Measurement. MX-1615 module has 16 channels which supports the strain gauged based sensors and used to connect the load cells and strain gauge while MX-840 module has 8 channels which supports all sensor types and used to connect the potentiometers to measure the displacements. Software named 'Catman Easy' was used for analyzing the signals i.e. normal load, time, displacement and axial pullout force.

Figure 2.9 Data acquisition system (DAQ system)

3.3.10 Pluviation setup

Fig. 3.13 shows the photograph of stationary pluviation device used for sand sample preparation. The plan dimensions of pluviation setup were 890mm x 890mm. This pluviation setup consists four sheets (Sheet B, Sheet C, Sheet D, and Sheet E) of 5mm thickness with different opening widths. The top two sheets, sheet B and sheet C are almost flush with one another while Sheet D and sheet E were located at a distance equal to 50mm and 105mm respectively from the bottom of sheet C. This pluviation device can move up and down inside the test chamber using hook and chain system. The height of fall can be adjusted with the help of hook and chain system to prepare the sand beds. Height of fall was considered from the bottom sheet E. Samples are prepared with 85% relative density in accordance with the procedure proposed by Hariprasad et al. (2016).

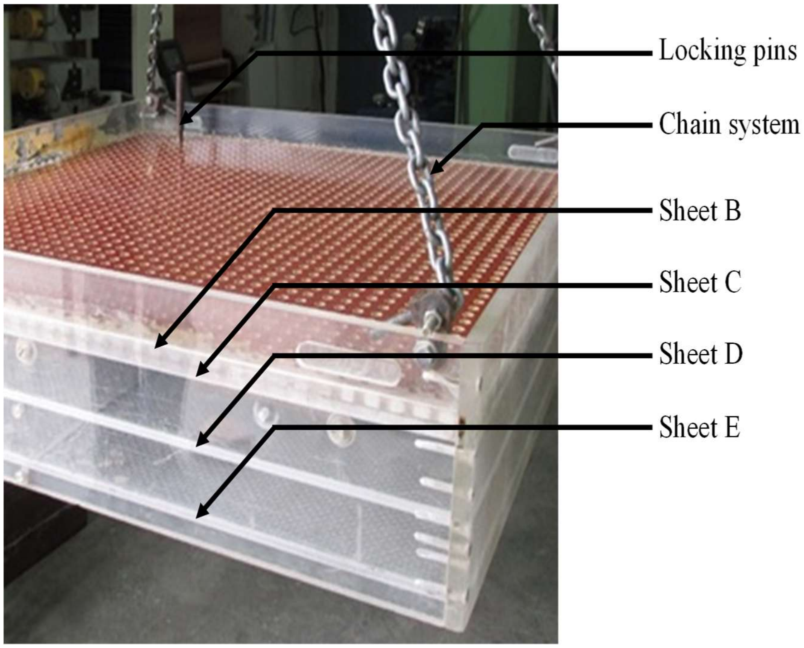
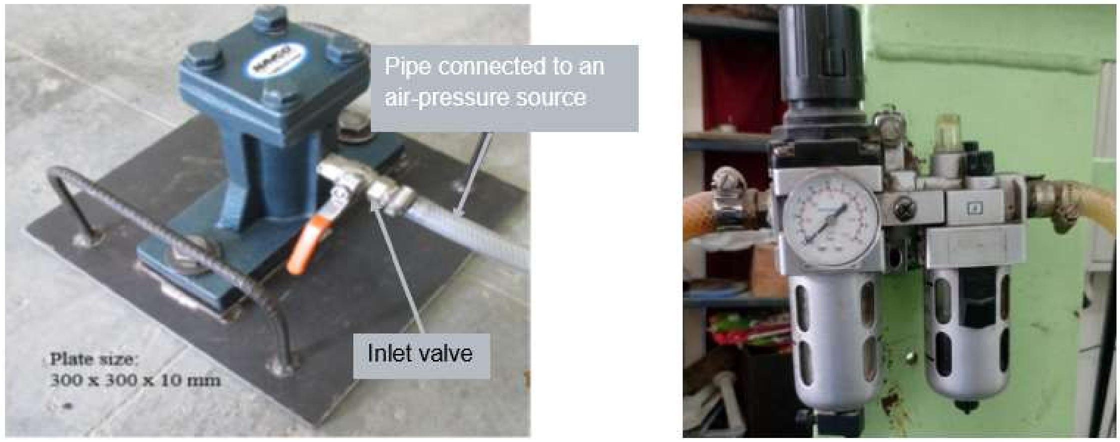


Figure 2.10 Photograph of pluviation device (Hariprasad et al., 2016)

3.3.11 Pneumatic vibrator

A pneumatically operated piston vibrator (Fig. 3.14a) was used for the compaction of pond ash in the test chamber. This vibrator plate is of square shaped with dimensions 300mm x 300mm x 10mm (length x width x thickness). The weight of vibrator with steel plate was 18 kg. Fig. 3.14b shows the pressure gauge in the system in order to set the required pressure to be applied for compaction. Compressed air was directed from one end to the other through internal ports to impart a high impact vertical vibratory force and transfer the energy to sample. All the samples were prepared at a pneumatic pressure equal to 3 bar. Pond ash sample was tested for grain size distribution before and after vibration and confirmed no heavy breakage of ash particles. Similar observation was made during vibrating sand particles (Hariprasad et al. 2016). In the laboratory, the pond ash was compacted using pneumatic vibrator to achieve a target relative compaction of 90%.



(a) **(b)**

Figure 2.11 (a) Photograph showing pneumatic vibrator (b) Photograph showing pressure gauge

3.4 Sample preparation

3.4.1 For Sand

Various methods are available to reconstitute the sandy soil in the laboratory like pluviation, vibration, compaction, etc. Many studies are available in literature on pluviation of sand particles through air. Pluviation of sand particles through air was the most preferred method because it provides homogeneous specimen of soil. In this study, to prepare the sand bed inside the test chamber stationary pluviation device given by Hariprasad et al., 2016 shown in Fig. 3.13 was used. The following steps were involved in the preparation of sample (for sand) inside the pullout test chamber:

1) First, stationary pluviation device was attached to the test chamber using hook and chain system as shown in the Fig. 3.15.
2) Pluviation of sand was done layer by layer. During pluviation, a constant height of fall (between bottom of sheet E and top of sand bed) of sand particles was maintained as 130mm to obtain the target relative density of sand equal to 85% (Hariprasad et al., 2016).
3) This procedure was continued up to a height 520mm from the bottom of test chamber.
4) After filling the test chamber up to a height 520mm, reinforcement was inserted through the opening between sleeves and made it placed between two steel plates in the clamping groove and tightened using screws. The placement and clamping of reinforcement is shown in Fig. 3.16a. Width of the reinforcements were limited to 330 to 350mm and ensured a minimum of 250mm side distance from the walls. A gap of 150mm should be maintained between the wall of test chamber and the reinforcement to avoid the friction along the wall during application of normal stress (ASTM D 6706).
5) Pluviation of sand was continued in the test chamber for the remaining height of 320mm to make the sand bed of total thickness equal to 840mm.
6) Density of the sample achieved in the test chamber was cross checked with the known weight of sand filled in the test chamber and the known volume filled.
7) The top surface was leveled with the help of straight edges and it was ensured with the help of leveling tube as shown in Fig. 3.16b.

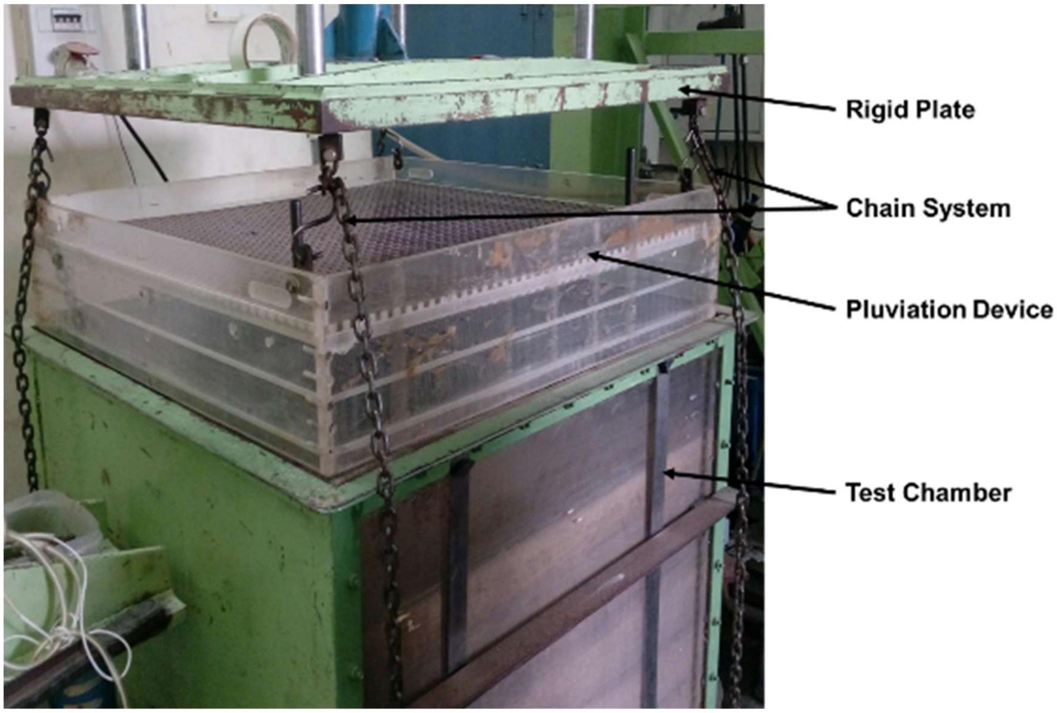
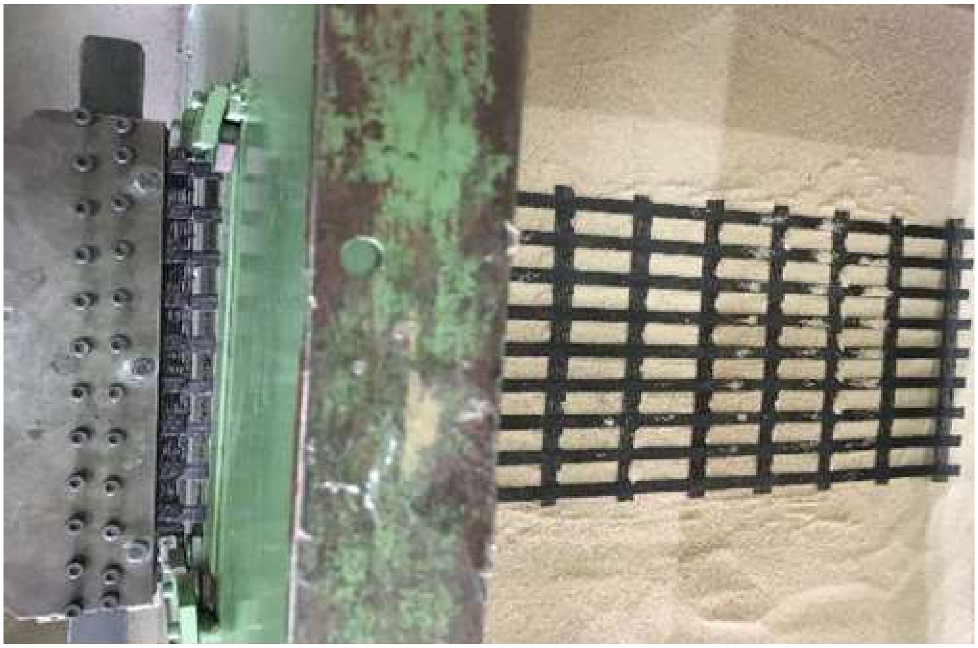


Figure 2.12 Photograph showing pluviation device with test chamber



(a)

(b)

Figure 2.13 (a) Top view of the geogrid placed at the slit level (b) Level check after the sample preparation

