PERFORMANCE EVALUATION OF POLYETHYLENE TEREPHTHALATE (PET) GEOCELL REINFORCED MUNICIPAL SOLID WASTE PAVEMENT LAYER: A FINITE ELEMENT (FE) NUMERICAL STUDY

A

PROJET REPORT

Submitted in partial fulfilment of the requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

of

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN-173234, HIMACHAL PRADESH, INDIA

MAY, 2022

STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitled **"PERFORMANCE EVALUATION OF POLYETHYLENE TEREPHTHALATE (PET) GEOCELL REINFORCED MUNICIPAL SOLID WASTE PAVEMENT LAYER: A FINITE ELEMENT (FE) NUMERICAL STUDY"** submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Saurabh Rawat.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"PERFORMANCE EVALUATION OF POLYETHYLENE TEREPHTHALATE (PET) GEOCELL REINFORCED MUNICIPAL SOLID WASTE PAVEMENT LAYER: A FINITE ELEMENT (FE) NUMERICAL STUDY"** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Hemang Jandrotia (181660) and Atul Vashisht (181621)** during a period from January 2021 to May 2022 under the supervision of **Dr. Saurabh Rawat**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ACKNOWLEDGEMENT

I would like to thank so many people who have helped in every possible way in successful completion of this project. Firstly, I would like to express my gratitude to my project guide Dr. Saurabh Rawat, who have provided me an opportunity to do this project under his guidance. He has provided valuable ideas and support during the course of this work. This work would not have been possible without his support. I would like to thank our project coordinator and all other faculty members and technical staff of Department of civil engineering of Jaypee university of information technology for providing valuable input through the course of this work. I would also like to thank my institute Jaypee University of Information Technology.

I would like to acknowledge my parents for supporting me and giving me liberty to choose what I desire. I appreciate the selfless love and the sacrifices my parents did for shaping my life.

ABSTRACT

This works presents the numerical modeling of Geocells using Abaqus /CAE 2017 software. Geocells are strong, lightweight and has 3-D honeycomb type structure. Plastic bottles cut in a cylindrical shape with various aspect ratios, arranged in tetrahedral and octahedral manner were used to reinforce the MSW ash base over a clay subgrade. Gradual loading of 25 N/cm^2 applied to simulate loading applied using a hydraulic jack. The impact of geocell on the vertical stress transferred to the MSW ash base at varying depth, performance of octahedral and tetrahedral arrangement and bearing capacity has been studied. Results indicate that tetrahedral geocell shows 9.4 % less bearing capacity at same settlement when compared with octahedral geocell. Also, the results indicate geocell made of plastic bottles can be used to reinforce poor soil to prevent excessive settlement and failure. Moreover, poor quality infill material can be used as base layer for flexible pavements if it is being reinforced with geocell. In place of original High-density polymer (HDPE) geocell, geocells made of plastic bottles are used in this work as plastic bottle show similar high tensile strength properties as original HDPE geocell also solving the problem of plastic waste disposal. The behavior of the stress distribution has been studied in this work when plastic bottle geocells are use to reinforce the MSW ash pavement instead of original geocell. Effect of changing the aspect ratio on the bearing strength and vertical load transfer on the soil is studied in detail in this work.

Key Words: Geocell, Numerical modelling, Plastic waste, soil stabilization.

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LIST OF ACRONYMS AND SYMBOLS

PET	Polyethylene Terephthalate
AR	Aspect ratio
FEM	Finite element method
Φ	Friction angle
ψ	Dilation angle
v	Poisson's ratio
c	Cohesion
E	Modulus of Elasticity

CHAPTER 1
INTRODUCTION

1.1General

This chapter discusses the importance of geocell research in soil stabilisation. It also explains the advancement of various soil stabilisation or ground enhancement techniques. The basic geocell reinforcement mechanism, as well as the overall organisation of the thesis, are discussed in this chapter.

1.2Need of Study

Expanding soil poses a threat to light structures and their foundations because of its expansive qualities, which cause uplift strain on the foundation. On the other hand, permanent deformations are seen as a result of the construction on the unstable soil. The bulk of black cotton soil is found in a considerable area of India, as seen in Fig. 1.1. Because of its expansive nature, it expands and contracts, causing voids between the soil to form, lowering the soil's strength and stiffness, and eventually leading to shear failure. Shear failure occurs in soil as a result of external boundary forces or the soil's own weight, as well as the expansion and contraction of the soil beneath the structure. As a result, reinforcement is required to form a tensile bond on the soil reinforcement surface, which will limit soil particle mobility. The geocell mattress, which is comprised of geotextile, provides physical confinement to the soil and aids in load transfer through geocells. The higher-strength geocell generates a mattress composite with bending stiffness, reducing pavement stress. Geocells minimises plastic deformation on work platforms as well as vertical settlement and lateral spreading.

Figure 1. 1 Distribution of black cotton soil in different parts of India [1]

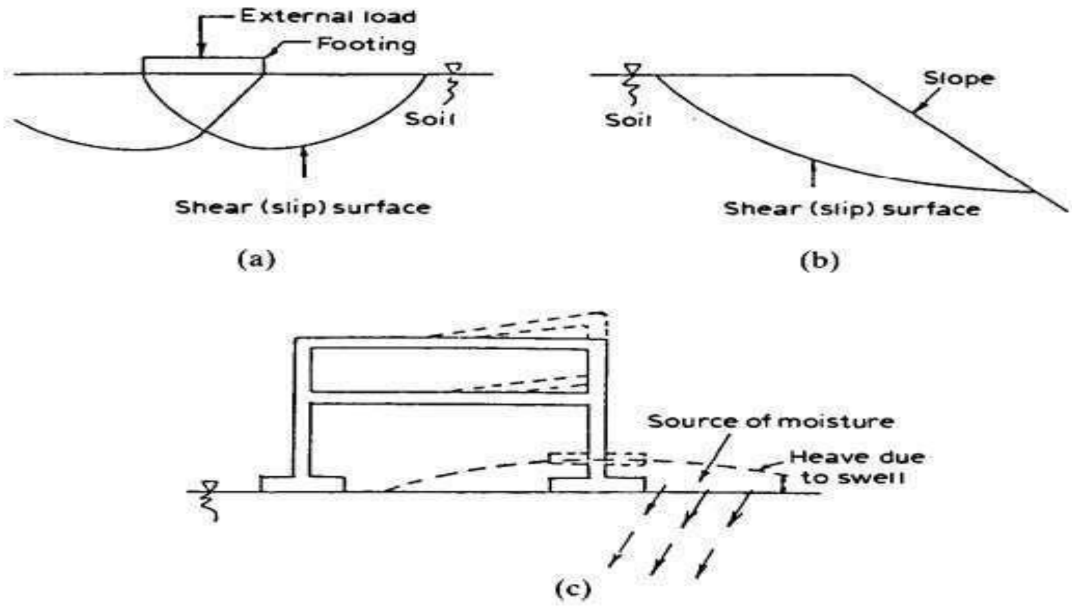


Figure 1. 2Shear failure due to (a) external load, (b) self-weight, (c) expansion of soil [1]

1.3 Waste Material

1.3.1 Plastic

Plastic garbage is collected in India at a rate of 3.92 million tonnes per year. More than half of its output is dumped into oceans, with the remaining being dumped on land, where they do not decay quickly, polluting the water..Plastic is a hazardous, non-biodegradable product that enters the food chain, posing a threat to human and animal health. Sulphur dioxide, dioxins, and other harmful gases are produced when plastic is burned. These emissions damage the lungs and put a lot of stress on the human immune system. Chlorinated plastic emits hazardous chemicals into the soil, which then seep into the groundwater and into the ecosystem. So, in order to reduce the adverse impacts of plastic, it must be recycled because it can be used as a container, jars, bottles, or a geocell for soil reinforcement. Plastic waste generation in India has been depicted in figure 1.3.

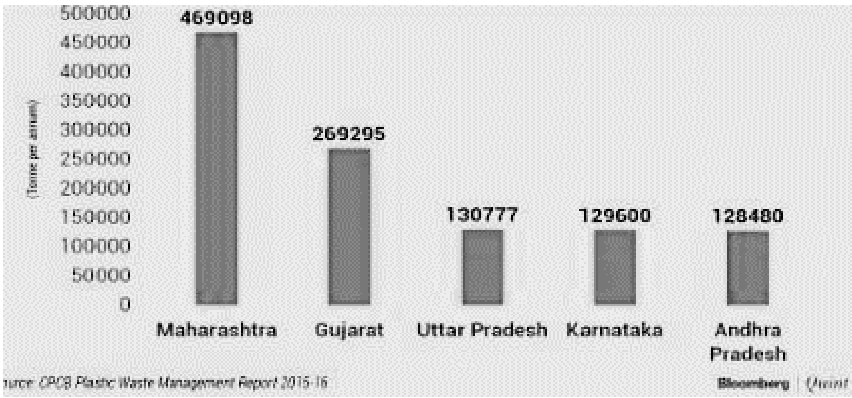


Figure 1. 3 Plastic waste generation in India [2]

1.3.2 MSW Fly Ash

Every year, a huge amount of municipal solid waste is generated. In many countries, waste management and usage are serious concerns. Incineration is an usually utilized technology for waste treatment since it reduces trash by 70% in mass and 90% in volume. In most cases, municipal solid waste incineration creates two forms of fly ash: bottom ash and fly ash. MSW Fly Ash has the components Si, Fe, Al, K, Ca, Na, and Cl. Calcium oxide, ferric oxide, and potassium oxide are among the oxides found in it. MSW Fly Ash can be utilised in the production of cement and concrete, among other things. It could be used as a raw material in the manufacturing of Portland cement. MSW Fly ash may give these nutrients to the soil in agriculture because nitrogen, phosphorous, and potassium are the three major nutrients for plant growth.

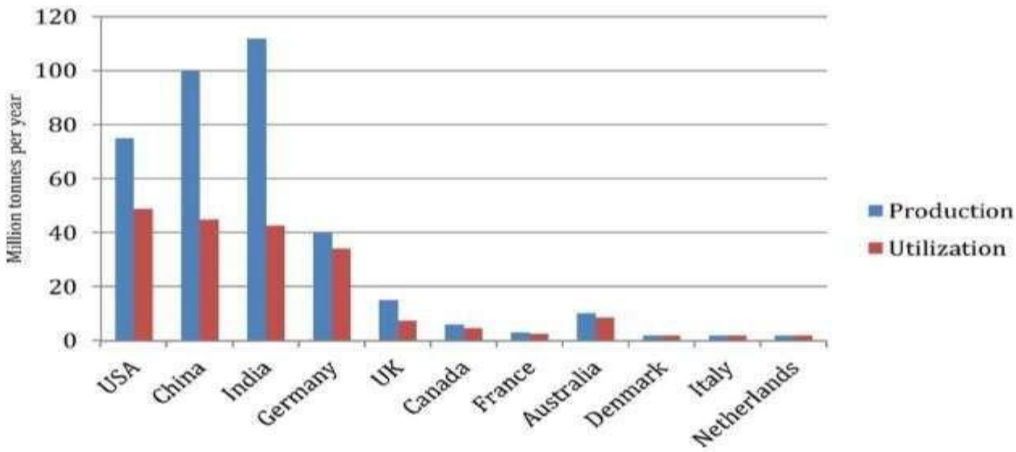


Figure 1. 4 Production and utilization of fly ash in various countries [2]

When constructing embankments, it is usual practise to stabilise the soil with lime or cement if the soil does not have the desired geotechnical qualities. It increases its shear strength. Because MSW Fly ash has a lower density than other fill materials used in embankment constructions, it can be utilised as a substitute for lime or cement. The Production and utilization of fly ash in various countries has been shown in figure 1.4.

1.4 Geocells

Geocells is a (3-D) three-dimensional, polymeric, honeycomb type structure. It is used to stabilize the base of a soft soil. Because the filled cells are connected, the panel works as a huge 3D mat. It prohibits any lateral movement of the infill material, indicating that the geocell provides strength to the infill material. When the infill material is placed inside the geocell, we can instantly place any heavy equipment on top of it, and with a base like geocell, we can have immediate traffic flow. It can also be used for slope control and channel control. New varieties of geocells with significant technological features are formed of a new polymeric structure that is similar to (HDP) High Density Polyethylene in terms of low temperature flexibility.

In road construction, the base layer reinforcement forced geocell mattress acts as a rigid slab or mattress for vertical traffic load distribution on a larger subgrade. As a result, the vertical force acting on the subgrade is reduced, while capacity improves. Because of their difficulty in handling and expensive cost, metallic geocells, particularly those constructed of aluminium, were not chosen.

Figure 1. 5 HDPE honeycomb structure geocell[3]

Above figure 1.5 shows the original honeycomb structure in which the geocells are manufactured. Geocells can also be formed from geogrid sheets joined together with bodkin joints. A sort of arrow head is the Bodkin joint. At the moment, the most common polymer utilised to make geocell by welding is high density polyethylene.

Geofoam is stretched polystyrene or extruded polystyrene (EPS) manufactured into large lightweight block. The blocks range in size from 2m x 0.75m x 0.75m to 2m x 0.75m x 0.75m. Geofoam's main purpose is to fill voids beneath highways, bridge approach embankments, and parking lots with a lightweight material. Geofoam is widely used in a variety of applications, including lightweight fill and green roof fill, due to its low settlement. Other typical fills with equivalent compressive strength are up to 50 times heavier than Geofoam.