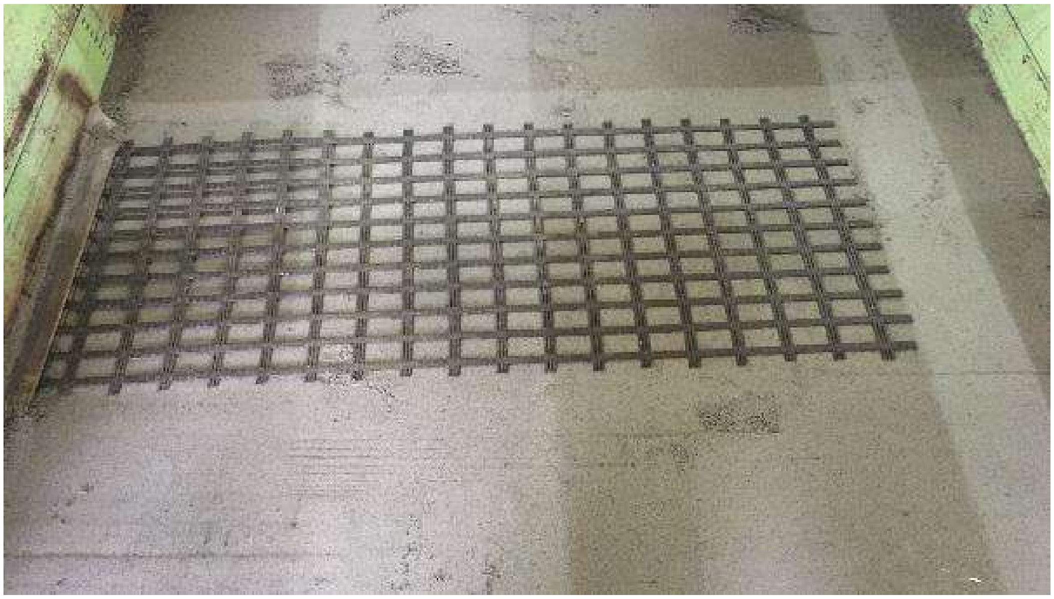
3.4.2 For Pond ash

Before testing pond ash samples for axial pullout, the bottom 200mm in the test tank was filled with light weight concrete blocks to achieve a uniform height of samples, above and below the reinforcement. The modified dimensions of the sample were equal to 900x900x640 mm (320 mm above the sample and 320mm below the sample). Pond ash samples were prepared using pneumatically operated piston vibrator (Fig. 3.13a). The following steps were involved in the preparation of pond ash sample inside the pullout test chamber:

1) Based on the targeted relative compaction of 90%, water content of 15% was considered for all the samples prepared using pond ash.
2) Based on the dry unit weight, quantity of dry pond ash was first mixed with water and ensured uniform mixing.
3) The pond ash was filled in the modified test chamber in six layers and each layer consists 110kg of wet pond ash. Bottom three layers were compacted by traversing the pneumatic vibrator on pond ash with three rounds of vibration with 3bar pneumatic pressure while top three layers were

compacted by traversing the vibrator with four rounds of vibration with same pressure.

4) After compacting first three layers, reinforcement was placed through the opening between sleeves and tightly fixed it with the clamping system using screws as shown in Fig. 3.17a. A gap of 150mm should be maintained between the wall of test chamber and the reinforcement to avoid the friction along the wall during application of normal stress (ASTM D 6706).
5) The remaining three layers were compacted up to the height of 840mm from the bottom of test chamber to complete the sample preparation.
6) Achieved relative compaction was cross checked for known weight and volume of the sample.
7) Water contents were taken while preparing the samples to confirm the relative compaction achieved.
8) The leveling of top surface was ensured with the help of leveling tube as shown in Fig. 3.17b.



(a)

(b)

Figure 2.14 (a) Placement of geogrid reinforcement on pond ash inside the tank (b) Leveling check after the sample preparation using leveling tube

3.5 Test Procedure

1) Samples were prepared for the desired relative density and relative compaction.
2) Normal stresses equal to 17, 52 and 87kPa were applied on all the sand and pond ash samples tested. The stresses are equivalent to overburden of sand for depths equal to 1, 3 and 5m respectively.
3) In the stage-1 of staged pullout test, 17 kPa normal stress condition was applied on the model ground and axially pulled under constant stress, up to an axial displacement of 25mm (20mm in case of metal strip reinforcement).
4) After completion of stage-1 of staged pullout test, normal stress was removed completely.
5) In the stage-2 of staged pullout test, normal stress equal to 52 kPa was applied on the model ground and axially pulled under constant stress, up to an axial displacement of 50mm (including 25mm of first stage displacement).

6) After completion of stage-2, normal stress is removed and the stage-3 was carried similarly at a normal stress equal to 87kPa. The axial pullout resistance loads were recorded up to axial displacement equal to 75mm.
7) The obtained results from staged pullout testing for 25 mm axial displacement under each normal stress were compared with the conventional pullout testing (three different samples for three different normal stresses).

Chapter 4

3. Results and Discussion

4.1 Overview

In this chapter, staged pullout behavior of inextensible reinforcement and extensible reinforcement subjected to axial pull is discussed. The results made from the staged pullout are compared with the conventional pullout results and fitted results from staged pullout are also compared with the experimental results of conventional pullout test. In the case of smooth metal reinforcement, pullout resistance was mobilized by the frictional resistance between the soil and reinforcement while for geogrids; pullout resistance was mobilized by the frictional resistance by the longitudinal and transverse ribs and passive resistance by transverse ribs. Finally, staged pullout results compared with the conventional pullout results and percentage change between the staged and conventional pullout results is presented.

4.2 Staged pullout results

Backfill material: Sand

Reinforcement: Smooth metal strip

Axial pullout tests were performed at three different normal stresses – 17 kPa, 52 kPa and 87 kPa during pullout testing, the axial pullout force and axial displacement of the reinforcement were monitored. Fig. 4.1 shows the experimental pullout curves of the conventional pullout testing (CPOT) done at three model ground which have normal stress conditions of 17 kPa, 52 kPa and 87 kPa. Fig. 4.2 shows the pullout curves of staged pullout testing (SPOT) done at one model ground which have the same normal stress conditions and also shows the comparison of conventional and staged pullout results. From the curves, it was observed that the smooth metal strip exhibited an increase in the axial pullout load with an increase in the normal stress. From the conventional pullout testing, peak pullout load of 1 kN, 2.05 kN and 3.7

kN were observed for the application of normal stresses equal to 17 kPa, 52 kPa and 87 kPa respectively. From the staged pullout testing axial pullout loads equal to 1 kN, 2.05 kN and 3.35 kN after correction for the length of reinforcement. Farrag et al. (1993) presented the effect of length of the pullout reinforcement. Lesser the length of reinforcement, lesser the pullout resistance of the reinforcement.

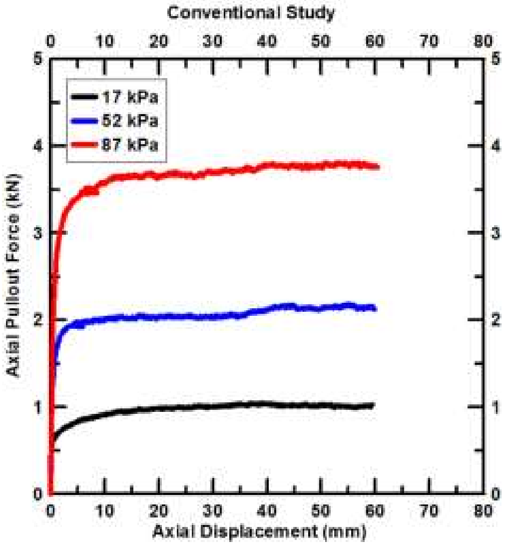


Figure 3.1 Pullout curves at CPOT

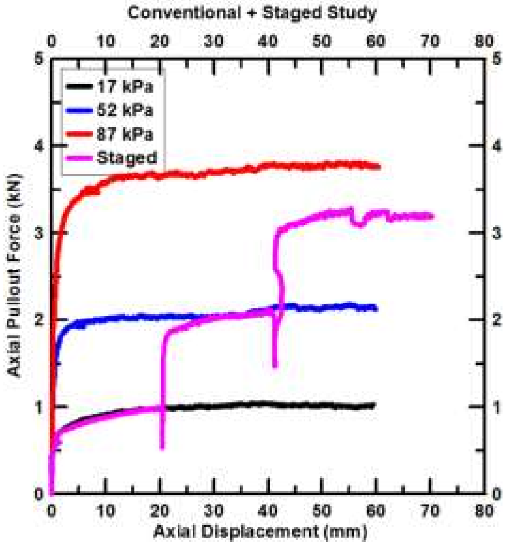


Figure 3.2 Pullout curves at CPOT and SPOT

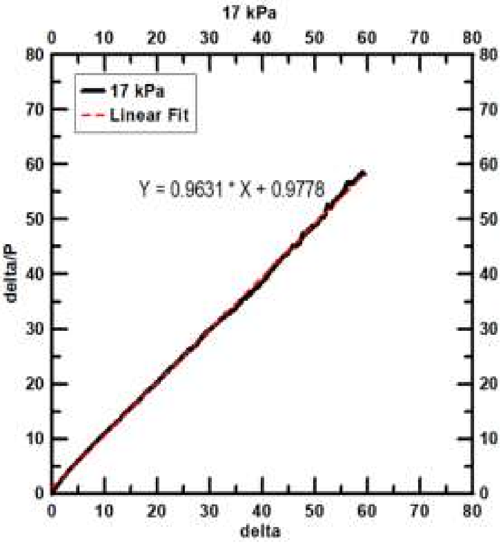
As the reinforcement moves in longitudinal direction, normal stresses are mobilized on the reinforcement from the surrounding soil leading to mobilization of higher shear stresses along the length of reinforcement. Results show that pullout load of smooth metal strip reinforcement embedded in sand only increases with the axial displacement up to a certain point and then remains constant. It is also observed that pullout load increases with the increase in normal stress. From the FHWA, it is recommended that a maximum deflection of 20 mm measured at the front end of the specimen be used to select the value of P in case of inextensible reinforcement.

Calculation of hyperbolic constants

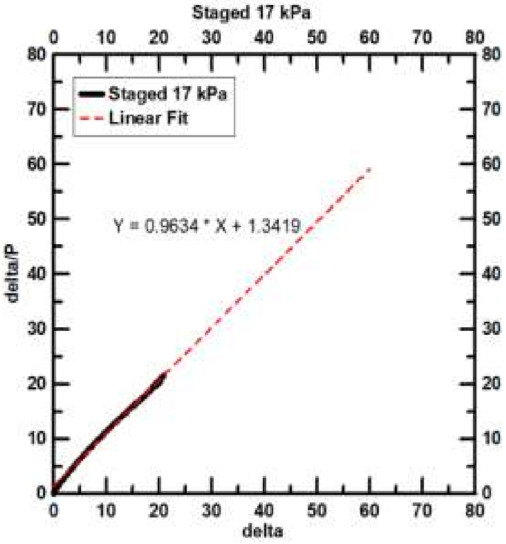
To get the hyperbolic constants a graph was plotted between the delta and delta/P where delta is the axial displacement and P is axial pullout force. From the linear equation we can obtain the slope and intercept where intercept means the value m and slope means the value n. Fig. 4.3 show the relationship between delta and delta/P from CPOT results and fig. 4.4 shows the relationship between delta and delta/P from SPOT results.

Table 4.1: Hyperbolic constants

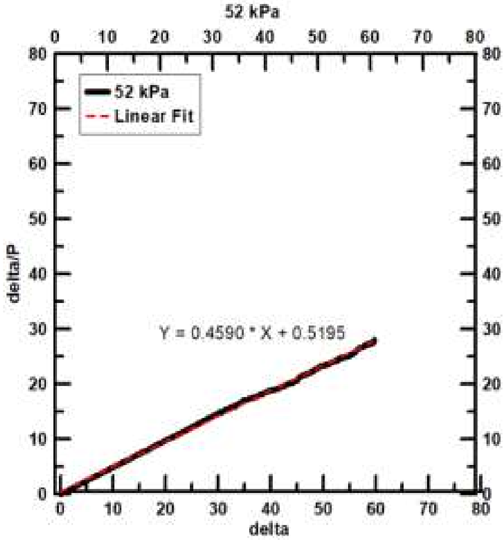
Normal Stress (kPa)	CPOT		SPOT	
	m	n	m	n
17	0.9778	0.9631	1.3419	0.9634
52	0.5195	0.4590	0.1670	0.4737
87	0.1859	0.2616	0.0073	0.3119



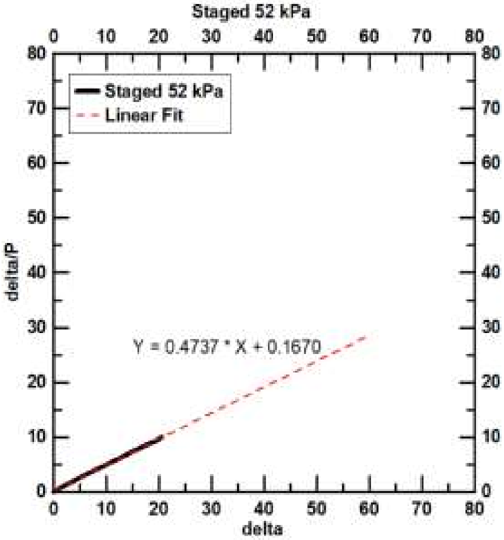
(a) 17 kPa



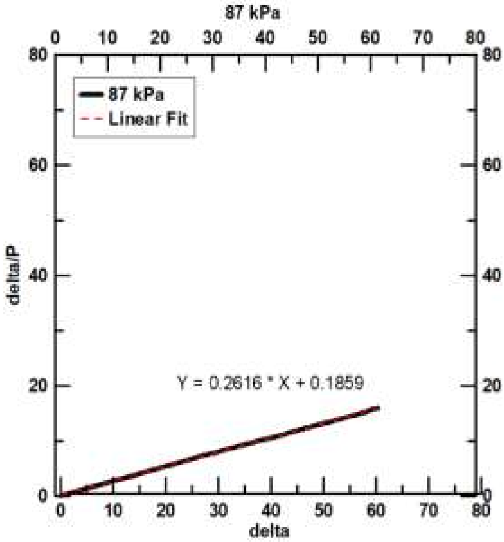
(a) Staged 17 kPa



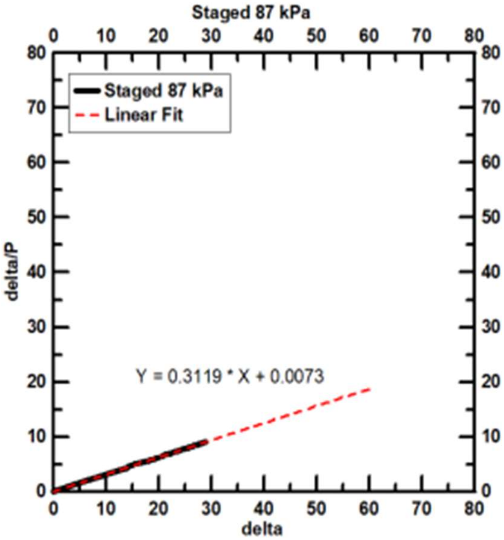
(b) 52 kPa



(b) Staged 52 kPa



(c) 87 kPa



(c) Staged 87 kPa

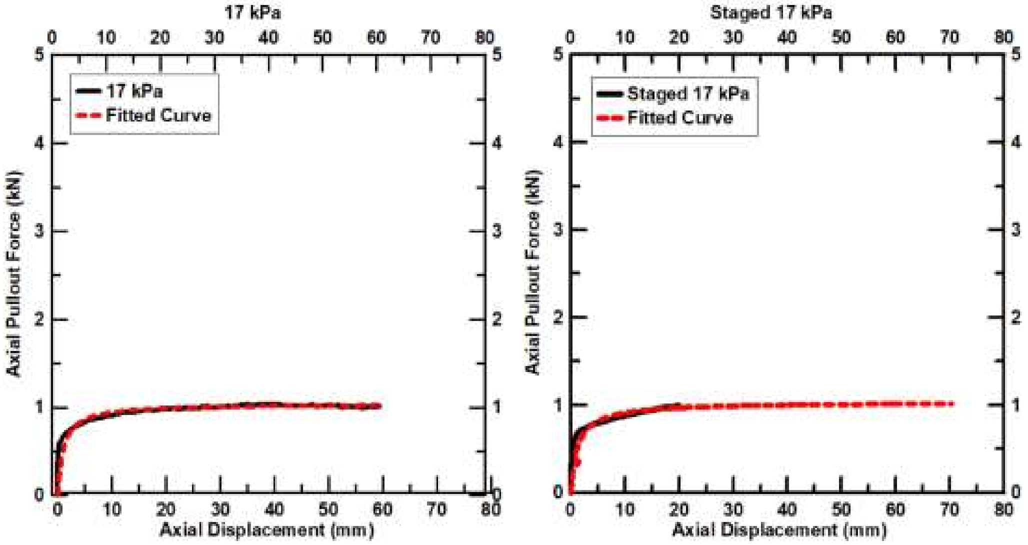
Figure 3.3 Hyperbolic constant at CPOT **Figure 3.4 Hyperbolic constant at SPOT**

Comparison between measured and estimated curve

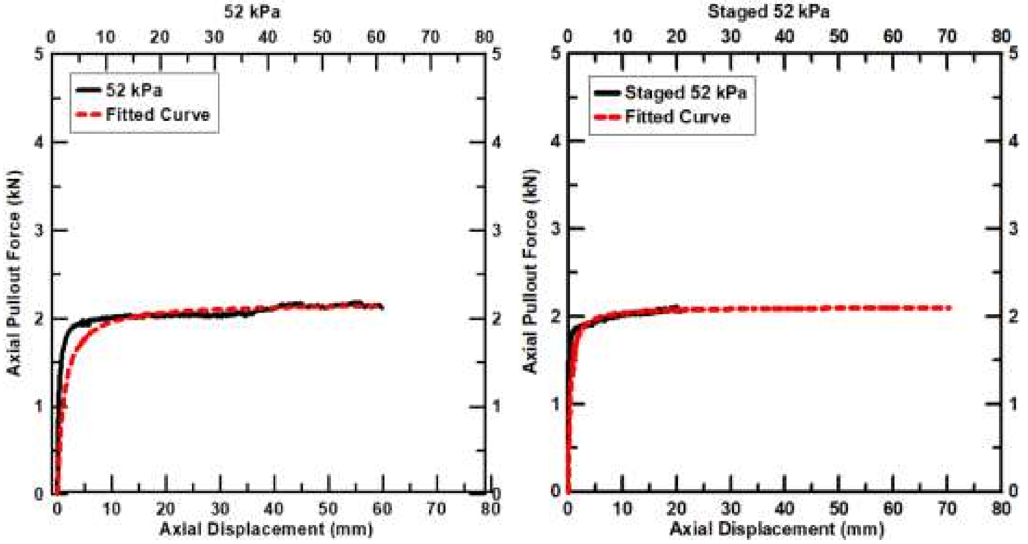
By using of hyperbolic constants m and n, pullout curves were estimated for the conventional pullout tests as well as staged pullout test. The following equation is used to estimate the entire pullout curve:

$$P_d = \frac{\delta}{m + n\delta} \qquad (1)$$

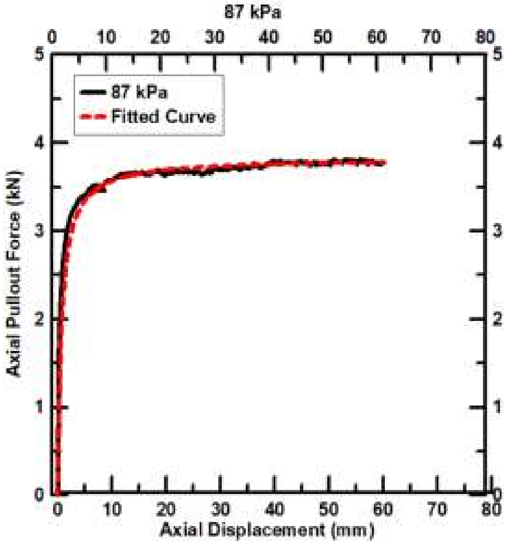
Where, δ = Axial displacement, P_d = Pullout force, m, n = Hyperbolic constant



(a) 17 kPa **(a) Staged 17 kPa**

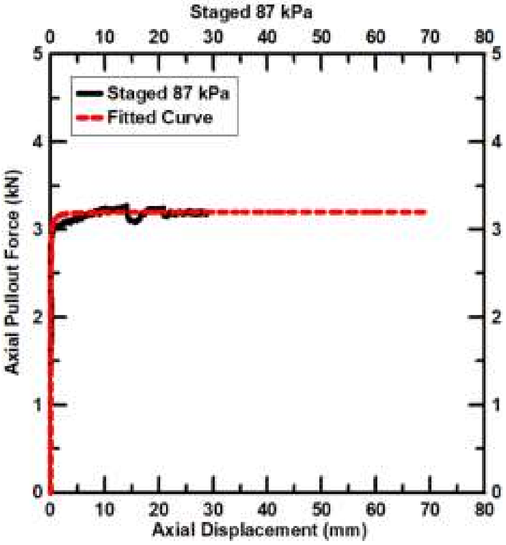


(b) 52 kPa **(b) Staged 52 kPa**



(c) 87 kPa

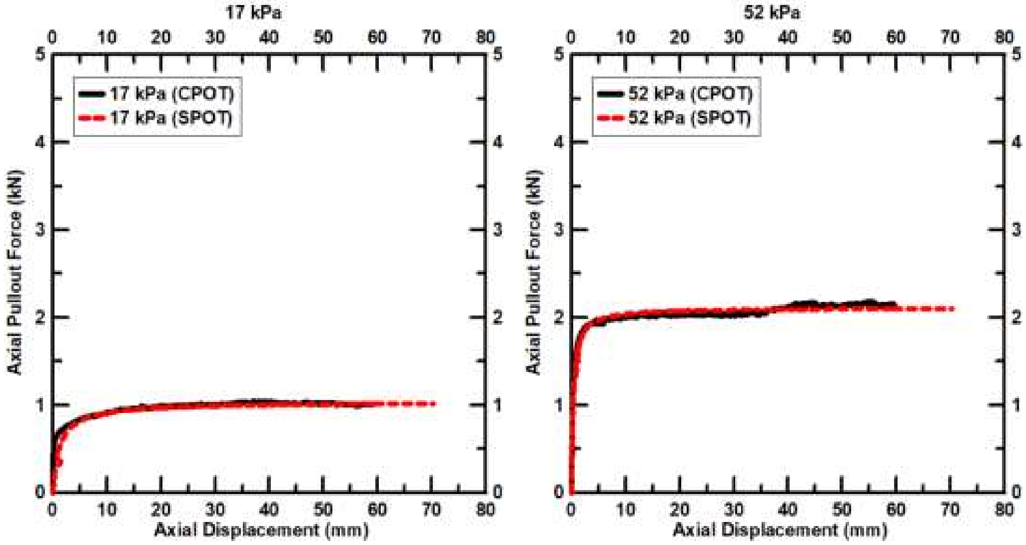
Figure 3.5 Measured and estimated curve at CPOT



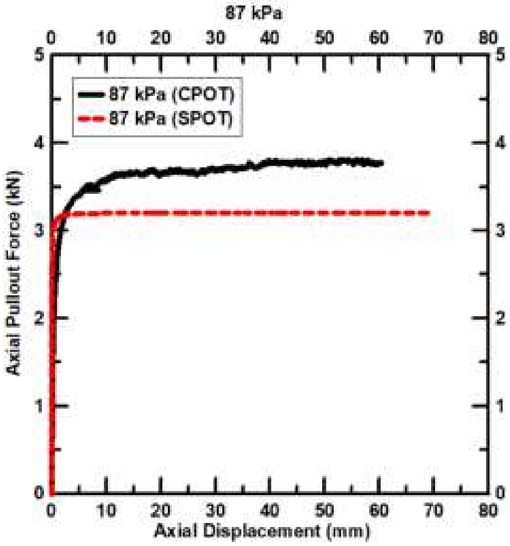
(c) Staged 87 kPa

Figure 3.6 Measured and estimated curve at SPOT

Fig. 4.5 shows the measured and estimated pullout curves (using the equation 1) for conventional pullout test and fig. 4.6 shows for the staged pullout test. From the curves, it can be observed that estimated curve has a good agreement with the experimentally measured curve. Fig. 4.7 shows the comparison result between the estimated curve from staged pullout testing and experimentally measure curve from the conventional pullout testing. From the curves, it can be observed that for the low normal stress conditions estimated curves are following the experimentally measured curve but when we are moving to higher normal stress condition there is a little difference between the estimated peak value and experimentally measured value. For 87 kPa, staged pullout results are differing with the conventional pullout testing with a factor of 1.2. It is attributed that it could be because of breakage of bond between the reinforcement and the fill material during the application of initial normal stresses.