Figure 1. 6 EPS geofoam in cubical form is the extruded polystyrene large lightweight blocks easy to handle and apply[4]

1.5 Geocell Application

Geocell reinforcement improves bearing capacity and modulus while being cost effective. The base layer thickness is decreased, and the pavement's service life is increased. It aids in the reduction of operational and maintenance costs. The following are a few of its applications.

1.5.1 Prevention of Soil Erosion

As the upper layer of soil on the slope surface is occasionally weak, soil particles can be easily shifted by elements such as wind and water, generating rills and gullies over time. The geocells hold the soil particles in place better, lowering the risk of erosion. The permeability structure of the geotextile allows water to freely move between the cells, promoting vegetation development and future soil erosion resistance.

Figure 1. 7 Geocell mat laid over the slope which helps in strengthening the soil and holding the top soil layer tightly. [2]

1.5.2 Load Support

Geocells spread the load across a vast area, improving the modulus of the infill material as shown in Figure 1.8, due to the confinement effect and honeycomb structure. Geocells have a lot of impact on pavement, ground improvement beneath embankments, and access roads across poor subgrades like expansive soils and black cotton areas. Geocells load support technology is appropriate for low CBR ground with heavy load needs, and it helps to conserve natural resources by reducing aggregate layer thickness.

Figure 1. 8 Geocells laid for soil stabilization. [2]

1.5.3 Retaining Wall

When a change in slope is encountered, a retaining wall is required in several cases. Retaining walls are typically costly to build and take a long time to complete. For such tasks, a geocell retaining wall is the optimum option. The wall can be built as a gravity wall or as a geogrid reinforced soil wall. Because the wall panels are manufactured and brought to the job site, there are few on-site operations necessary.

Figure 1. 9 Geocells used to stabilize retaining wall. [2]

1.5.4 Slope Liner Protection

Geocell liner protection system is the ideal solution when a geomembrane liner or other surface protective membrane is used on the slope that cannot be damaged or punctured. The Geocell mat is spread on the liner without the need to puncture it and is anchored at the crest of the slope shown in Figure 1.10. The crest anchorage is designed to withstand all of the mat's sliding forces. For extremely steep slopes, the Geocell mat liner protection system can be built.

Figure 1. 10 Slope Concreting is done in order to protect geomembrane lined slope from uplift [2]

1.6Advantages and Limitations of Geocells

1.6.1 Advantages

Geocells provide a number of advantages, including being easy to transport and install on-site. Low cost and increased durability, as well as being environmentally friendly and lightweight. It lowers the cost of operating and maintaining roadways. It is a more efficient use of trash and a more stable stabilisation of weak soil or infill material.

1.6.2 Limitations

Careful quality control and quality assurance are required for handling, storage, and installation. Proper additives, such as antioxidants and fillers, must be utilized to ensure the long-term functioning of a particular resin used to produce the next geocell mechanism.

1.7 Geocell Mechanism

The load carrying capacity of geocell reinforced soil is influenced by the lateral resistance effect, vertical dispersion effect, and membrane effect.

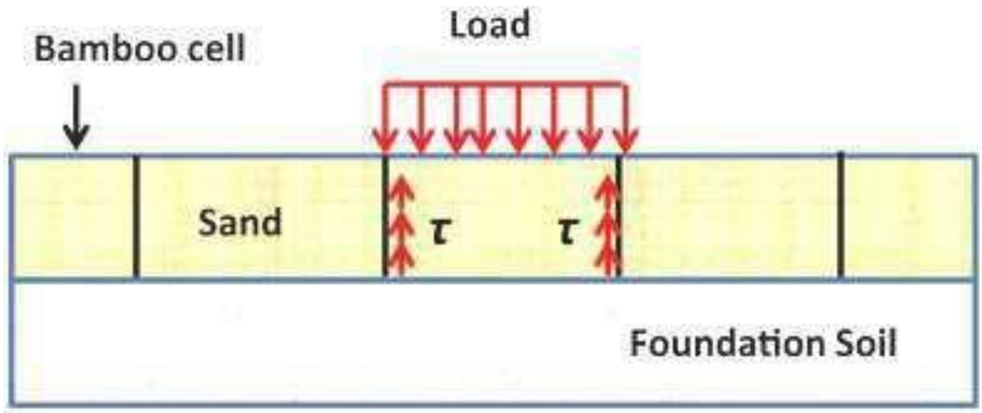


Figure 1. 11 Mechanism of mobilization of shear strength due to wall friction [5]

The lateral resistance effect included in the formulation refers to the mobilisation of additional shear strength in the soil bed as a result of contact between the inner surface of geocells and the infill soil. Figure 1.11 shows how wall soil friction causes shear strength to be mobilised. The geocell's inner surface has a specific roughness that produces friction between the substance and the geocell's inner surface. The fictitious force created resists the applied load and increases bearing capacity. Figure 1.12 shows the variation of vertical stress with depth.

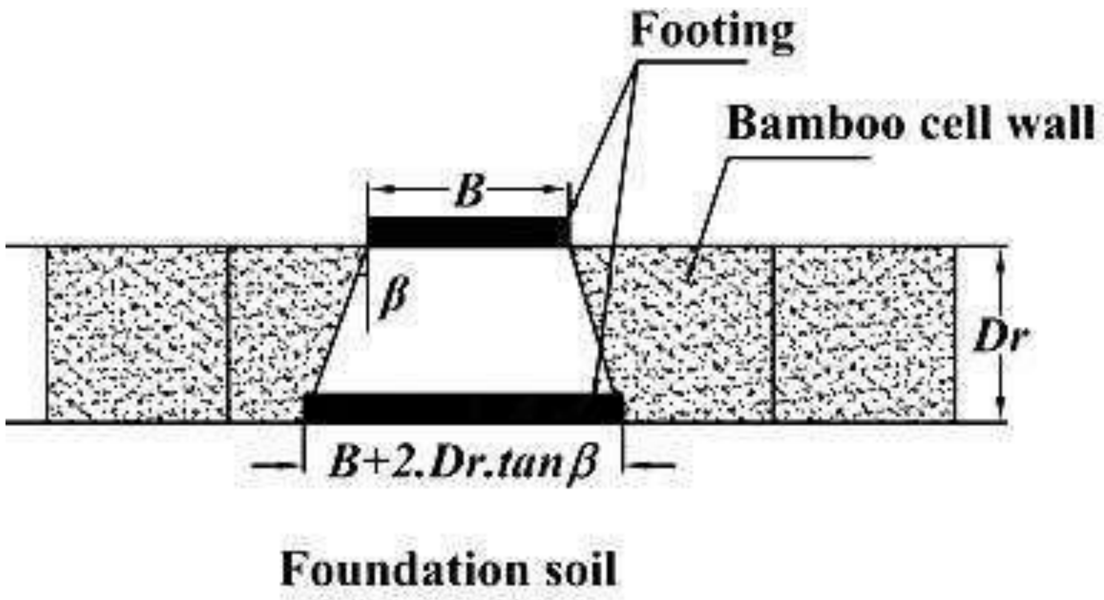


Figure 1. 12 Vertical stress distribution mechanism [5]

The vertical component of the mobilized tensile strength of the planer reinforcement, if exists, contributes to the membrane effect mechanism. Because to the membrane effect, the load carrying capacity increases.

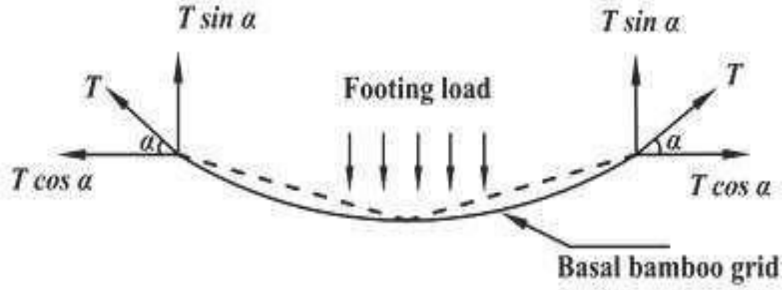


Figure 1. 13 Deformed basal geogrid contribution to membrane effect [5]

1.8 Organization of thesis

The first chapter discusses the importance of geocell research in soil stabilisation and use it as a component to increase the tensile strength of the soil. Different technique used for soil stabilization using geocell have been discussed in this chapter. The application and advantages of using geocells as a ground improvement technique in pavements and assess roads across poor subgrade like expansive soils, membrane effect and influence of geocells on the load carrying capacity have been discussed in this chapter.

In second chapter various parametric studies and numerical analysis conducted on the concept of using geocells as soil reinforcement. This chapter deals with the effect on the behaviour of geocells by varying different parameters generally aspect ratio of geocell and height of the geocell reinforcement layer. Impact of geocells on the strength of the soil.

The third chapter deals with the methodology used for the numerical modelling of plastic bottle geocell reinforced MSW ash pavement, material used and parts and properties assigned to the assembly in the numerical analysis of MSW fly ash reinforced with plastic bottle geocell in ABAQUS using finite element analysis. This chapter summarizes the design of plastic bottle geocell reinforced MSW ash, boundary conditions applied to the model assembly and the interaction used for simulating field behaviour of the reinforced soil.

The fourth chapter discusses the results obtained from the numerical analysis of the plastic bottle geocell reinforced MSW ash pavement. Variation of vertical stress with different aspect ratio and the type of arrangement showing better load transfer have been studied in detail. In this chapter Major stress regions in the geocells and the stress distribution in the reinforced MSW ash layer. This chapter discuss the impact of tetrahedral and octahedral arrangement in the strength of geocell.

In the fifth chapter we have emphasized on the results obtained from the numerical analysis on the MSW ash pavement reinforced with plastic bottle geocell. It can be concluded that the geocells made of plastic bottles is sufficiently effective in the soil restraining and increasing the load bearing capacity for long term stability of the soil.

CHAPTER 2

LITERATURE REVIEW

2.1General

This chapter discusses the many years of research on the design of reinforced soil structures. In 1970, the United States Army Corps of Engineers came up with the concept of cellular confinement. Paper saturated in phenolic water-resistant resin was then used to make geocells. Metal geocells were later used to meet the requirements, but because to their difficulty in handling and increased cost, other options were sought. Geocell reinforcement research has included experiments with a variety of parameters, such as aspect ratio (L/D), geocell matt positioned at various heights from the top, and working with various reinforcements of different materials, such as PET bottles and P.P.B. This chapter attempts to compile the results of many parametric studies on the topic of soil reinforcement.

2.2Research on Geocell Reinforced soil

Phoharel (2017) used a medium scale loading device to evaluate the geocell reinforced base under repeated loading. A 15 cm diameter air cylinder with a 900kPa air pressure was used in the loading system. The loading plate had a diameter of 15 cm which was used. The load was applied by controlling the air pressure in the cylinder, and it was applied in a trapezoidal pattern at 1 minute per cycle. The geocells enhanced the bearing capacity and stiffness, according to the findings. Reduce the required thickness and increase the pavement's service life. Reduce the amount of maintenance required and the expense of operations.

Figure 2.1 depicts a cross sectional view of a geocell with granular infill material and a loading plate that serves as a footing, as well as a plane view of the geocell with the loading plate in the centre.

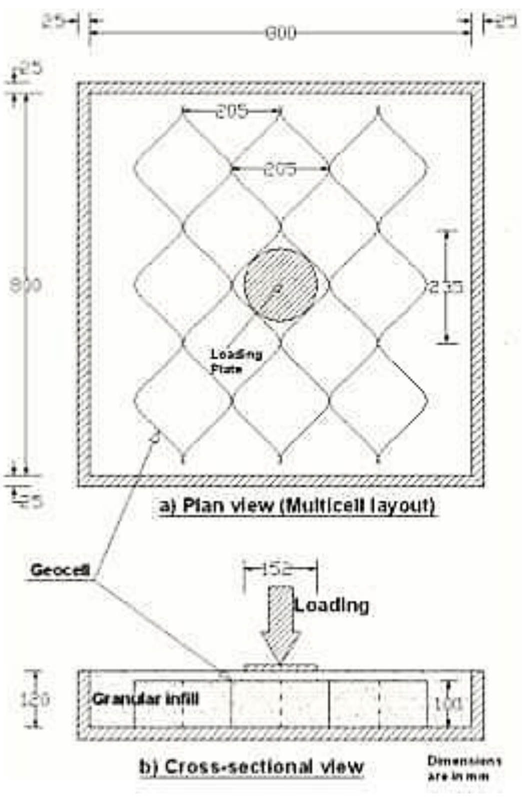


Figure 2. 1Test box with geocell layout [3]

Humayoo (2016) improved CBR by employing a waste plastic matt as the geocell. Tests are carried out on samples that have or do not have a plastic matt. Different heights and thicknesses of waste plastic bottles are cut. A map-like structure is formed by joining the rings. Waste plastic mats of various thicknesses, such as 1cm, 2cm, 3cm, 4cm, and 5cm, are collected. Individual tests are carried out for various thicknesses at depths of 2cm, 4cm, 6cm, and 8cm. The maximum CBR was discovered at a depth of 4cm, which equalled 2.9.

The CBR value was lower at various depths when compared to the value at 4 cm, and as the CBR value decreases, the thickness of the pavement increases, making the structure uneconomical, and as the CBR value increases, the thickness of the pavement decreases, requiring less material to build the pavement, making it more economical.

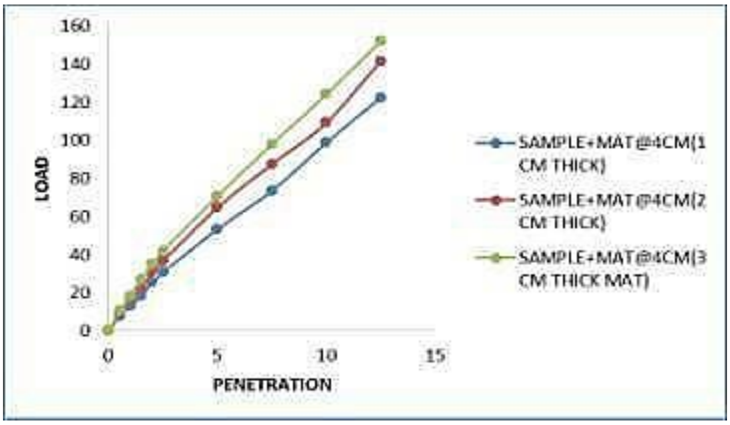


Figure 2. 2 load vs. penetration graph [6]

The load penetration curve in Fig. 2.2 at a depth of 4 cm indicates that as the thickness increases, so does the load bearing capacity.

Swaraj and Shakthi (2014) conducted an experimental study on geocell reinforced foundations, concluding that utilising geocells as reinforcement increases the bearing capacity of soft soil foundations. The performance of a geocell made of a stronger material with a smaller aperture in the orthogonal direction is better. When the foundation soil is dense, geocells have a significant impact.

Marto et al. (2012) conducted a series of experiments to determine the impact of geocell reinforcement in sand on footing bearing capacity. It was discovered that placing the geocell mattress at a depth of 0.05B from the base provides the best footing performance. Around b/B=5 and (u/B)=0.35, the optimal width and depth of a cellular mattress can be found. Footing settlement reduces as the number of reinforcement layers grows, whereas bearing capacity improves.

Vaddi et al. (2015) used waste rubber tyre chips to perform an experimental research on CBR for mechanically stabilising expansive soil. CBR and compaction were discovered to be dependent on the clay content of the soil. In comparison to lime and tyre chip, the MDD and CBR values for expansive soil will be low. Increases in lime MDD decreases and increases in lime OMC in general increases.

Choudhary et al. (2011) investigated how to increase CBR value on expansive soil utilising geosynthetic as reinforcement and found that adding reinforcement within the expansive soil subgrade considerably aids in limiting swelling. The amount of reinforcing layers and type of reinforcement employed will determine the percentage reduction. The CBR value rises as the number of reinforcing layers and their relative positions increase.

Dash and Bora (2013) investigated the impact of stone columns and geocells on soft clay foundation improvement. The bearing capacity of a stone column increased by 3.7 times, whereas the bearing capacity of a geocell alone increased by 7.8 times. When employed in conjunction with precise spacing and depth, the bearing capacity of the stone column and geocell increases by 10.2 times. The recommended optimum length and spacing of stone columns is 2.5 to 5 times the diameter of the geocell. The maximum height of geocell that can be employed is equal to the foundation depth.

Emersleben (2008) Large scale test carried out in a test box to study the influence of geocells on bearing capacity of soil. Load was applied using a hydraulic jack on the steel plate which acts a footing. A stress reduction between 30% and 36% was observed. The load applied on the geocell was distributed over a wider area with the help of geocell. To measure the stress transferred to the bottom of soil, pressure cells and displacement gauges were used. Use of geocells improve the tensile strength of the soil and can be used to reinforce weak soils as they fail in tension. Also, significant stress reduction was observed in the infill material.

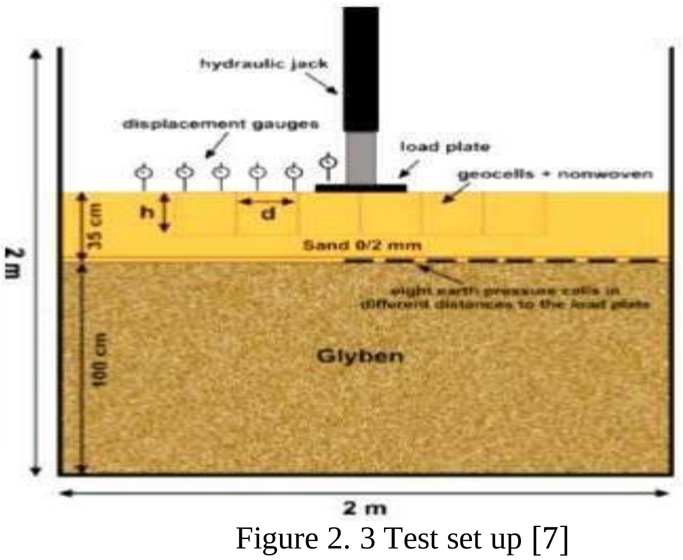


Figure 2. 3 Test set up [7]

Figure 2.3 depicts a schematic diagram of a test setup that contains earth pressure cells for measuring pressure, a dial gauge for measuring displacement, a hydraulic jack for loading, and a load plate for footing.

Geocell reinforced base bearing capacity: an experimental study by **Yu Quian (June 2009).** A medium scale loading apparatus was used to conduct laboratory plate load tests. With a maximum air pressure of 2100KPa, the loading system has a diameter of 15.2cm. A 345kPa cyclic load was used. Geocell reinforced bases have up to 1.5 times the bearing capacity and stiffness of unreinforced bases.

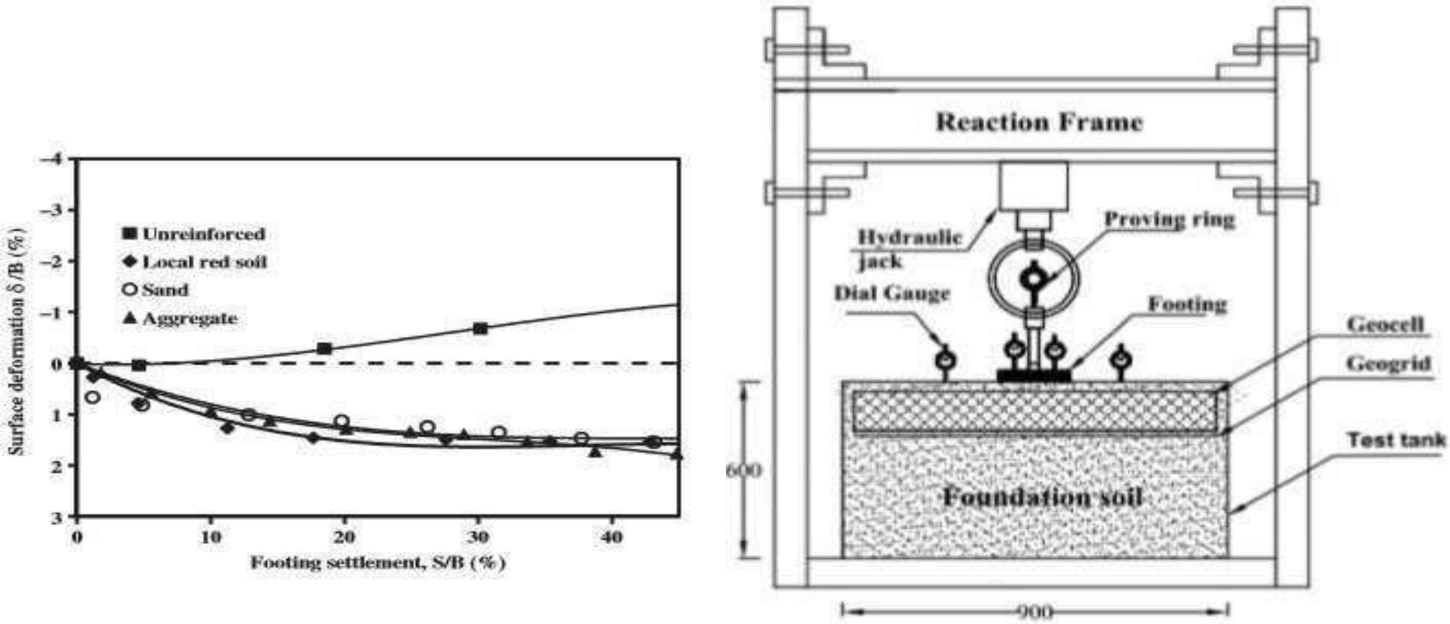
In the field of civil engineering, Gourav Dhan (2014) experimented with a unique technology of soil reinforcement. The geocell reinforced base, on the other hand, provides more lateral confinement. It also gives the cohesionless soil an appearance of cohesion, which is mostly determined by the tension modulus of the geosynthetic used to create the geocells. The footing performance improves when the aspect ratio (L/D) is one because the load is dispersed over a greater surface. Geocells form more efficiently in a diamond arrangement. The influence of geocell reinforcement depth on soil bearing capacity was also investigated, with the findings revealing that geocell reinforced soil at a given depth provided a 4-fold increase in ultimate bearing capacity. The laboratory findings show that the cycle stress ratio and frequency have a large impact on the settlement behaviour of geocell reinforced foundations

Figure 2. 4 Geocells filled with various infill materials are shown

Jha (2011) studied the application of geosynthetics to improve the CBR value of expansive soil. The investigation employs two types of reinforcements: geotextile and geogrid. It was discovered that by putting in reinforcements, the swelling was decreased and controlled within the expansive soil subgrade. The amount of reinforcing layers and types of reinforcements utilised will determine the percentage reduction in swell potential. The CBR value of soil increases dramatically as the number of layers and their positions inside the soil, as well as the type of reinforcement, increase.

Sitharam and hedge (2015) investigated the impact of infill material on geocells employed as reinforcements. Red soil, sand, and aggregate were the three infill materials used. The load carrying capacity of geocell reinforced soil increased 13 times with aggregate infill, 11 times with sand infill, and 10 times with red soil infill, according to the data. Aggregates, sand, and red soil material settlements were also reduced to 78 percent, 73 percent, and 70 percent, respectively. The most useful filler materials were aggregates. In general, the effect of infill material is negligible, and it is up to the engineer to determine which infill to employ based on site conditions.

The load settlement curve of an unreinforced bed, shown in Fig. 2.5, demonstrates a punching shear failure mechanism.



(a) (b)

Figure 2. 5 (a) model test set up (b) surface deformation with footing settlement [5]

Emersleben and Meyer (2008) created a model with precise dimensions. The final conclusion was that as compared to unreinforced soil, the infill material or soft soil subgrade employed minimises vertical stress. The vertical stress decreases by 45 percent depending on the aspect ratio, and eight earth pressure cells were utilised in the experiment. When in-situ testing of the road K-23 was done, it was discovered that the stress was reduced by 30%. When compared to an unreinforced layer, the geocells layer enhances the modulus of the gravel base layer.

The experiment on the stability of geocell reinforced soil was carried out by **Mandal and Gupta (1994)**. The stiffness of the layer above the soft clay was discovered to become stiffer. The settlement ratio is 5-10%, and the membrane action occurs when the ratio settlement ratio is 20%. Geocell reinforcement improves load and settlement characteristics, and the bearing capacity of reinforced soil increases when compared to unreinforced soil. The large settlement bearing capacity with a 50 percent settlement ratio. In the case of a low settlement curve, a smaller geocell opening should be recommended.

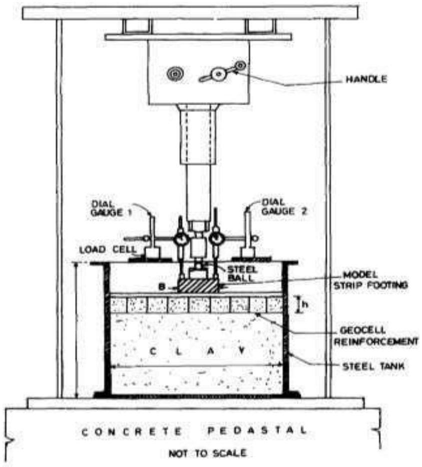
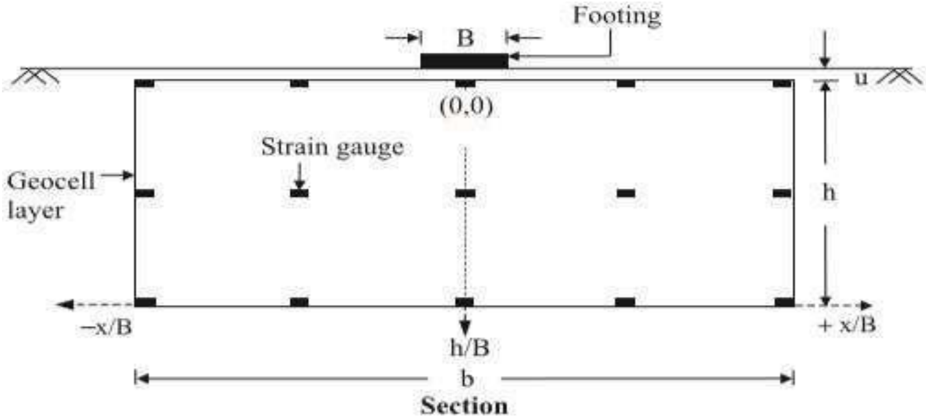


Figure 2. 6 Model test set up [8]

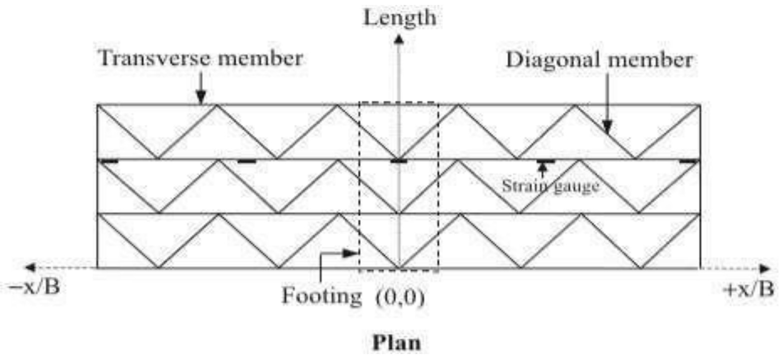
In Figure 2.6, a steel tank is filled with geocell-reinforced soil and a load is imparted to a strip footing.