(a) 17 kPa **(b) 52 kPa**



(c) 87 kPa

Figure 3.7 Comparison between estimated curve by SPOT and measured curve by CPOT

Backfill material: Sand

Reinforcement: Geogrid 120 x 30 kN/m

In similar lines to the smooth metal strip reinforcement, tests were performed on geogrids at three normal stress conditions – 17 kPa, 52 kPa and 87 kPa and axial pullout force and axial displacement of the geogrid reinforcement were monitored. Fig. 4.8 shows the experimental measured pullout curves of CPOT while fig. 4.9 shows the experimentally measured pullout curves of SPOT and CPOT.

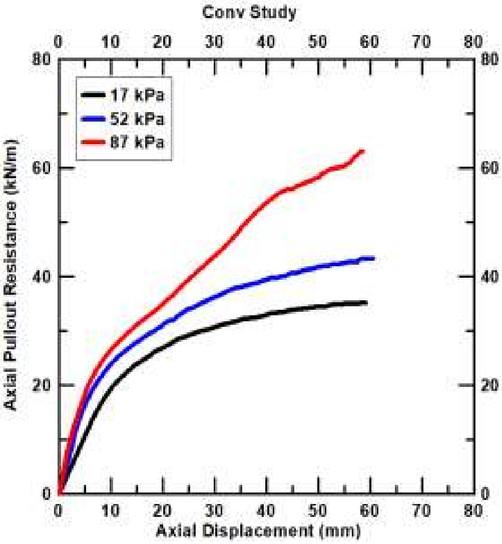


Figure 3.8 Pullout curves at CPOT

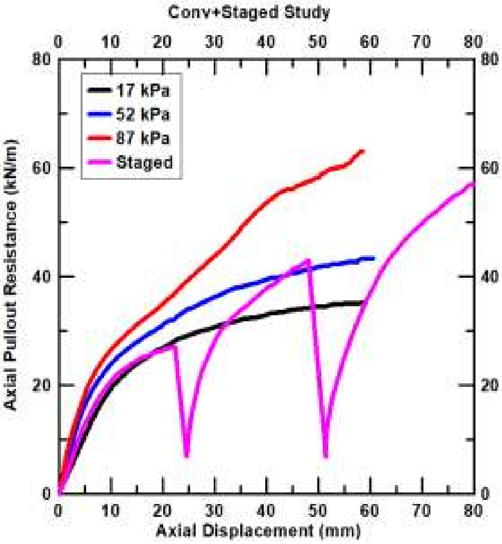
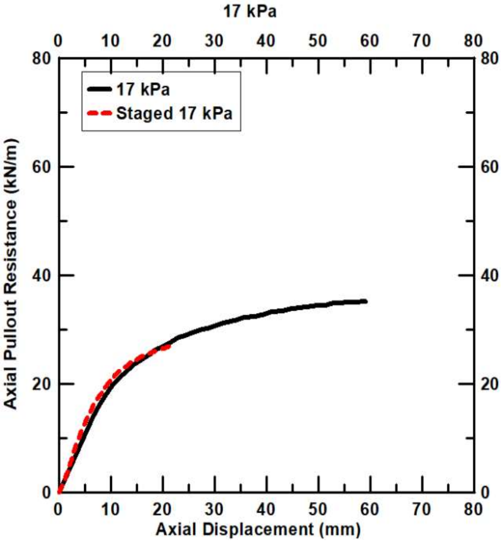
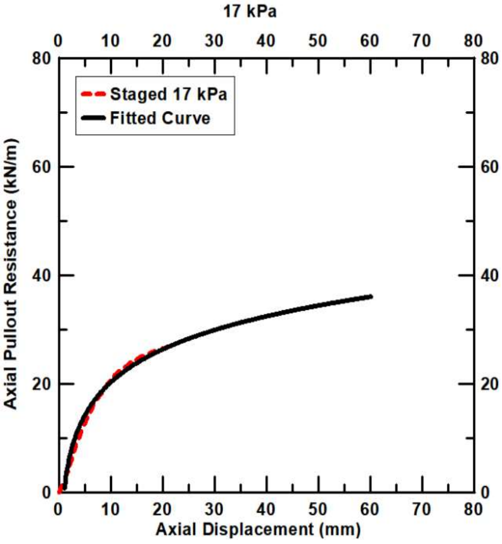


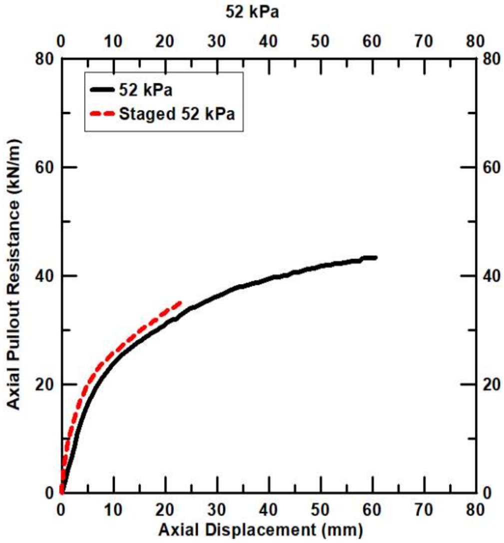
Figure 3.9 Pullout curves at CPOT and SPOT



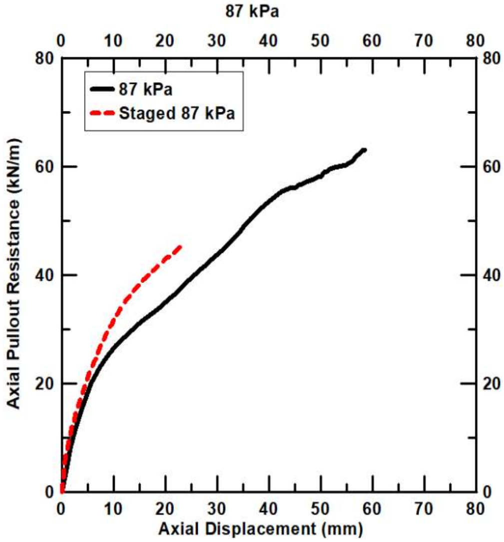
(a) 17 kPa



(a) Staged 17 kPa

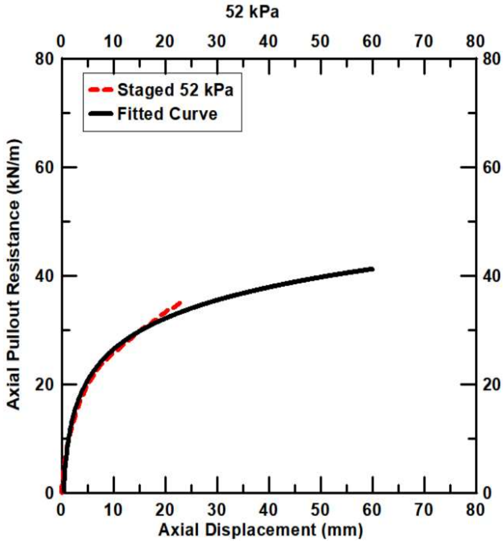


(b) 52 kPa

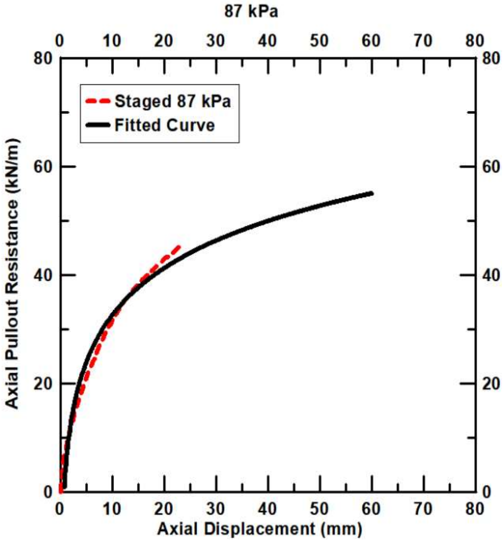


(c) 87 kPa

Figure 3.10 Experimentally measured curve at CPOT and SPOT



(b) Staged 52 kPa



(c) Staged 87 kPa

Figure 3.11 Measured and estimated curve at SPOT

Fig. 4.10 shows the experimentally measured curve at SPOT and CPOT where staged pullout curves are plotted by considering first point of each stage as origin and then plotted against the respective normal stress conditions. From the CPOT, pullout resistance at 20mm displacement were 27kN/m, 31.4kN/m and 34.9kN/m for the normal stress equal to 17 kPa, 52 kPa and 87 kPa respectively while from the SPOT 27kN/m, 32kN/m and 42kN/m were observed for the same normal stress conditions. It shows that staged pullout results are in close agreement with conventional pullout results for first 20 mm displacement. It has also observed that pullout resistance of geogrid reinforcement embedded in sand increases with increase in the axial displacement and not showing any peak value within the axial displacement allowed. Pullout capacity of geogrid is defined as the maximum pullout load taken for the considered geogrid width. From the FHWA, when the pullout curves don’t show the peak value, it is recommended that a maximum deflection of 15 mm measured at the back end of the specimen be used in design purposes.

To estimate the pullout curve over the entire pullout displacement from the staged pullout results, following logarithmic equation are used and full curve is estimated with the help of software named ‘Grapher’.

$$P = B*\ln(\delta) + A \qquad (2)$$

Fig. 4.11 shows the experimentally measured results from the SPOT and fitted curve with the help of logarithmic equation. Fig. 4.12 shows the comparison results between the estimated curves from the staged pullout testing and experimentally measured curves from the conventional pullout testing.

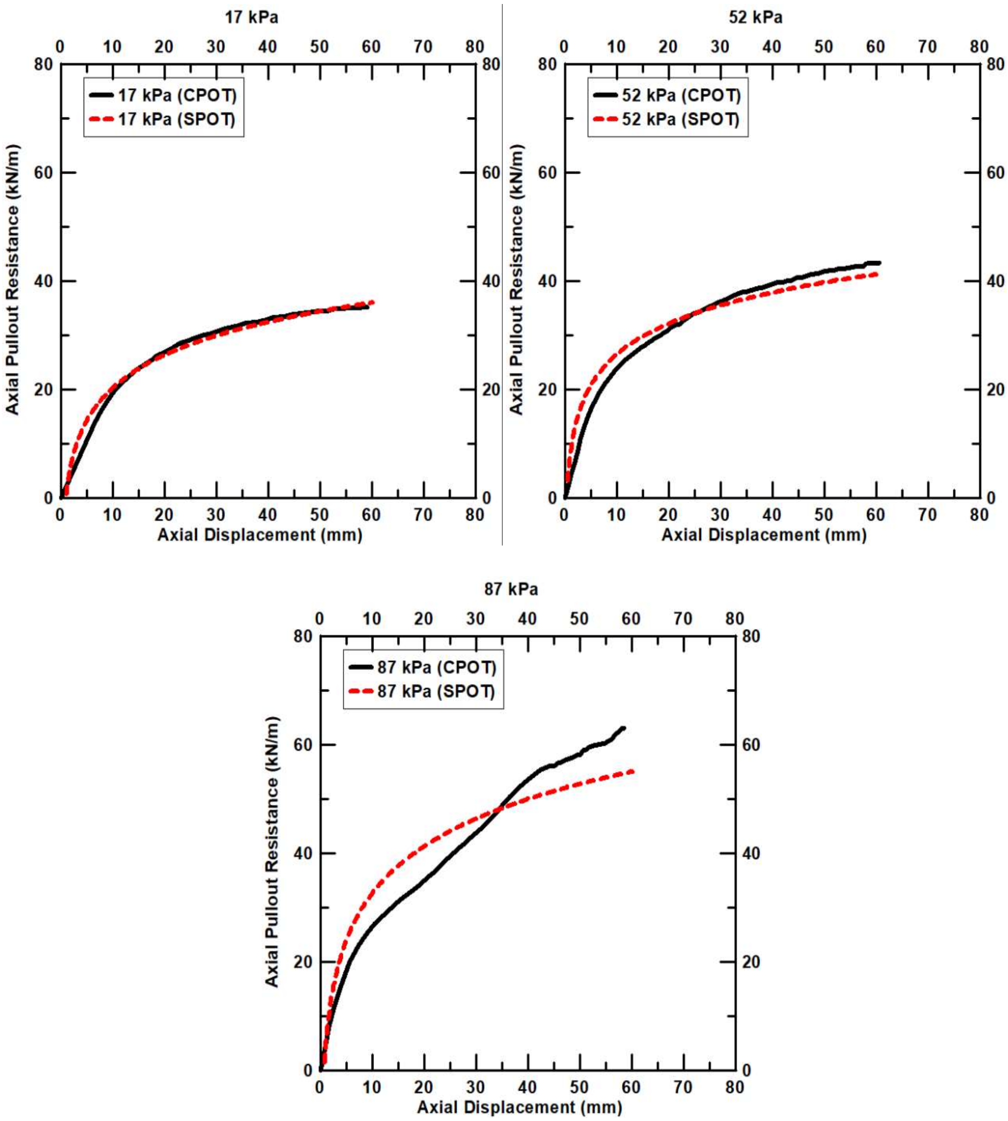


Figure 3.12 Comparison between estimated curve by SPOT and measured curve by CPOT

From the comparison between experimental and estimated results, it shows less than 5% variation for 17kPa and 52kPa while 13% variation for 87kPa. So, we can say that estimated curves are matching closely with the experimental results for 17 kPa and 52 kPa. For 87 kPa the difference between conventional and estimated results are higher because of repetitive loading. Overall, Staged results can be used to get the conventional results with a factor of safety of 1.1 to 1.15.This factor is close to the factor observed in the case of smooth metal strip reinforcement.

Backfill material: Pond ash

Reinforcement: Geogrid 120 x 30 kN/m

Similarly from the previous reinforcement, test were performed on geogrids at three normal stress conditions - 17 kPa, 52 kPa and 87 kPa and axial pullout force and axial displacement of the geogrid reinforcement were monitored. Fig. 4.13 shows the experimentally measured curves for CPOT and fig. 4.14 shows the experimentally measured curves for CPOT and SPOT.

Staged pullout curves were plotted in the similar way of previous reinforcement where first point of each stage has to be considered as origin and plotted against the corresponding stress conditions as shown in fig. 4.15 and it shows the comparable results with CPOT up to 20mm axial displacement.

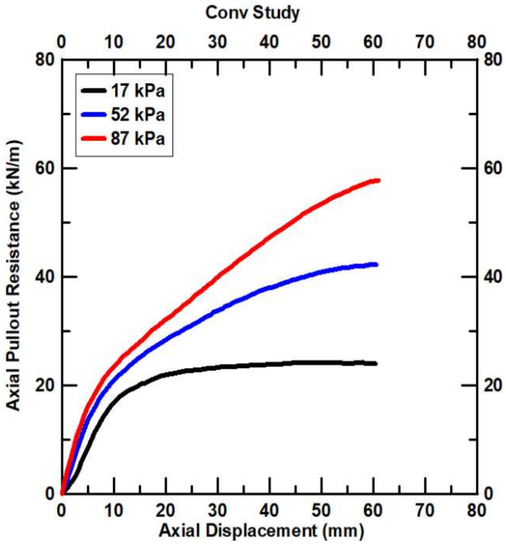


Figure 3.13 Pullout curves at CPOT

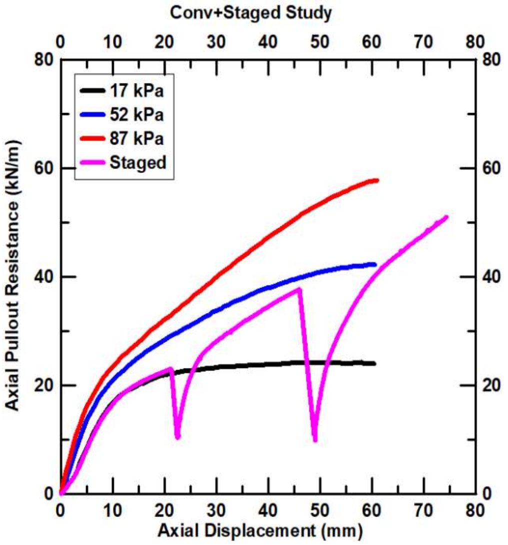
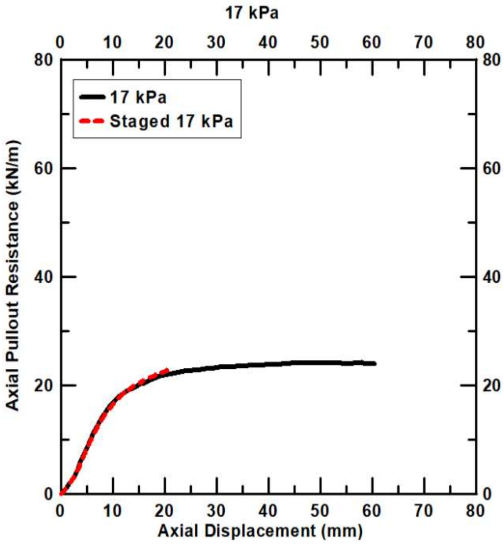
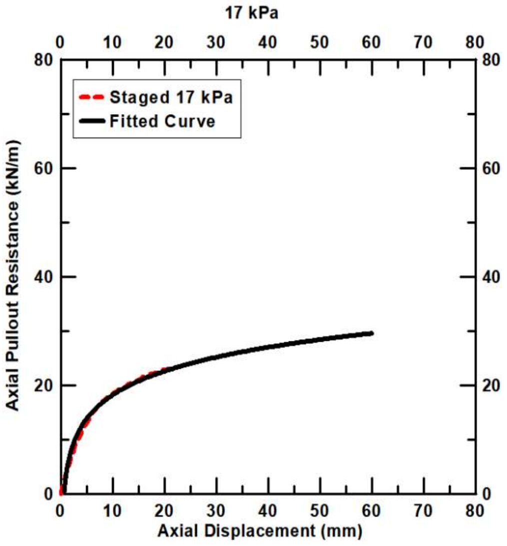


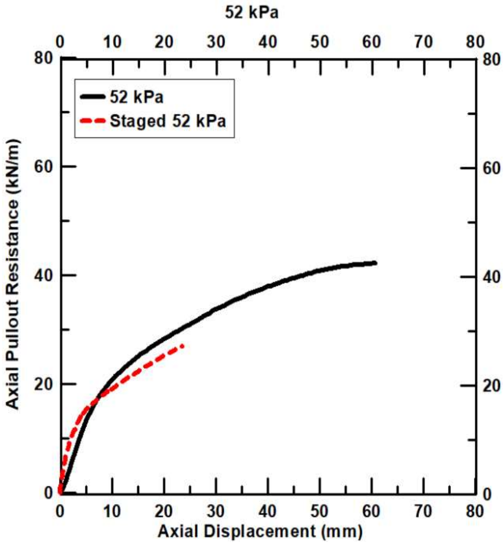
Figure 3.14 Pullout curves at CPOT and SPOT



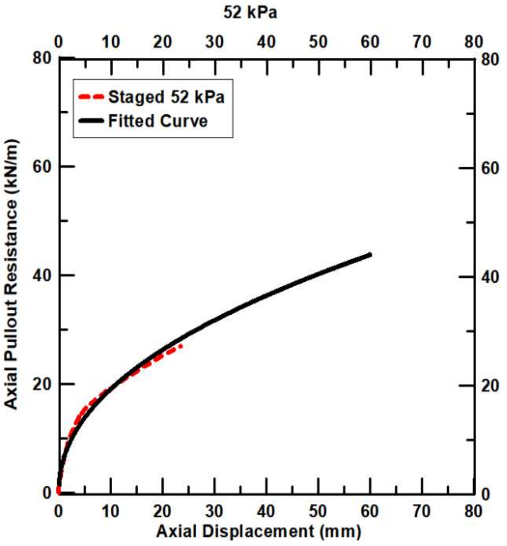
(a) 17 kPa



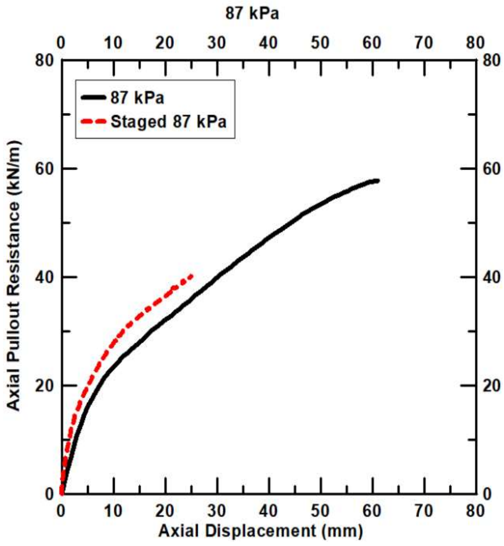
(a) Staged 17 kPa



(b) 52 kPa

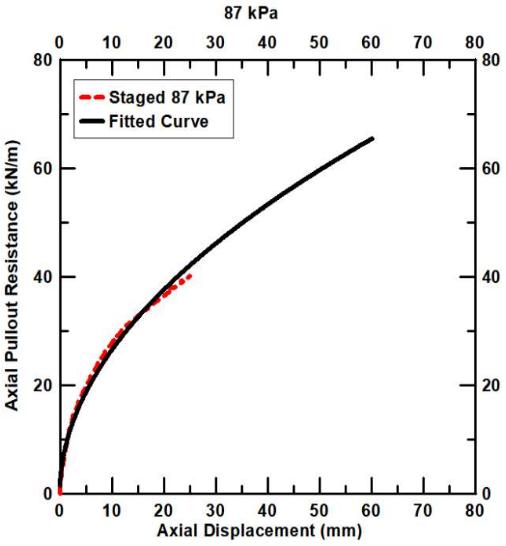


(b) Staged 52 kPa



(c) 87 kPa

Figure 3.15 Experimentally measured curve at CPOT and SPOT



(c) Staged 87 kPa

Figure 3.16 Measured and estimated curve at SPOT

Form the CPOT results, pullout resistance were 23kPa, 28.3kPa and 32.5kPa while from SPOT results, pullout resistance were found 23kPa, 24kPa and 34kPa at 20mm displacement for the normal stress condition 17kPa, 52kPa and 87kPa respectively. These results are close agreement up to 20mm axial displacement.

To get the estimated curve from staged pullout results, same logarithmic equation (2) was used and estimated curves plotted for displacement up to 60mm with the experimental SPOT results as shown in fig. 4.16. It can be observed that staged pullout results are closely matching with the CPOT results for first 20 mm displacement.