Dash and Rajagopal (2007) conducted an experiment in which sand bed under strip loading was reinforced with geocell. It was observed that majority of strain occurs at the center of the geocell than at the edges.



(a)

Less effect of geocell was seen at the edges when sand bed was reinforced with geocell and maximum effect was seen just below the footing.

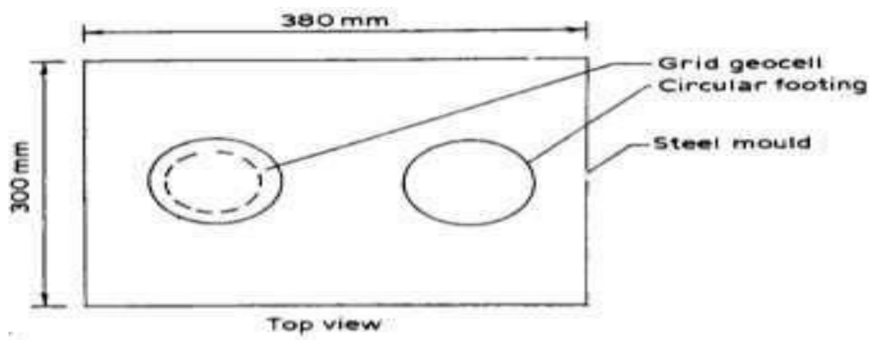


(b)

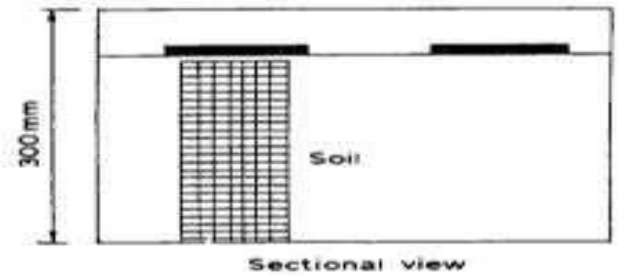
Figure 2. 7 (a) and (b) Geometric parameters and layouts of strain gauges on the geocell mattress [4]

The geometry of the problem is presented in Fig. 2.7 with diagonal and transverse members as well as a strain gauge to measure the strain produced.

Omari and Hamodi (1991) Instead of being utilised to improve soil strength, tensile geogrids could alternatively be used to manage soil swelling. This type of study had already been carried out. The swelling test was carried out with an oedometer equipment that had been expanded in size. When the soil was reinforced, the swelling of the soil was significantly reduced, according to the results of the trials. There is a significant reduction in swelling as the number of reinforcements increases. However, when the stiffness value is taken straight from the manufacturer's index test, the idea of surcharge is found to be invalid.



(a)



(b)

Figure 2. 8 (a) and (b) Exemplification of model test footing [1]

From the top and sectional views, Fig. 2.8 depicts a heavy steel mould with perforated steel base and 100 mm diameter circular rigid plate.

Carter et al. (1991) In order to meet the needs of civil engineering, oriented polymer geogrid was used in the late 1970s. By that time, current usage had risen. Providing reinforced soil walls, slopes, the base of embankments over
soft soil, the reinforcement of roadways of sub base over weak soil, and the reinforcement of bituminous layer are just some of the applications. Because of the high demand for land in nations like Japan and the United Kingdom, development typically occurs on locations with soft or weak soil. Oriented polymers can easily overcome the issue that such sites have raised. The mechanism of failure of sliding, overturning, tilting, and slip is depicted in Fig. 2.9.

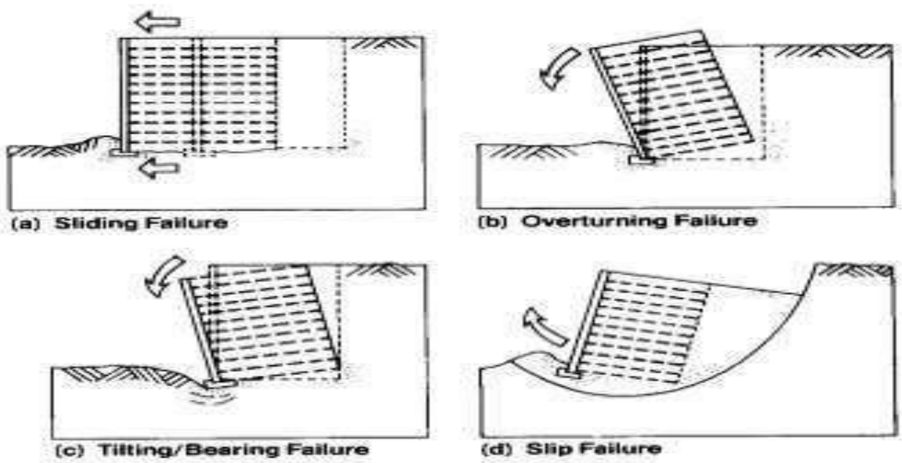


Figure 2. 9 Stability of soil wall that have been reinforced[9]

Pokharel et al. (2011) Four test sections were used in the full-scale accelerated moving wheel test, including one control section with AB-3 base coarse and three NPA geocell reinforced bases with AB-3, QW, and RAP as infill materials. Even though the reinforced base was not compacted as well as the control base, an NPA geocell reinforced crushed stone section 17 cm thick had similar and even greater performance than a crushed stone control section 30 cm thick. With the same base thickness, the NPA geocell reinforced RAP section outperformed the geocell reinforced crushed stone section. The geocell reinforced QW section, on the other hand, performed worse then the geocell reinforced crushed stone secton. The NPA geocell reinforcement increases the stress distribution angle in the reinforced crushed stone section by 13.4 and in the reinforced RAP section by 11.6.

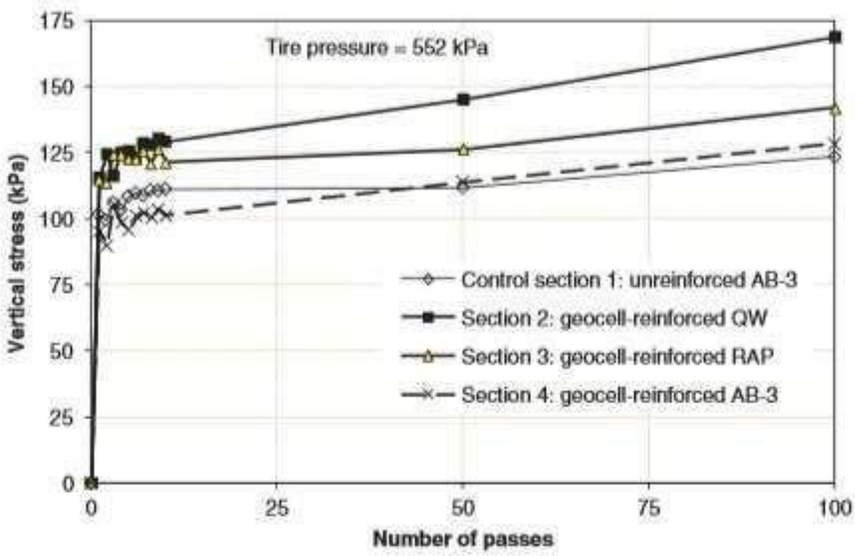


Figure 2. 10Measured vertical stresses at subgrade base interface [10]

The vertical stress observed is lower than the tyre pressure of 552kPa, as shown in Fig. 2.10.

Leshchinsky et al. (2012) Under various loads, such as cyclic or monotonic loads, geocell confinement aids in minimising vertical settlement under the specified conditions. By providing reinforcement, the confining device can prevent lateral spreading. Geocells withstand vertical displacements under cyclic loading. In both monotonic and cyclic examples, the comparison between actual and simulated lateral displacement was not perfect, but the stimulations reveal a tendency of decreasing deformation. The lowest corner of the cell underlying the loading plate had the highest concentration of strain and stress.

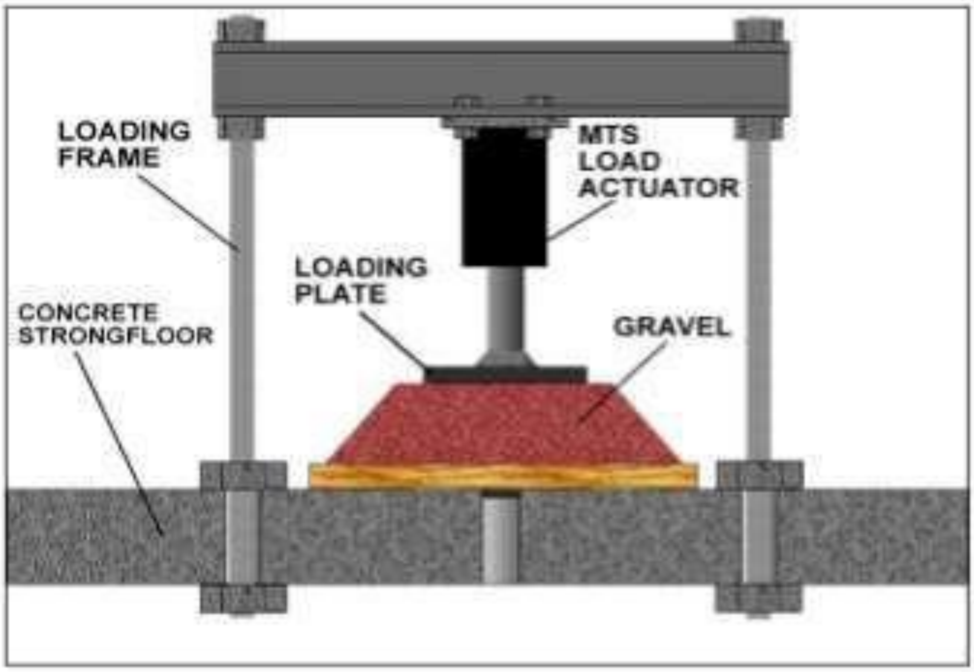


Figure 2. 11 Schematic of testing apparatus [11]

Figure 2.11 depicts the model's setup, which includes a loading frame, a loading plate that serves as a footing, a load actuator that generates load, and a gravel layer that distributes the load.

2.3 Summary of Literature Review

We can easily determine from many researches that geocell reinforcement is a versatile technique in terms of cost effectiveness and that it provides all-around confinement to the material, preventing lateral spreading of soil during the application of load. As a result, geocell reinforcement improves the strength and stiffness of soft soil, boosting bearing capacity. It also gives the cohesionless soil an appearance of cohesion, which is mostly determined by the tension modulus of the geosynthetic used to create the geocells. The footing performance improves when the aspect ratio (L/D) is one because the load is dispersed over a greater surface. Geocell formation is more advantageous in a diamond configuration.

The influence of geocell reinforcement depth on soil bearing capacity was also investigated, with the data revealing that geocell reinforced soil at a given depth provided a fourfold increase in ultimate bearing capacity. With geocell reinforcement, the CBR value rises, resulting in a reduction in pavement layer thickness. With higher aspect ratios, geocell-supported performance improved, although this improvement was minimal when the aspect ratio was greater than unity. To get the best performance in terms of enhancing the surcharge-carrying capacity and lowering deformations, granular soils are suggested for filling inside the geocells. Geocell reinforcement has a 30 to 42 percent reduction in weight. Using geocells to safeguard a slope can increase its overall stability and efficiently prevent slope surface displacement. The occurrence of a sudden increase in local displacement is limited.

2.4Research Objectives

1. To investigate the effect of Geocell reinforced flexible pavement constructed using MSW soil through FEM using Abaqus.
2. To evaluate the response of Geocell reinforced MSW soil pavements for tetrahedral and octahedral Geocell arrangements.
3. To carry out parametric study of Geocell reinforced MSW soil pavement by carrying various aspect ratio of Geocell and loading condition.

CHAPTER 3

METHODOLOGY

3.1 General

This chapter deals with the numerical set up, material used and parts, properties assigned to the assembly in the numerical analysis of MSW fly ash reinforced with plastic bottle geocell in ABAQUS.

3.2 Finite element analysis using ABAQUS

We have used ABAQUS software for the finite element analysis of the plastic bottle geocell reinforced MSW ash pavement. FEM is a powerful numerical technique that uses computational power to calculate approximate solutions. FEM approaches the problem by splitting the body into number of small elements that are connected together at nodes and collection of nodes is called mesh.

3.3 Parts, Material and Properties

The whole assembly is divided into three parts. First is the base layer of MSW fly ash layer which is 140 mm deep with length and width of 300 mm, then clay subgrade is 160 mm deep with 300 mm as its length and width[14], the load is applied on a steel plate with a width of 10 mm and length and breadth of 300 mm. Final part is the geocell made of plastic bottles which were designed in the form of cylinder of height 7cm, 6cm, 5cm and diameter 7cm and 10cm, providing us geocells of various aspect ratio i.e 1, 0.8, 0.7, 0.6 as shown in Fig. 3.1, 3.2 and 3.3 respectively.

The subgrade and base layers are modelled as Mohr–Coulomb plastic elastoplastic materials. Linearly elastic structural elements are used to represent the geocell and steel plate. The material properties and model feature assigned to the various elements as summarized in Table 3.1 and Table 3.2.

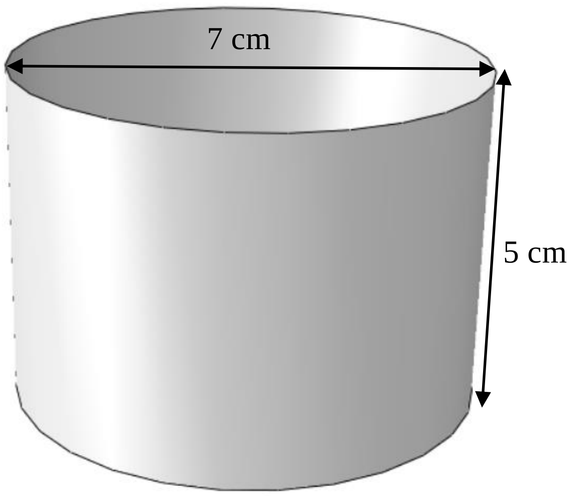


Figure 3. 1 Geocell aspect ratio 0.7

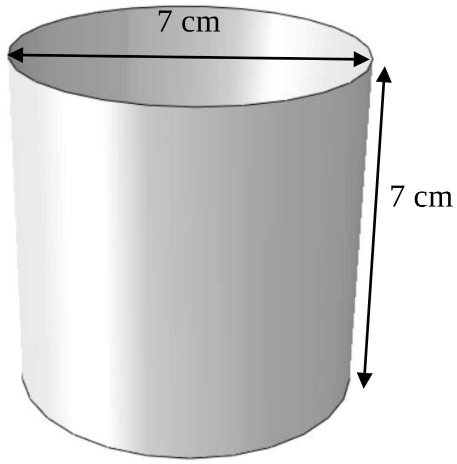


Figure 3. 2 Geocell aspect ratio 1

Tetrahedral and Octahedral arrangements are formed using various aspect ratio 1, 0.7, 0.6 respectively and the whole arrangement is placed at a depth of 4 cm from the surface of MSW ash layer in order to study the change in the behavior of the load transfer to the MSW ash when geocells are introduced.

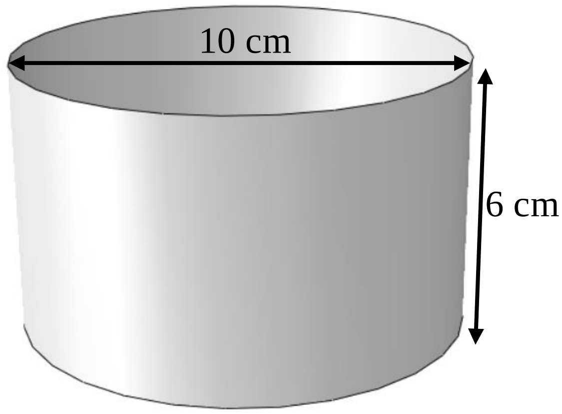


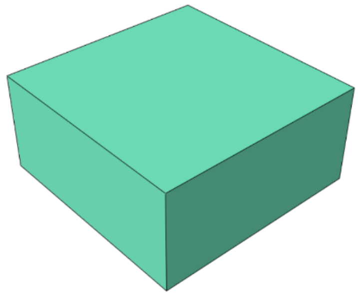
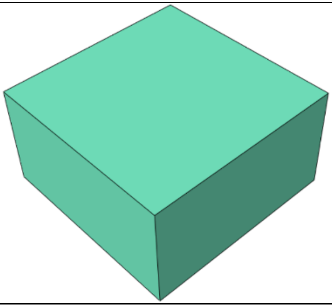
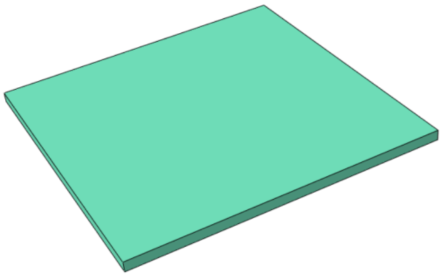
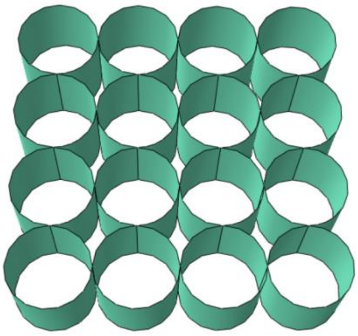
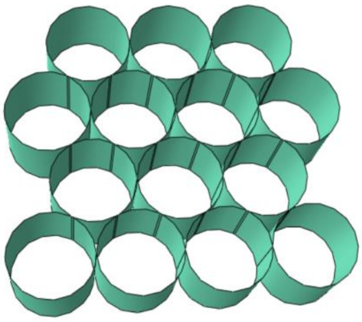
Figure 3. 3 Geocell aspect ratio 0.6

The variation in aspect ratio was done by varying the height of the geocell in the 7 cm and 10 cm diameter plastic bottles. As the aspect ratio (h/D) is a primary contributing factor in the performance of geocells. The dimensions of the different parts used in this numerical modelling is depicted in Table 3.1.

Table 3. 1 Material and Properties

Part name	**Length (mm)**	**Width (mm)**	**Depth (mm)**	**Density (tonne/m^3)**	**Modulus of Elasticity (E) (MPa)**	**Poisson's ratio (υ)**	**Friction angle (Φ) (◦)**	**Dilation angle (ψ) (◦)**	**Cohesion yield stress (c) (MPa)**
MSW ash layer	300	300	140	1335×10^{-12}	4.5	0.35	30	3	0.014
Subgrade (clay)	300	300	160	1800×10^{-12}	1.9	0.3	30	25	0.009
Geocell	AR = 1, AR = 0.7, AR = 0.6			910×10^{-12}	2500	0.28	-	-	-
Steel plate	300	300	10	7.85×10^{-9}	200×10^{3}	0.3	-	-	-

Table 3. 2 Parts and material model

Part name	**Abaqus view**	**Model feature**	**Material model**
Base layer (fly ash)		3D Deformable Solid Homogenous	Mohr coulomb
Subgrade (clay)		3D Deformable Solid Homogenous	Mohr coulomb
Steel plate		3D Deformable Solid Homogenous	Linear elastic
Geocell **TETRAHEDRAL** **OCTAHEDRAL**	 	3D Deformable Shell Homogenous	Linear elastic

3.4 Assembly and Interaction

In the interface between the plate and the base, as well as the base and the subgrade no slip and separation were allowed. General and rough tangential contact, as well as harsh normal contact without separation, are used to achieve this condition. The components in contact with the plate at the start were considered to be of the loading process would notice loose contact with the plate. When tangential friction and plate and base layer interface separation in normal contact were used. The zero slip and zero separation condition were shown to be superior and more accurately replicates the experimental set up.

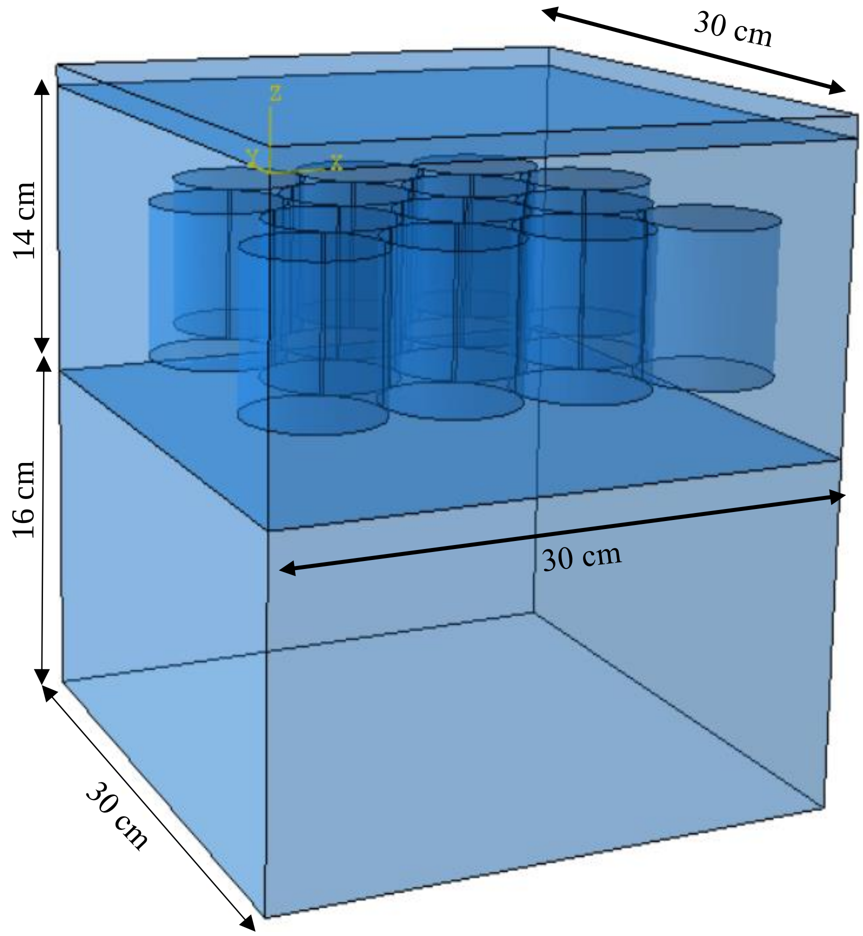
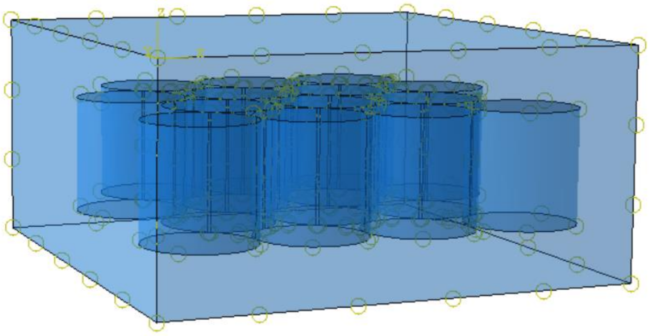


Figure 3. 4 Assembly

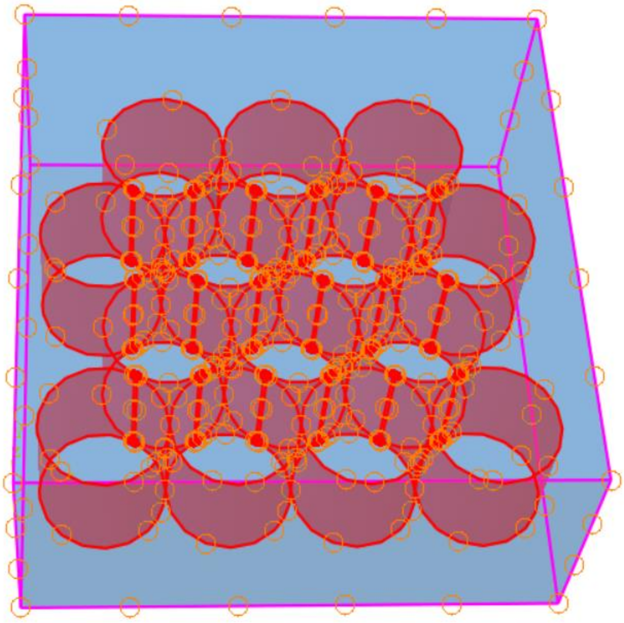
The contact and interaction conditions applied to simulate the field conditions is depicted in Table 3.3

Table 3. 3 Modelling of interaction between the geocell and MSW layer

Interaction property	Normal behavior	Tangential behavior	Constraints
General contact	Hard contact	Rough	Embedded region (for geocell)



a



b

Figure 3. 5 (a) and (b) Embedded region condition

The geocells are given embedded region condition, selecting the MSW ash layer as Master region and Geocells as embedded region as depicted in Figure 3.5 (a) and (b). Abaqus itself calculates the joint Modulus of the following assembly, as now embedded region condition is introduced Geocells acts as a tensile reinforcement in the MSW ash layer similar like the steel bars acts as a reinforcement in the concrete beam.

3.5 Loading and Boundary Conditions

The pressure is applied on the top of the steel plate which increases gradually from 0 to 25 N/cm^2 to simulate the load applied by and hydraulic jack. The load is applied in Step 1, Static loading and the boundary conditions are applied in the initial step. The amplitude plotted for the gradual increasing load is shown in Figure 3.6.