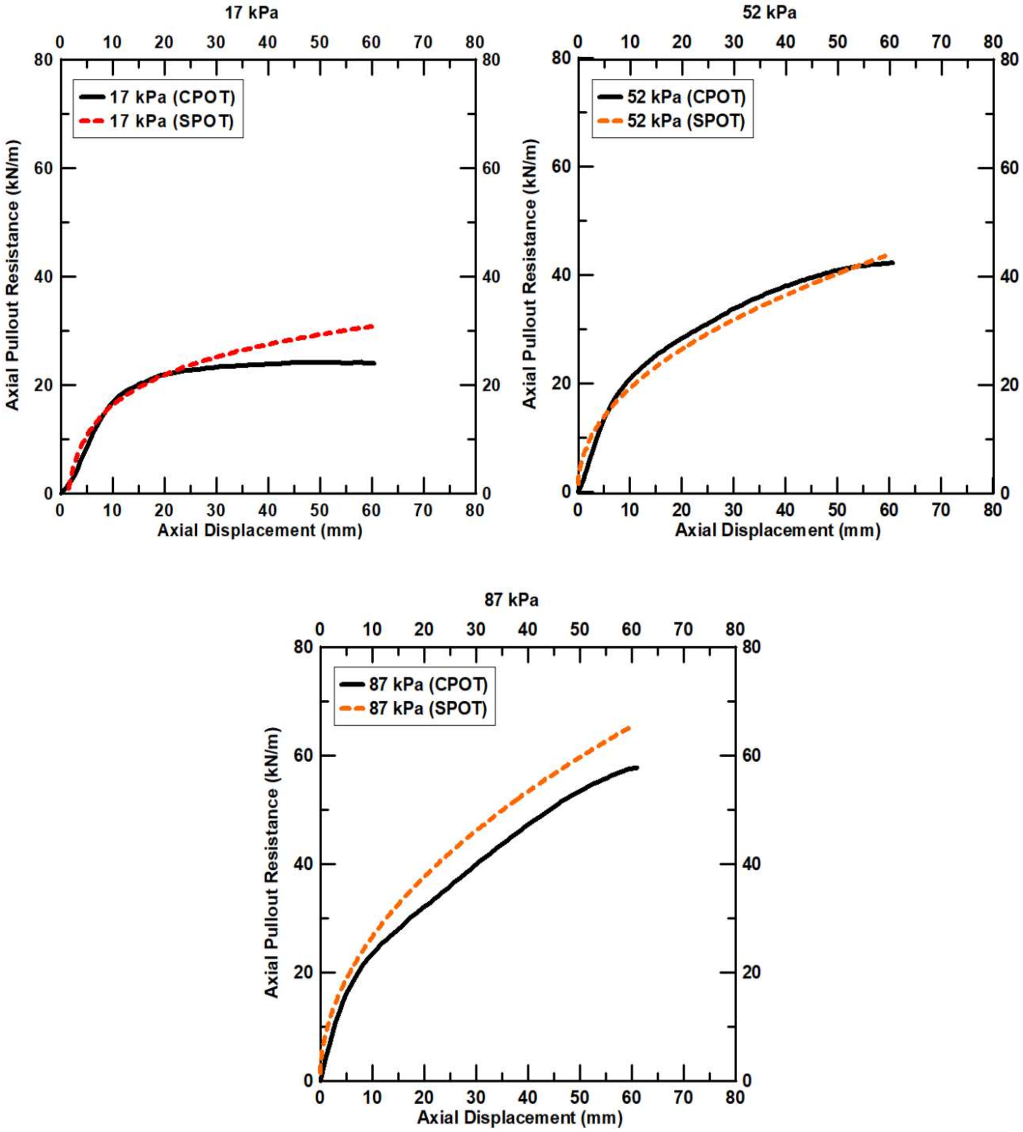


Figure 3.17 Comparison between estimated curve by SPOT and measured curve by CPOT

Finally, full length estimated results were plotted against the conventional pullout results as shown in fig. 4.17. From the results, it can be observe that estimated results are differing with a variation of less than 10%. With experimental results for all three stress conditions so, we can use staged results to get the conventional results with a factor of safety of 1.1 which is closer to the factor of safety for same grid embedded in sand. Hence for geogrid 120 x 30 kN/m staged pullout results can be used with a factor of safety of 1.1 to 1.2 irrespective of the backfill material.

Backfill material: Pond ash

Reinforcement: Geogrid 200 x 30 kN/m

Similar to the previous reinforcements, SPOT and CPOT were performed on geogrid at three different normal stress conditions - 17 kPa, 52 kPa and 87 kPa and axial pullout force and axial displacement of the geogrid reinforcement were monitored. Axial displacement vs. axial pullout resistance data has been plotted for different normal stress conditions and conventionally measured curve compared with the staged pullout results for respective normal stress conditions as shown in fig. 4.18 and 4.19.

Comparison of staged pullout results is in such a way that first point of each stage pullout results consider as origin and plot it against the respective stress conditions as shown in fig. 4.20. At 20mm axial displacement, 21.2kPa, 32.4kPa and 37.5kPa were the axial pullout resistance for 17kPa, 52 kPa and 87 kPa respectively during CPOT while 21kPa, 33kPa and 45kPa during SPOT for the same normal stress conditions. It shows that staged pullout test results are showing closer value with CPOT results for 20mm displacement but the value is slightly higher in case of 87kPa because the reinforcement has taken two loading conditions prior to 87kPa loading condition.

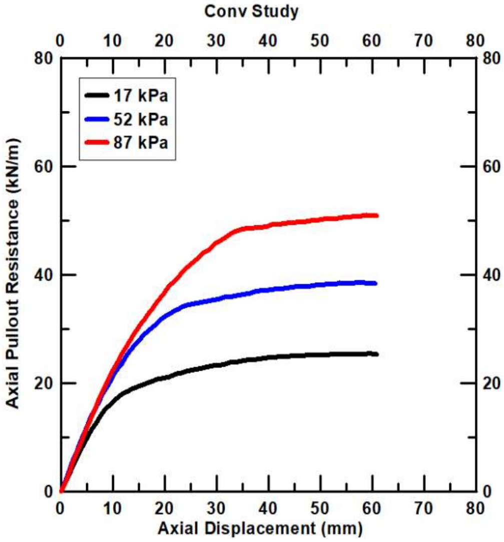


Figure 3.18 Pullout curves at CPOT

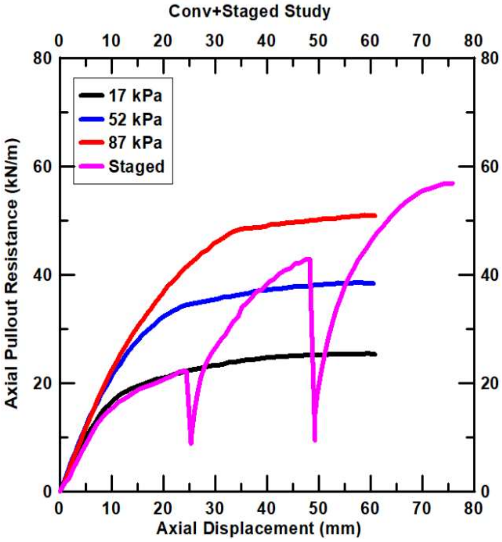
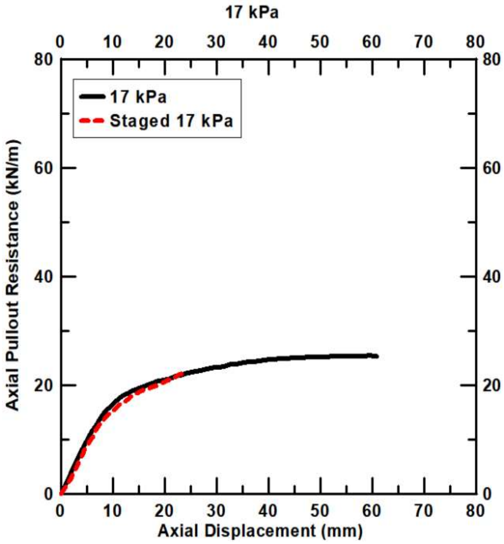
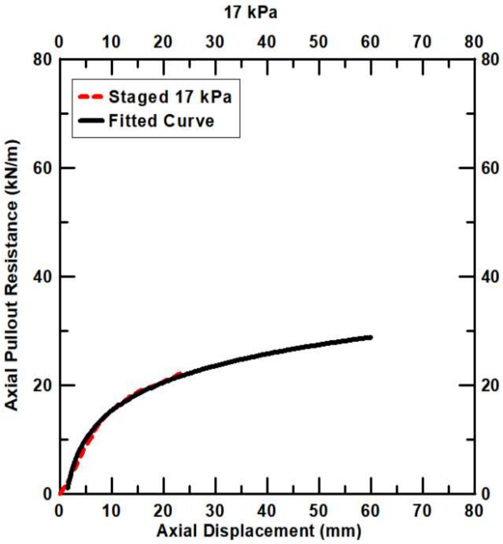


Figure 3.19 Pullout curves at CPOT and SPOT

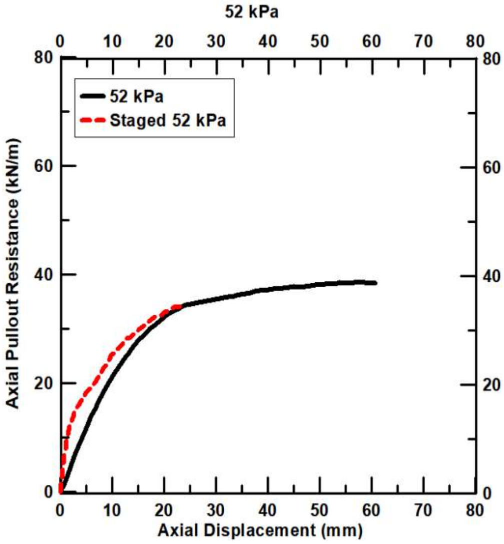
To get the full estimated curve up to 60mm displacement from staged pullout result, logarithmic equation (2) was used and experimental staged pullout results up to 20mm plotted with the estimated results as shown in fig. 4.21.