The geocells are placed 4 cm below the top of the MSW ash layer as shown in Figure 3.7 (a)

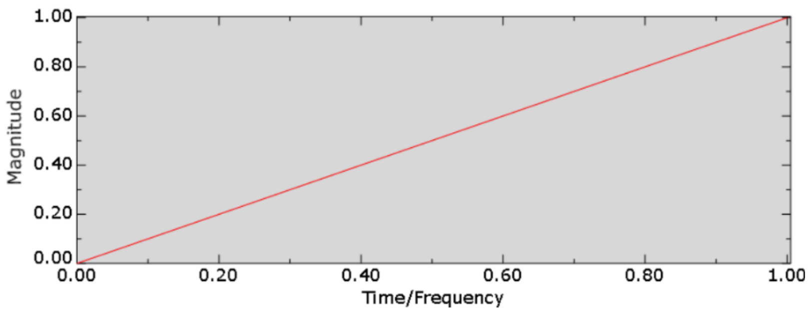
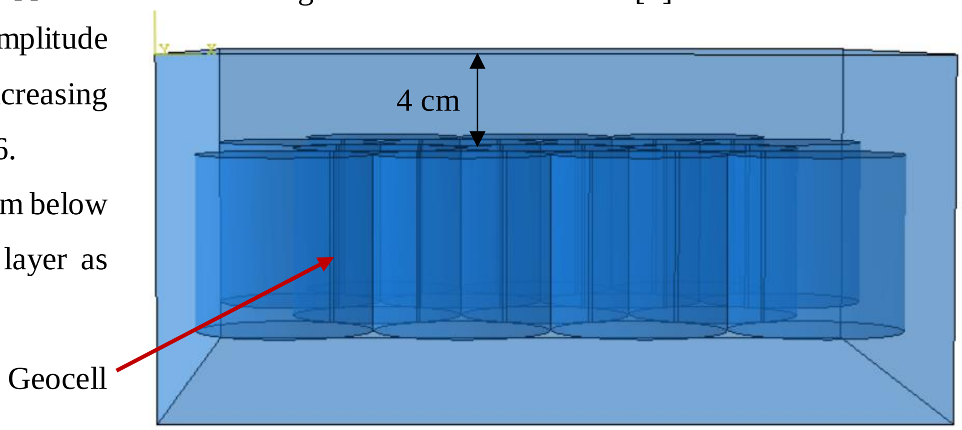


Figure 3. 6 Load definition [2]



(a)

A uniform load is applied on the steel plate placed above the MSW base layer as shown in Figure 3.7 (b). Use of steel plate provides uniform loading over the Base layer and acts as a flexible pavement above the base. The loading of 25 N/cm^2 was applied on the assembly with Tetrahedral and Octahedral arrangement and the load bearing capacity and the load transfer due to the two arrangement was observed.

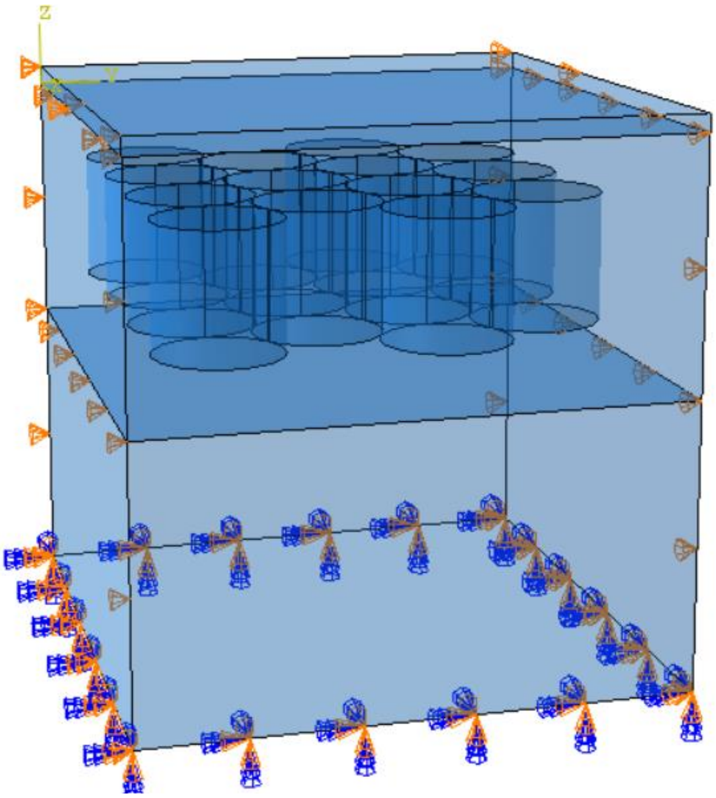


Figure 3. 7 Boundary condition

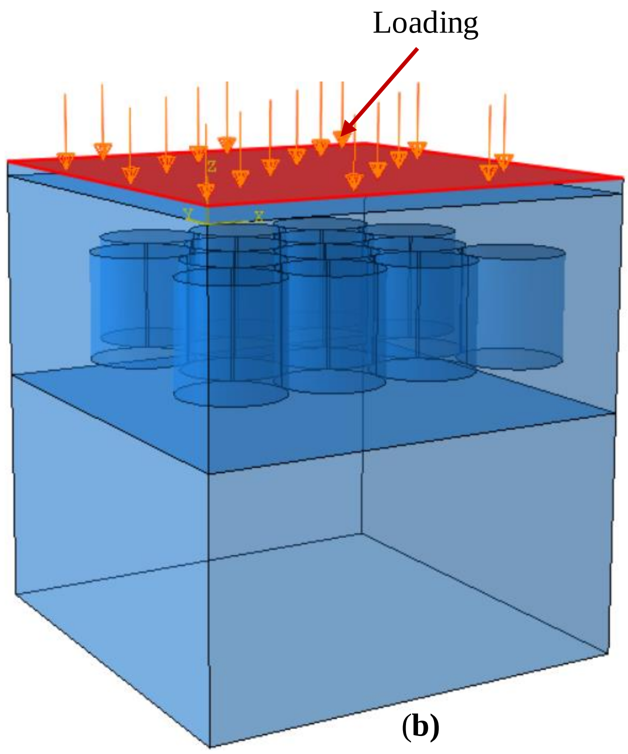


Figure 3. 8 (a) and (b) Loading and geocell location

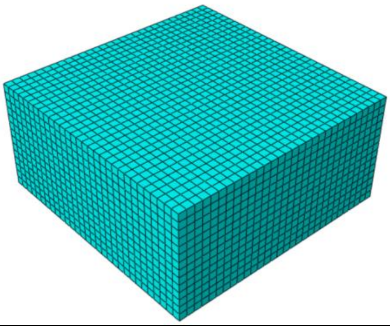
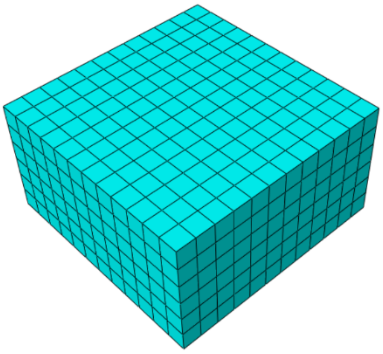
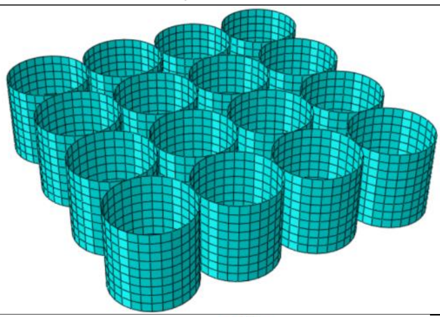
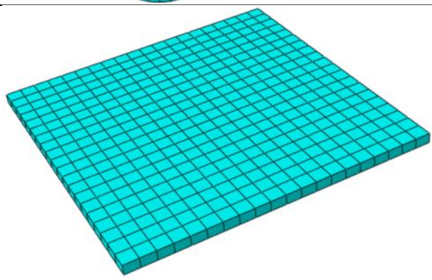
The boundary conditions chosen for the model shown in Figure 3.8 i.e.,

1. All movement were restricted at the bottom of the model.
2. Horizontal movements were restricted on the vertical sides.
3. The following model is free to move in the Vertical direction giving us the displacement in the vertical direction due to the load applied by hydraulic jack.

3.6 Meshing

For all materials except the geocell layer, a solid eight-noded hexahedral mesh element with reduced integration (C3D8R) is utilized in the simulation. Four-noded shell element with reduced integration (S4R) is used for geocell.

Table 3. 4 Meshing

PART	**MODEL**	**ELEMENT TYPE**	**SEED SIZE (mm)**
MSW Ash Base Layer		C3D8R	10
Clay Subgrade		C3D8R	25
Geocell		S4R	8
Steel Plate		C3D8R	15

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

The fourth chapter discusses the results obtained from the numerical analysis of the plastic bottle geocell reinforced MSW ash pavement. Variation of vertical stress with different aspect ratio and the type of arrangement showing better load transfer have been studied in detail. In this chapter Major stress regions in the geocells and the stress distribution in the reinforced MSW ash layer. This chapter discuss the impact of tetrahedral and octahedral arrangement in the strength of geocell.

4.2 Vertical Stress at Varying Depth

4.2.1 Vertical stress vs Depth Curve for MSW ash Reinforced with Tetrahedral Geocell

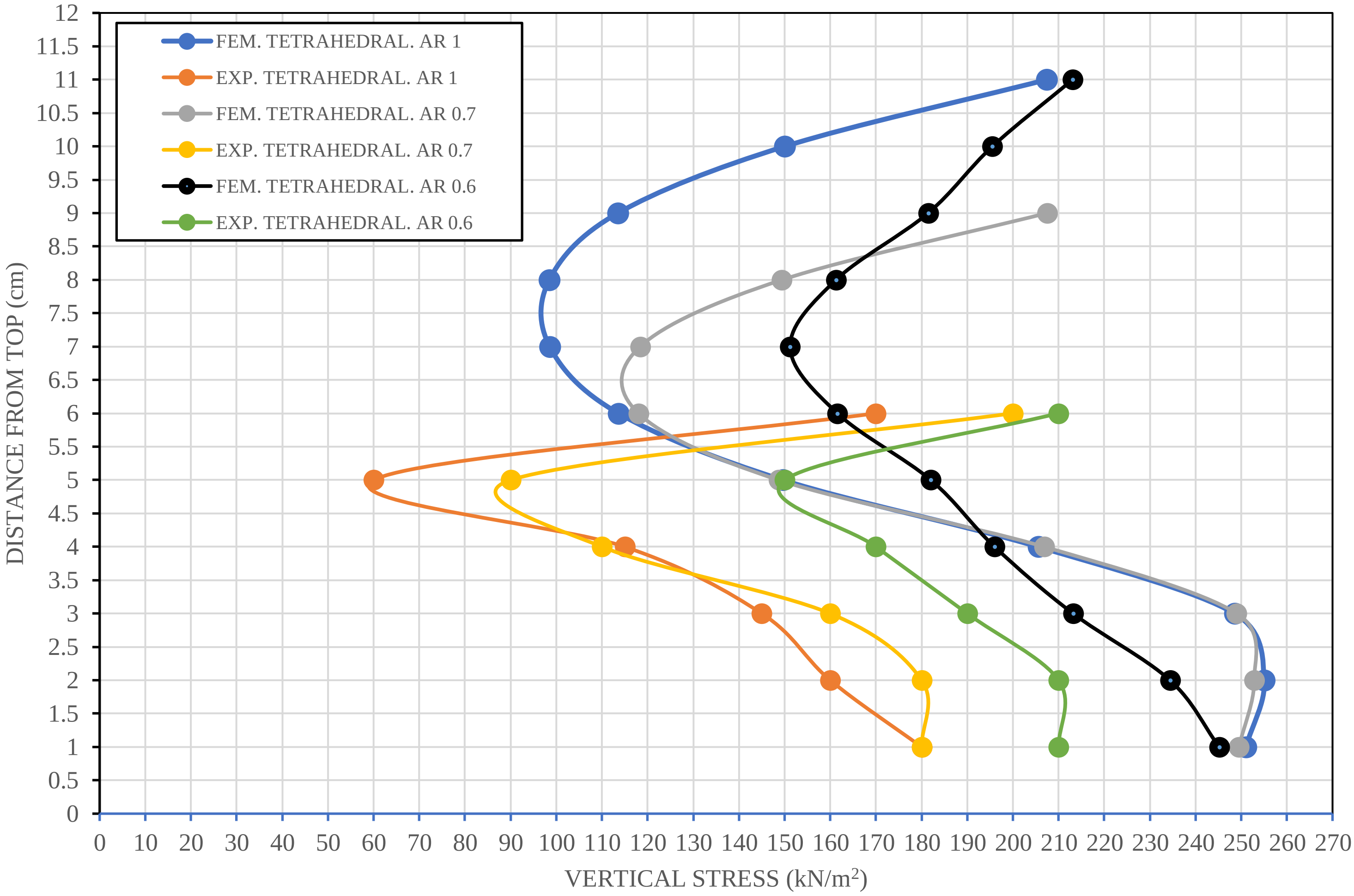


Figure 4. 1 Vertical stress vs depth curve for Tetrahedral Geocell

The following graph shows the variation of vertical stress with depth when tetrahedral geocell made of plastic bottles with various aspect ratio is placed 4 cm below the top MSW fly ash layer. It can be depicted that when MSW layer was reinforced with Tetrahedral geocell arrangement at 4cm depth, vertical stress acted by hydraulic jack is minimum for aspect ratio 1 then the decreasing aspect ratio. This was owing to increased strength and weight carrying capacity resulting in little load transfer across soil

Table 4. 1 Vertical stress vs Depth for MSW ash reinforced with Tetrahedral Geocell

For aspect ratio 1			
Finite element analysis		Experimental	
Distance (cm)	Vertical stress (kN/m^2)	Distance (cm)	Vertical stress (kN/m^2)
1	251	1	180
2	255	2	160
3	248	3	145
4	205	4	115
5	149	5	60
6	113	6	170
7	98	–	–
8	98	–	–
9	113	–	–
For aspect ratio 0.7			
Finite element analysis		Experimental	
Distance (cm)	Vertical stress (kN/m^2)	Distance (cm)	Vertical stress (kN/m^2)
1	249	1	180
2	252	2	180
3	249	3	160
4	206	4	110
5	148	5	90
6	117	6	200
7	118	–	–
8	149	–	–
9	207	–	–
For aspect ratio 0.6			
Finite element analysis		Experimental	
Distance (cm)	Vertical stress (kN/m^2)	Distance (cm)	Vertical stress (kN/m^2)
1	245	1	210
2	234	2	210
3	213	3	190
4	195	4	170
5	182	5	150
6	161	6	210
7	151	–	–
8	161	–	–
9	181	–	–

4.2.2 Vertical stress vs Depth Curve for MSW ash Reinforced with Octahedral Geocell

The following graph shows the variation of vertical stress with depth when octahedral geocell made of plastic bottles with various aspect ratio is placed 4 cm below the top MSW fly ash layer

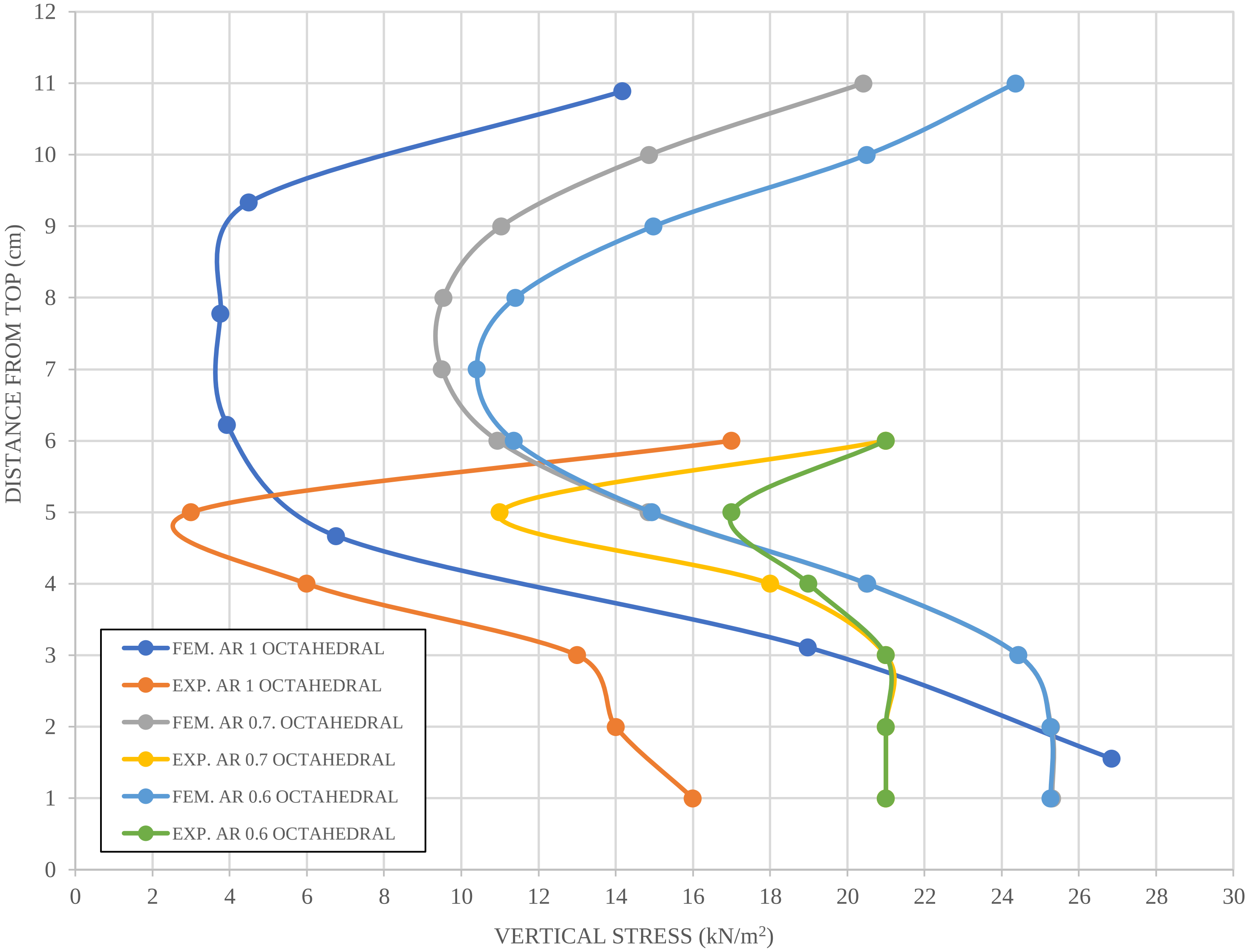


Figure 4. 2Vertical stress vs depth curve for MSW ash reinforced with Octahedral Geocell

When octahedral geocell of aspect ratio 1 was placed in MSW ash at a depth of 4 cm, least vertical stress was observed. Because the neighboring geocells are closer together, this occurs.

Table 4. 2Vertical stress vs depth for MSW ash reinforced with Octahedral Geocell

For aspect ratio 1			
Finite element analysis		Experimental	
Distance (cm)	Vertical stress (kN/m^2)	Distance (cm)	Vertical stress (kN/m^2)
1.5	26.8	1	16
3.1	18.9	2	14
4.6	6.7	3	13
6.2	3.9	4	6
7.7	3.7	5	3
9.3	4.4	6	17
10.8	14.1	–	–
For aspect ratio 0.7			
Finite element analysis		Experimental	
Distance (cm)	Vertical stress (kN/m^2)	Distance (cm)	Vertical stress (kN/m^2)
1	25.3	1	21
2	25.2	2	21
3	24.4	3	21
4	20.5	4	18
5	14.8	5	11
6	10.9	6	21
7	9.4	–	–
8	9.5	–	–
9	11.0	–	–
10	14.8	–	–
11	20.4	–	–
For aspect ratio 0.6			
Finite element analysis		Experimental	
Distance (cm)	Vertical stress (kN/m^2)	Distance (cm)	Vertical stress (kN/m^2)
1	25.2	1	21
2	25.2	2	21
3	24.4	3	21
4	20.5	4	19
5	14.9	5	17
6	11.3	6	21
7	10.4	–	–
8	11.4	–	–
9	14.9	–	–
10	20.5	–	–

4.3 Load settlement curve

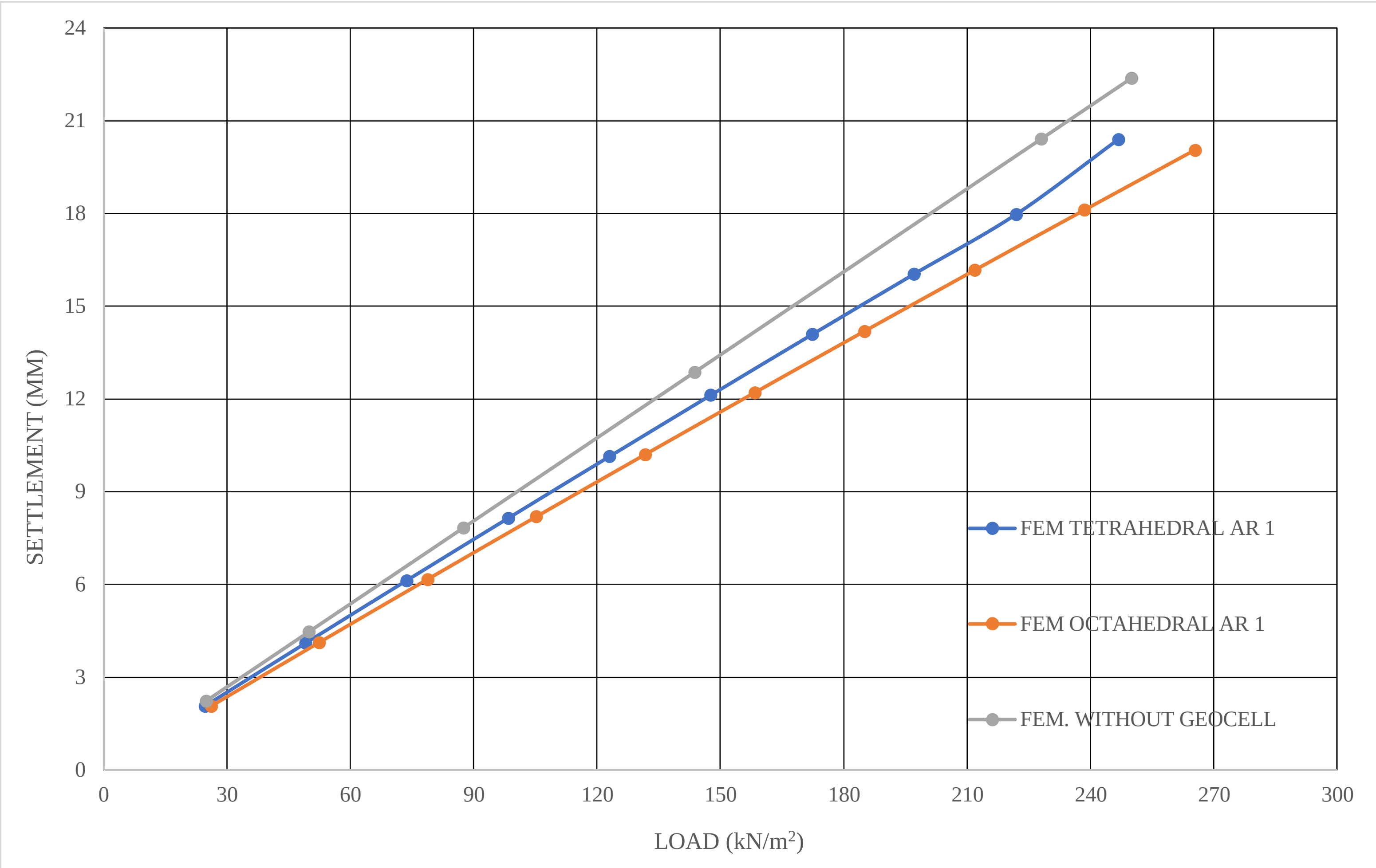


Figure 4. 3 Load vs Settlement

From the above figure 4.2 it can be depicted that the MSW fly ash layer shows the most settlement when it is unreinforced and shows the least settlement when reinforced with octahedral geocell with aspect ratio 1.

Moreover, when Tetrahedral and Octahedral geocells were compared, octahedral geocells showed 9.4 % more load bearing capacity at same settlement.