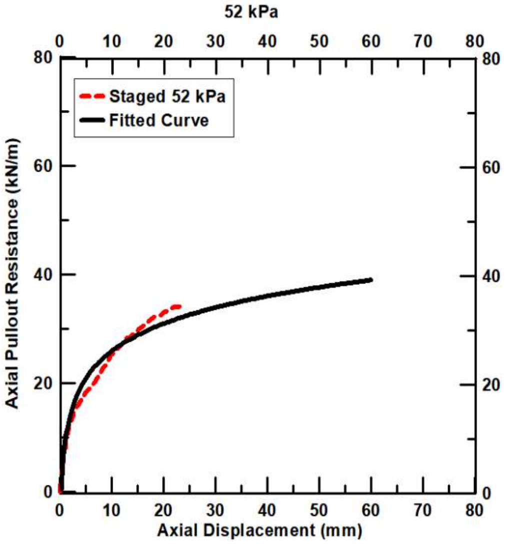
(a) 17 kPa



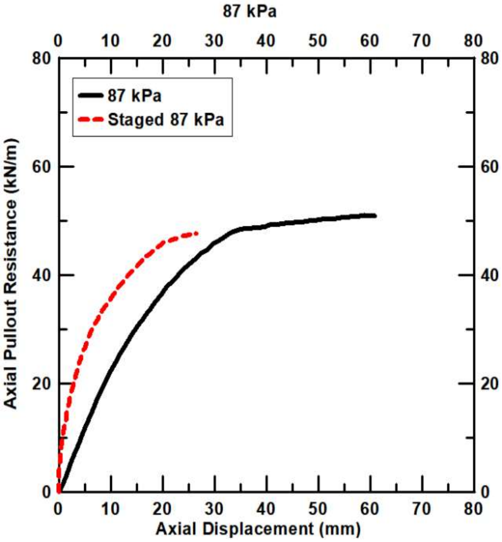
(a) Staged 17 kPa



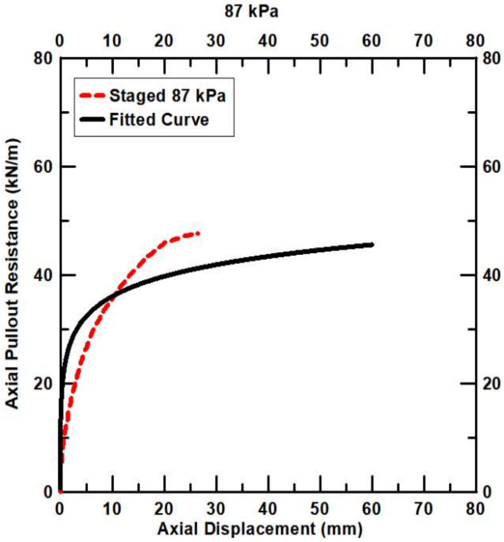
(b) 52 kPa



(b) Staged 52 kPa



(c) 87 kPa

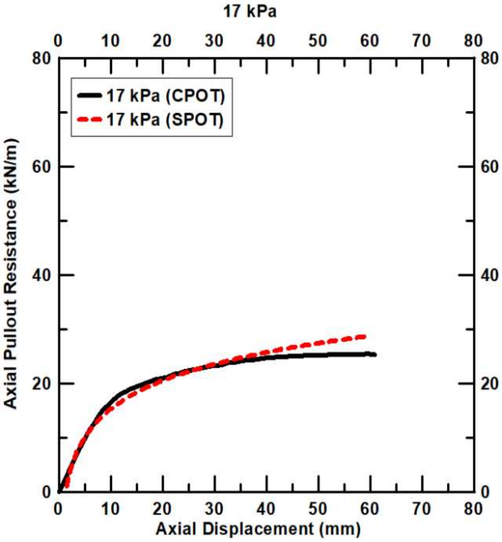


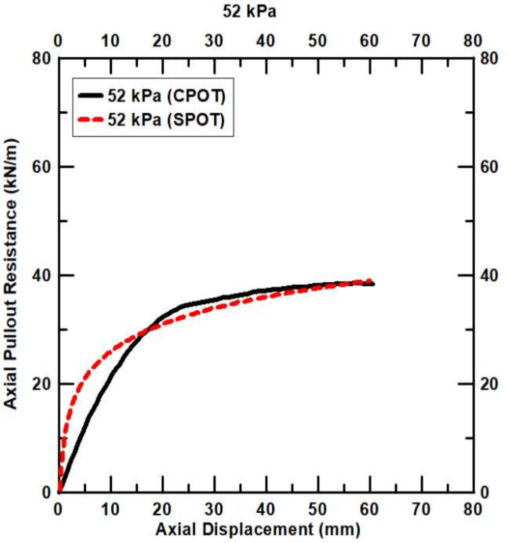
(c) Staged 87 kPa

Figure 3.20 Experimentally measured curve at CPOT and SPOT

Figure 3.21 Measured and estimated curve at SPOT

Now, estimated results from SPOT are plotted with the experimental results from CPOT as shown in fig. 4.22 which shows the comparable results for 17kPa and 52kPa but for 87kPa estimated results are differing with a factor of safety 1.8. It could be because of breakage of bond between the reinforcement and the backfill material during the application of initial normal stress conditions.





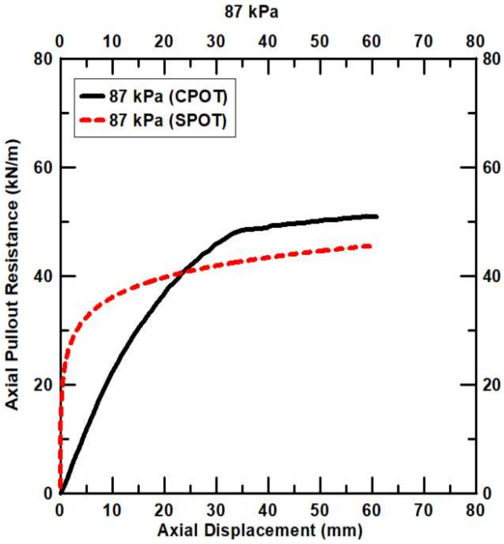


Figure 3.22 Comparison between estimated curve by SPOT and measured curve by CPOT

Finally, it could be concluded for this geogrid that estimated results are close agreement with the conventional results for the stress condition 17kPa and 52kPa with a less than 10% variation with respect to conventional pullout results while the variation is up to 20% for 87kPa stress condition. So, the staged pullout results could be used instead of conventional pullout results with a factor of safety between 1.1 - 1.2. This factor of safety is matches with the other reinforcements either embedded in sand or pond ash.

Backfill material: Pond ash

Reinforcement: Geogrid 250 x 30 kN/m

Tests were performed on three normal stress conditions - 17 kPa, 52 kPa and 87 kPa and axial pullout force and axial displacement of the geogrid reinforcement were monitored. Axial displacement vs. axial pullout resistance results were plotted for different normal stress conditions and conventionally measured curve compared with the staged pullout results for respective normal stress conditions as shown in fig. 4.23 and 4.24.

Similar to the previous geogrids staged pullout results were compared with the conventional pullout results up to 20mm axial displacement as shown in fig. 4.25. Pullout resistance was found to be 22.6kPa, 44kPa and 58.3kPa at 20mm displacement for CPOT while 22.6kPa, 44kpa and 59kPa for SPOT at normal stress 17kPa, 52kPa and 87kPa respectively. Experimental results show the closer value for CPOT and SPOT up to 20mm displacement.

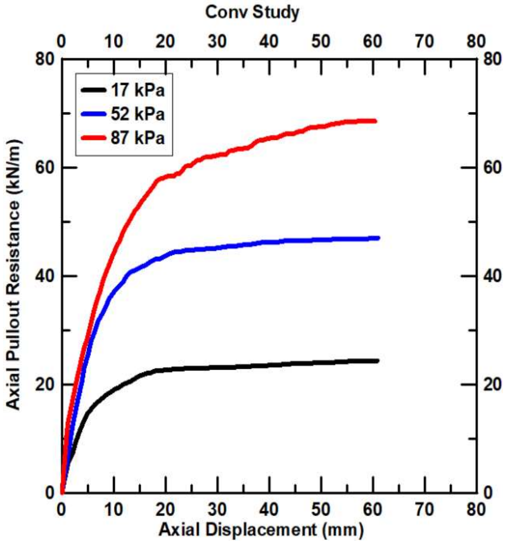


Figure 3.23 Pullout curves at CPOT

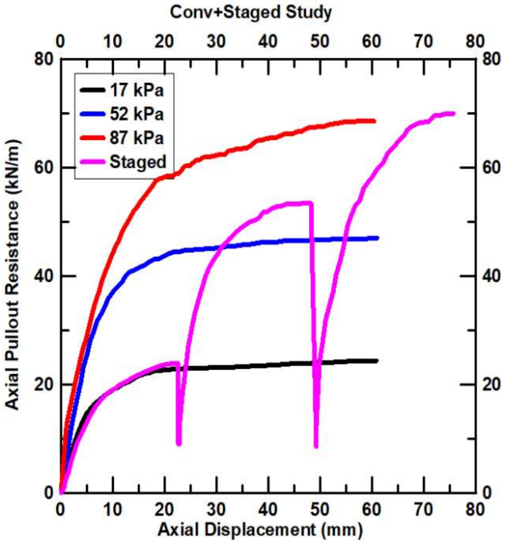
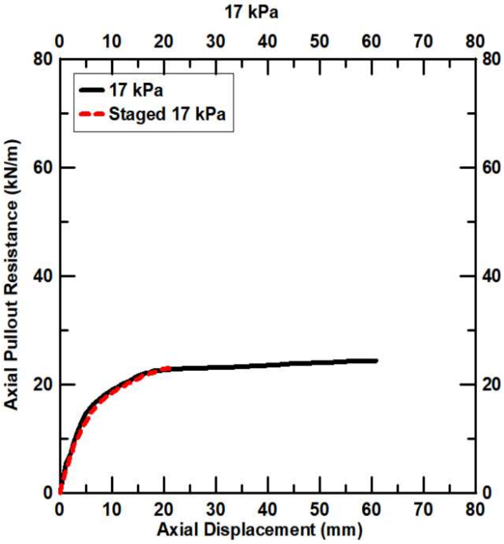
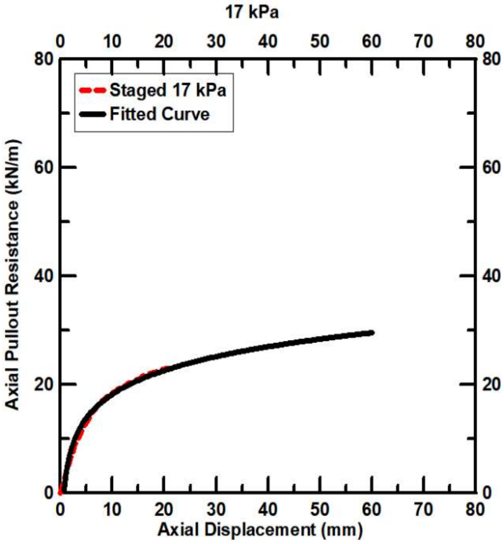


Figure 3.24 Pullout curves at CPOT and SPOT

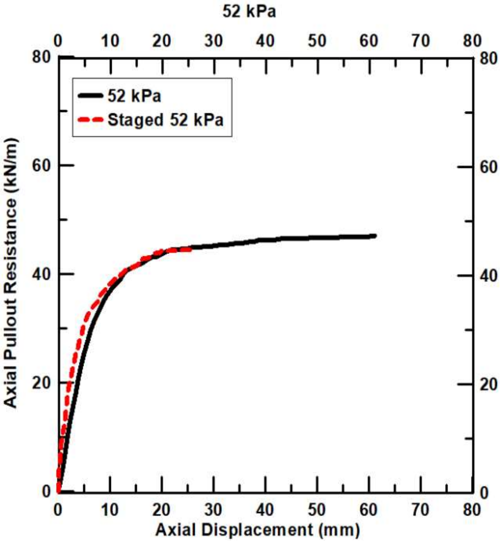
Similar to the other geogrids, estimated curves were plotted using logarithmic equation (2) and plotted with the staged pullout results as shown in fig. 4.26. Now, estimated results from SPOT are plotted with the experimental results from CPOT as shown in fig. 4.27 which shows less than 10% variation up to 20mm displacement.



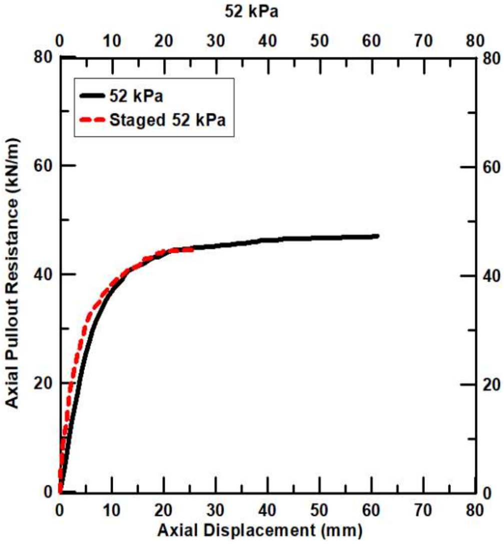
(a) 17 kPa



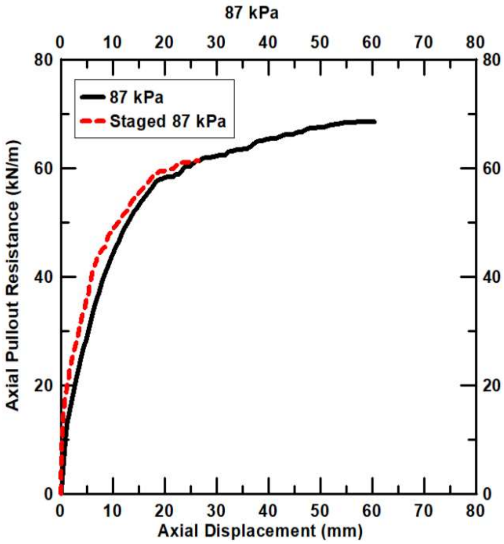
(a) Staged 17 kPa



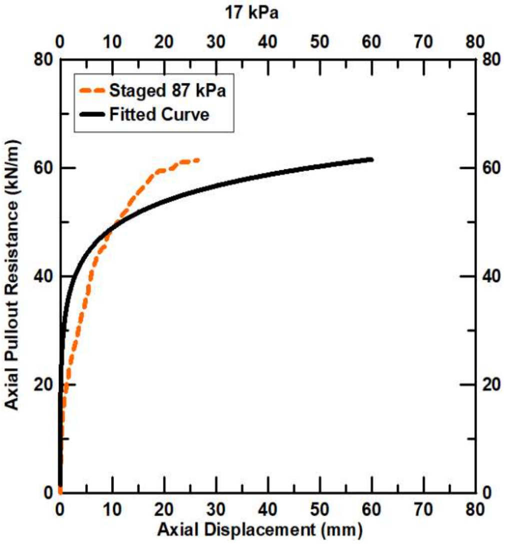
(b) 52 kPa



(b) Staged 52 kPa



(c) 87 kPa



(c) Staged 87 kPa

Figure 3.25 Experimentally measured curve at CPOT and SPOT

Figure 3.26 Measured and estimated curve at SPOT

Finally, it could be concluded for this geogrid that estimated results are showing closer value with the conventional results for the initial stress condition 17kPa and 52kPa with a less than 10% variation with respect to conventional pullout results while the variation is going to increase for higher normal stress conditions. So, the staged pullout results could be used instead of conventional pullout results with a factor of safety between 1.1 - 1.2. This factor of safety is matches with the other reinforcements either embedded in sand or pond ash.