Table 4. 3Load vs Settlement

Octahedral geocell		Tetrahedral geocell		Without geocell reinforcement	
Load (kN/m²)	Settlement (mm)	Load (kN/m²)	Settlement (mm)	Settlement (mm)	Load (kN/m²)
26.2	2.0	24.6	2.1	2.2	25.0
52.4	4.1	49.2	4.1	4.5	50.0
78.8	6.1	73.7	6.1	7.8	87.5
105.2	8.2	98.4	8.1	12.8	143.7
131.7	10.2	123.1	10.1	20.5	228.1
158.4	12.2	147.7	12.1	22.4	250.0
185.1	14.2	172.4	14.1	–	–
211.8	16.2	197.1	16.0	–	–
238.6	18.1	222.0	17.9	–	–
265.4	20.0	246.8	20.4	–	–

4.4Stress Contours

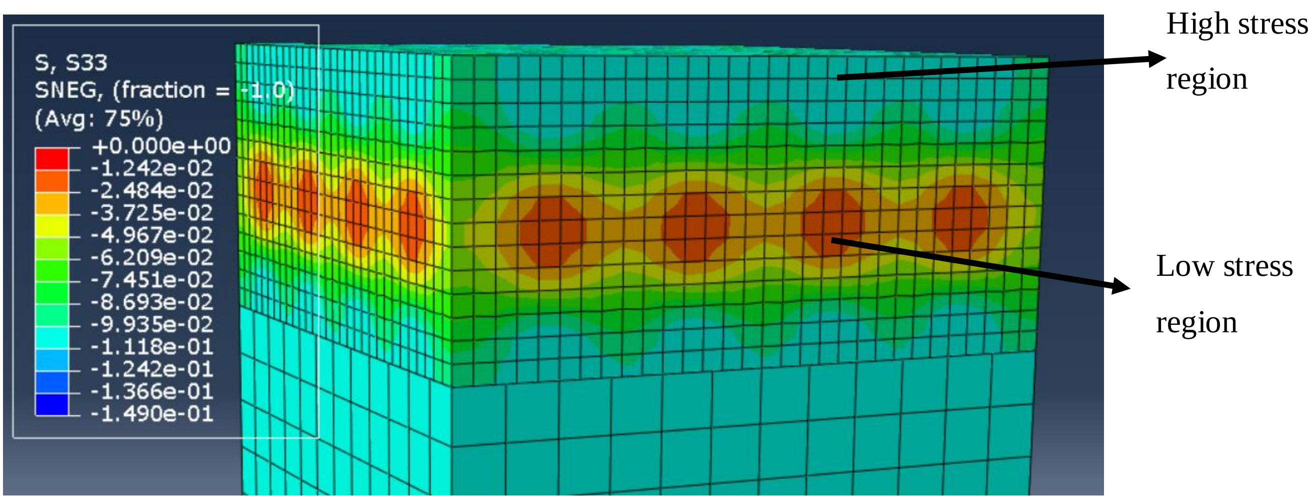


Figure 4. 4 Vertical Stress contour in the MSW ash layer

From the above figure 4.4 it can be seen that at the upper region the MSW fly ash layer experiences higher stress symbolized by bluish contours up to the point where geocell is introduced, then the vertical load in the fly ash decreases shown by red orange contours as the load is taken by the geocell which reduces the amount of load transferred to the MSW fly ash layer

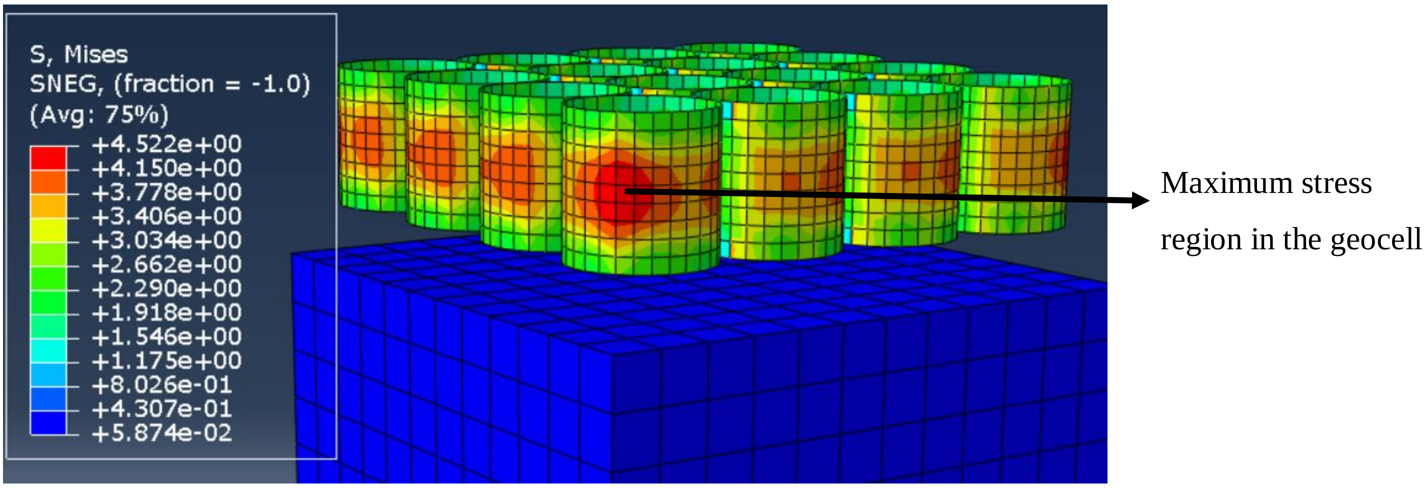


Figure 4. 5 Vertical Stress contour in the geocell

Above figure 4.5 shows the maximum stress region in the geocell occurs in the middle and if the height of geocell is beyond certain value it will start to show buckling.

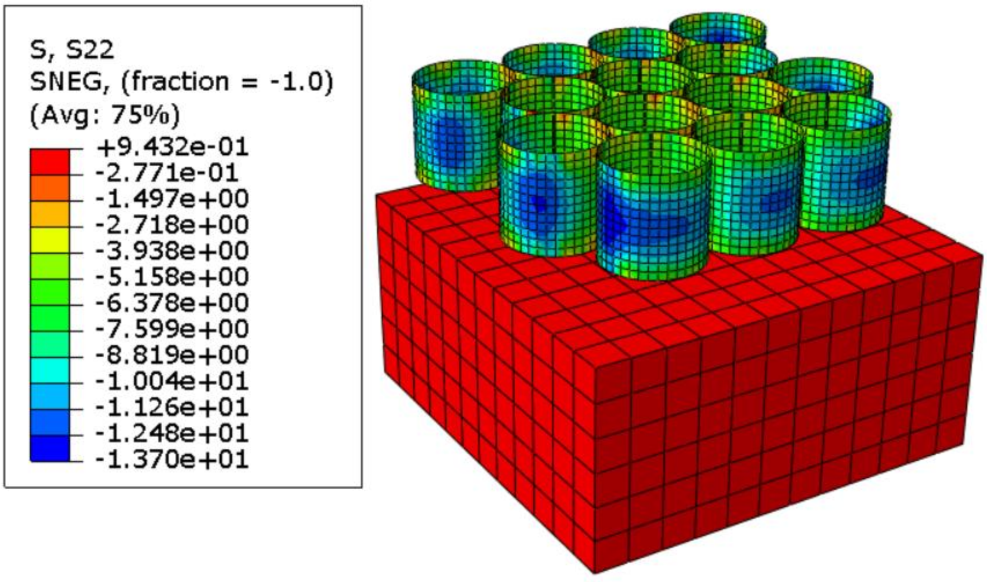
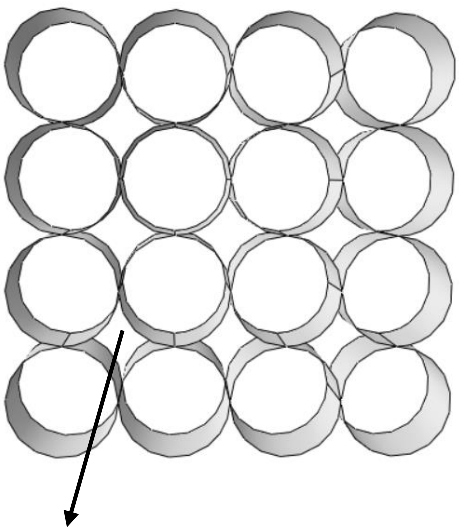


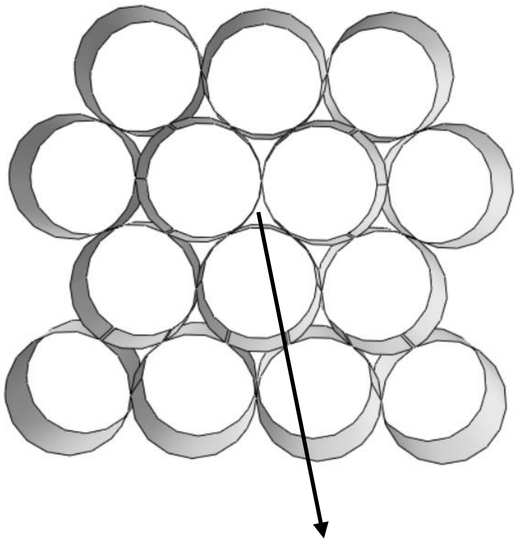
Figure 4. 6 Lateral stress contours in the Geocell

In Fig 4.6 Blue contours show the stress acting in the lateral direction in the Geocell due to the vertical load acted upon it causing MSW ash to displace laterally confined in the Geocell.

4.5 Discussion

Octahedral arrangement of geocells perform better in stress reduction than tetrahedral arrangement due to less gap between the adjacent geocells.





Large void gaps, Low packing efficiency

Figure 4. 7 Voids in Octahedral and Tetrahedral arrangement of geocell

Small void gaps, Higher packing efficiency

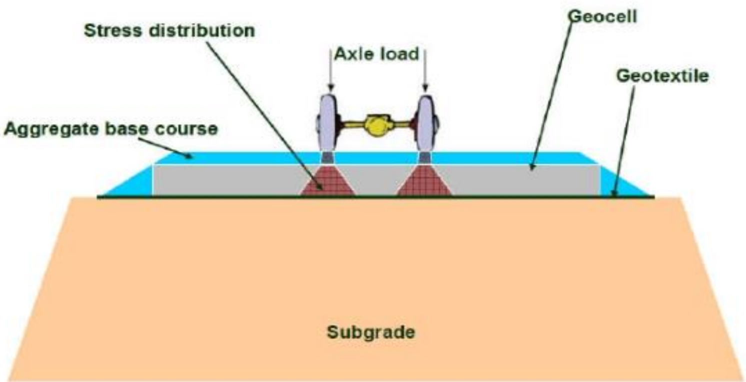


Figure 4. 8 Stress distribution in pavement reinforced with geocells

- As per Boussinesq the magnitude of load increases with depth and if we have a weak/soft soil below, the increase in vertical stress will cause the soil to fail due excessive settlement. But when we place the geocell in the weak soil it will bear the vertical as well as lateral load and decrease the load transfer to the soil this preventing failure.

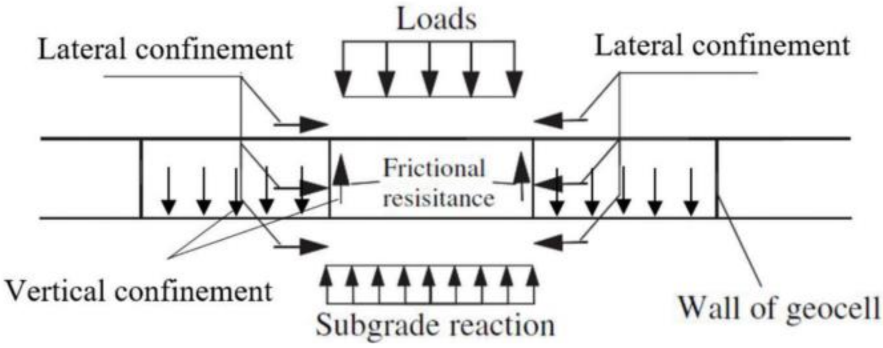


Figure 4. 9Lateral restrain function of geosynthetics [19]

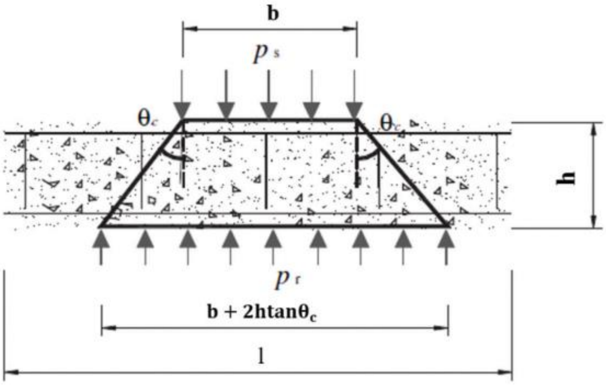


Figure 4. 10 Vertical stress dispersion [19]

Asphalt pavement cracking is widely recognized as one of the most serious issues facing highway maintenance engineers leading to formation of pot holes. Inadequate soil conditions, poor drainage, weathering impacts, increased traffic weight, and the age of the surface are all factors that contribute towards road surface deterioration and instability. As flexible pavements do not have high flexural strength, the soil beneath settles each time a vehicle passes over a soft area in the pavement it pushes the pavement down and when the pavement comes back to its original position it pulls some of the water out seeped into the soil, taking out some of the soil with water from the cracks which eventually leads to the formation of pot holes. Using Geocell keeps the soil intact and takes lateral and vertical load preventing settlement and provides long terms stability of potholes.

CHAPTER 5

CONCLUSIONS

5.1 General

This chapter deals with the emphasis on the results obtained from numerical analysis on the MSW ash pavement reinforced with plastic bottle geocell. It can be concluded that the geocells made of plastic bottles is sufficiently effective in the soil restraining and increasing the load bearing capacity for long term stability of the soil.

5.2 Conclusions

1. Least deformation was seen in the MSW fly ash when reinforced with octahedral geocell when compared with tetrahedral arrangement and the model without geocell. In comparison to tetrahedral arrangement the octahedral arrangement have less voids in between and have a greater packing efficiency. Hence, providing us larger confinement area.
2. When Tetrahedral and Octahedral geocells were compared, octahedral geocells showed 9.4 % more load bearing capacity at same settlement.
3. When octahedral geocell of aspect ratio 1 was placed in MSW ash at a depth of 4 cm, least vertical stress was observed. Because the neighboring geocells are closer together, this occurs.

5.3 Future Scope

In this numerical analysis of MSW ash reinforced with Geocell made of plastic bottles, behaviour of Tetrahedral and Octahedral Geocell arrangement under vertical load has been studied, but the bond between the adjacent geocell was not defined as done experimentally and no holes were designed in the plastic bottle geocell as there are in the original geocell for drainage. In future, a welded bond between the adjacent geocell made of plastic bottles could be defined. The strength of the bond and the variation in the results obtained will be studied when seepage holes are provided.

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