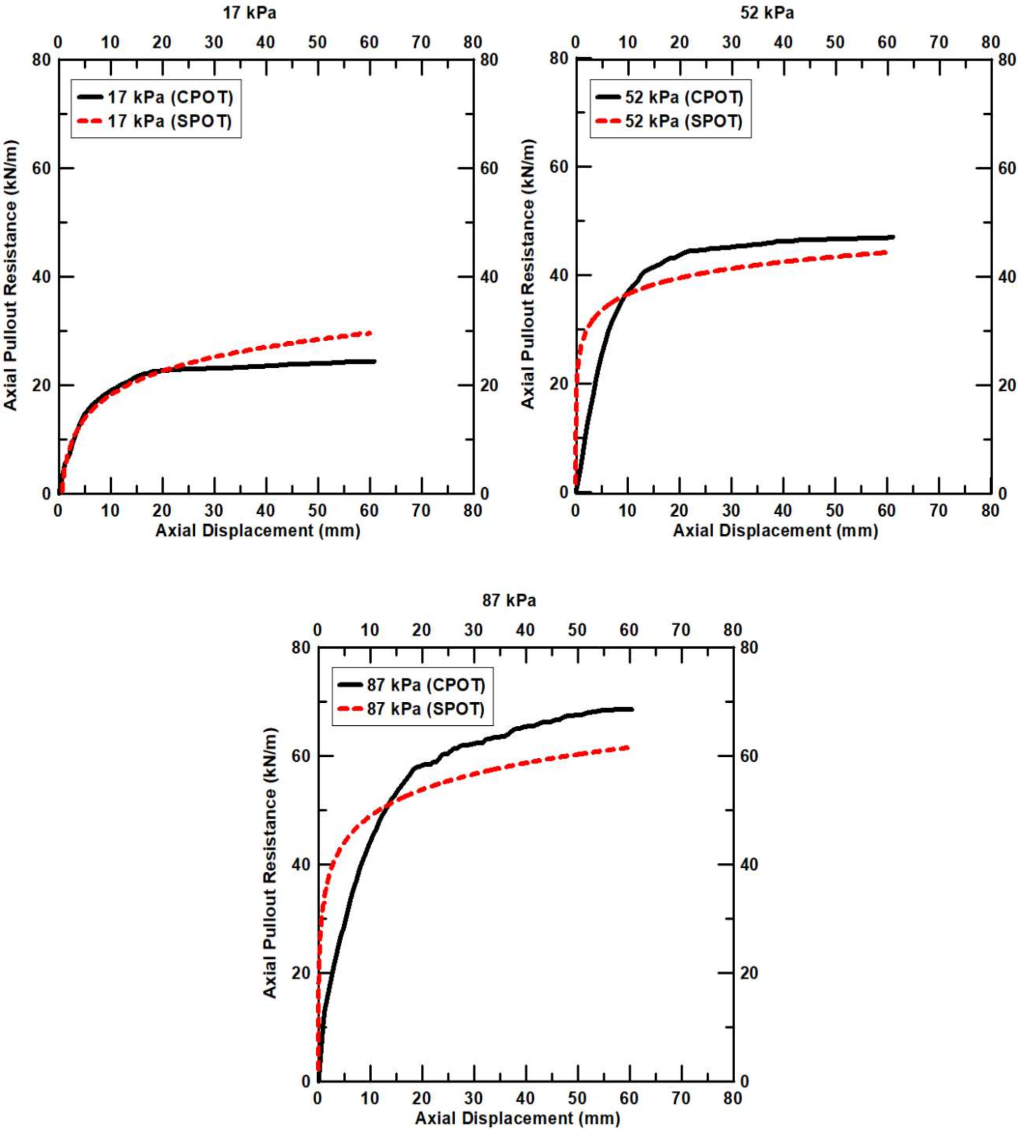


Figure 3.27 Comparison between estimated curve by SPOT and measured curve by CPOT

4.3 Pullout resistance of various types of reinforcements (kN or kN/m)

17 kPa							
Backfill Material	**Reinforcements**	**CPOT**			**SPOT (From fitted curve)**		
		20 mm	**40mm**	**60mm**	**20 mm**	**40mm**	**60mm**
Sand	Smooth metal strip	1.0	1.03	1.03	1.0 **(0%)**	1.03 **(0%)**	1.03 **(0%)**
	Grid 120x30	27	33.2	35.1	27 **(0%)**	33 **(0.6%)**	35 **(0.2%)**
Pond ash	Grid 120x30	22	23	24	22 **(0%)**	26 **(-13%)**	30 **(-25%)**
	Grid 200x30	21.2	24.7	25.3	21 **(0.9%)**	24 **(2.8%)**	28 **(-10%)**
	Grid 250x30	22.6	23.5	24.3	22.6 **(0%)**	23 **(2.1%)**	29 **(-19%)**
52 kPa							
Backfill Material	**Reinforcements**	**CPOT**			**SPOT (From fitted curve)**		
		20 mm	**40mm**	**60mm**	**20 mm**	**40mm**	**60mm**
Sand	Smooth metal strip	2.1	2.2	2.2	2.1 **(0%)**	2.1 **(4.5%)**	2.1 **(4.5%)**
	Grid 120x30	31.4	39.6	43.3	31 **(1.2%)**	39 **(1.5%)**	41 **(5.3%)**
Pond ash	Grid 120x30	28.3	38.1	42.1	28 **(1%)**	36 **(5.5%)**	41 **(2.3%)**
	Grid 200x30	32.4	37.2	38.3	30 **(7.4%)**	35 **(5.9%)**	38 **(0.7%)**
	Grid 250x30	44	46.1	46.9	40 **(9%)**	41 **(11%)**	42 **(8.3%)**
87 kPa							
Backfill Material	**Reinforcements**	**CPOT**			**SPOT (From fitted curve)**		
		20 mm	**40mm**	**60mm**	**20 mm**	**40mm**	**60mm**
Sand	Smooth metal strip	3.85	3.98	3.98	3.2 **(17%)**	3.2 **(19.5%)**	3.2 **(19.5%)**
	Grid 120x30	34.9	53.1	63	39 **(-11.7%)**	49 **(7.7%)**	55 **(12.7%)**
	Grid 120x30	32.5	47.4	57.8	32 **(1.5%)**	47 **(0.8%)**	59 **(-2%)**

	Grid 200x30	37.5	50.9	51.9	37 **(1.3%)**	42 **(17.5%)**	45 **(13.3%)**
	Grid 250x30	58.3	65.4	68.4	53 **(9%)**	58 **(11.3%)**	61 **(10.8%)**

Chapter 5

4. Conclusions

In this study, a new pullout test method named staged pullout test was performed on smooth metal strip reinforcement and different strengths of geogrid reinforcement with sand and pond ash as backfill materials. A series of tests have been performed to compare the staged pullout results with conventional pullout results and get to know the influence of normal stress on pullout resistance. These staged pullout results are compared with experimentally measured conventional pullout results and a comparison made between the estimated pullout results from SPOT and conventional pullout results. Based on the interpretation of results, following conclusion can be drawn from the study:

1. Pond ash was a type of poorly graded sand (SP) with a specific gravity of 2.36.
2. The axial pullout force increased continuously with increase the axial displacement due to mobilization of normal stress on the surface of reinforcement.
3. An increase in the axial pullout load with an increase in the normal stress was observed irrespective of the type of reinforcement.
4. In staged pullout study, only one model ground is needed for three normal stress conditions while in conventional pullout study three model ground needed for three normal conditions. Hence, it is a very convenient method and reduce the testing time and manpower by 1/3 amount.
5. The results of various reinforcements embedded in sand and pond ash were found to be in close agreement with the CPOT results under the normal stress considered in this study.
6. For smooth metal strip reinforcement, peak pullout load from SPOT is similar to CPOT for 17kPa and 52 kPa while lesser for 87kPa because of

breakage of the bond between the reinforcement and fill material during the initial normal stresses (17kPa and 52 kPa).

7. Estimated results are close agreement with conventional results for 17kPa and 52kPa while for 87 kPa staged results could be used with a factor of safety of 1.2.
8. It was observed that pullout resistance for grid 120 x 30 kN/m is lesser in case of pond ash because of lesser frictional resistance between pond ash and geogrid.
9. In case of extensible reinforcements experimentally measured results for CPOT and SPOT are closer up to 20mm axial displacement.
10. For extensible reinforcements, estimated results were plotted using logarithmic equation.
11. Estimated results are differing with a variation less than 10% with respect to conventional pullout results up to 20mm displacement and this variation is keep on increasing up to 20% for further displacements (up to 60mm).
12. It was observed that percentage change with respect to conventional pullout test is more in case of higher normal stress condition because of reinforced has already loaded by two normal stress conditions prior to third normal stress condition.
13. From the comparison, it could be concluded that staged pullout test method could be used instead of conventional pullout test method with a factor of 1.2 to 1.3 irrespective of the reinforcement.

From the comparison study, a staged pullout test method could be used in place of conventional pullout test but it has been thought that continuous study should be done for various types of geosynthetic reinforcements and backfill materials.

References

Ahmad M.A., Shahnawaz M., Siddiqui M. F. &. Khan Z. H. "A Statistical Review on the Current Scenario of Generation and Utilization of Fly-Ash in India." International Journal of Current Engineering and Technology, vol. 4, no. 4, 2014, pp. 2434–38.

Alder, D., et al. "Design Principles and Construction Insight Regarding the Use of Electrokinetic Techniques for Slope Stabilisation." Proceedings of XVI ECSMGE, 2015, pp. 1531–36, doi:10.1680/ecsmge.60678.

ASTM, D6706. "6706. Standard Test Method for Measuring Geosynthetic Pullout Resistance in Soil." American Society for Testing and Materials, vol. 07, no. October, 2001.

Balunaini, Umashankar, et al. "Pullout Response of Uniaxial Geogrid in Tire Shred-Sand Mixtures." Geotechnical and Geological Engineering, vol. 32, no. 2, 2014, pp. 505–23, doi:10.1007/s10706-014-9731-1.

Balunaini, Umashankar, and Monica Prezzi. "Interaction of Uibbed-Metal-Strip Reinforcement with Tire Shred-Sand Mixtures." Geotechnical and Geological Engineering, vol. 28, no. 2, 2010, pp. 147–63, doi:10.1007/s10706-009-9288-6.

Engineering, Civil. Pullout Behaviour of Geogrids * f. Moghadas Nejad ** and j. c. Small. Vol. 29, 2005.

Farrag, Khalid, et al. "Pull-out Resistance of Geogrid Reinforcements." Geotextiles and Geomembranes, vol. 12, no. 2, 1993, pp. 133–59, doi:10.1016/0266-1144(93)90003-7.

Hariprasad, Chennarapu, et al. "Preparation of Uniform Sand Specimens Using Stationary Pluviation and Vibratory Methods." Geotechnical and Geological Engineering, vol. 34, no. 6, Springer International Publishing, 2016, pp. 1909–22, doi:10.1007/s10706-016-0064-0.

Ju, J. W., et al. Staged Pullout Test Method of Reinforced Earth Using Hyperbolic Function. no. 1, pp. 369–76.

Kim, Bumjoo, et al. "Geotechnical Properties of Fly and Bottom Ash Mixtures for Use in Highway Embankments." Journal of Geotechnical and Geoenvironmental Engineering, vol. 131, no. 7, 2005, pp. 914–24, doi:10.1061/(ASCE)1090-0241(2005)131:7(914).

Pandey, Piyush Kant, and Raj Kumar Agrawal. "Utilization of Mixed Pond Ash in Integrated Steel Plant for Manufacturing Superior Quality Bricks." Bulletin of Materials Science, vol. 25, no. 5, 2002, pp. 443–47, doi:10.1007/BF02708024.

rad Krunoslav Minažek, Pregledni, et al. "A Review of Soil and Reinforcement

Interaction Testing in Reinforced Soil by Pullout Test." Građevinar Građevinar GRAĐEVINAR, vol. 3, no. 3, 2013, pp. 235–50.