Application of Geofoam as a Backfill Material in Both Static and Dynamic Loading Conditions on the Perspective of Bangladesh

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CERTIFICATE OF RESULT

It is hereby certified that the work presented in this thesis was carried out by the following final year students of session 2021-2022 under the direct supervision of Istiakur Rahman, Assistant Professor of Civil and Environmental Engineering (CEE), Islamic University of Technology, Gazipur, Dhaka.

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DECLARATION

It is hereby declared that this entitled “Application of geofoam as a backfill material in both static and dynamic loading conditions on the perspective of Bangladesh” thesis report or any part of it has not been submitted elsewhere for the award of any Degree or Diploma (except for publications).

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DEDICATION

We would like to dedicate this thesis work to our ***parents and family****. We want to show our gratitude for their continuous support throughout our life.*

We also express our utmost respect for our thesis supervisor Istiakur Rahman (Assistant professor).

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Abstract

Expanded Polystyrene (EPS) geofoam works like a compressible material between the backfill soil and retaining wall. It absorbs a huge amount of both static and dynamic loads induced by the backfill soil and pass the rest to the retaining structures. Geofoam between retaining wall and backfill soil can control the development of deformation, that is caused by those loads. As Bangladesh is a seismic prone country, so in order to build sustainable structures, geofoam was needed to use as a backfill material behind retaining wall. In this study, a finite element model was used by employing PLAXIS2D software to evaluate the effect of installing geofoam as a compressible buffer between backfill soil and retaining wall on the soil of Dhaka and Chittagong against static and dynamic loading. The numerical analysis defined the advantages of geofoam on EPS density, EPS relative thickness and excavation depth with pile-raft foundation. The outcome of the numerical analysis presented that for excavation depth of 3m, the displacement reduction was achieved from 28.3% to 46.59% with increasing of thickness. Lower density of EPS geofoam was effective for this excavation depth. For excavation depth of 6m, with increasing of EPS thickness ratio, the displacement reduced from 29.91% to 49.65%, but here, higher density of EPS geofoam cooperated in reduction of the displacement.

CHAPTER ONE: INTRODUCTION

1.1. General:

Bangladesh is a country of different types of soils structured with the help of rivers. Many types of uncertain loads like loads from rail track vibration, earthquake etc are generated differently in these various types of soils. As a seismic active country, these loads affect the structures severely.

The retaining walls are inserted in the soils after excavations experience both the static and dynamic loading. These walls are there in the soil to support the soils laterally. It is used to restrain soil to a slope that is not naturally possible. There are several types of retaining wall to use effectively in different soil situation.

I. Gravity wall
II. Cantilevered wall
III. Diaphragm wall
IV. Sheet Pile wall
V. Bored Pile wall
VI. Anchored wall

These walls behave differently in different loads and soils conditions. In this study we use diaphragm wall to evaluate the result.

After excavations and insertion of diaphragm wall, it experiences both static and dynamic lateral loads. For these extra loads the wall fails sometimes. So we need to insert a compressible inclusion between the diaphragm wall and backfill soil. Expanded Polystyrene (EPS) geofoam is a compressible inclusion. It is a polymeric foam and is structured with tangentially fused beads. The formation of the closed cells is in an arrangement of tridimensional structure. The expansion of beads throughout the production process creates these cells (Gibson, 2003). The cellular structure of this compressible material is filled with 95% air of the total volume. The pre-expansion and moulding process is needed respectively to manufacture EPS. 80°C to 110°C temperature is needed for the pre-expansion process. After the expansion by the heat, moulding process starts and finally an EPS is constructed (Horvath, 1994). If the moulding is improper like concavity, then water may pool and absorption happens by the blocks. As a result, the unit weight increases of blocks that may cause settlement and pavement reconditioning (E.L.Santiago, 2018). So perfection in moulding of EPS is necessary to use effectively. It's a light substance, weighing only 1% of the weight of soil and less than 10% of other lightweight fill options. As it is a lightweight compressible material, it can be used as a backfill material behind retaining wall to absorb extra unexpected lateral loads induces from the earth.

1.2. Background and Present State of the Proposed Topic:

EPS geofoam has been used widely in recent years. In the middle of the last century, first EPS geofoam was introduced in a Flom Bridge embankment reconstruction, Oslo, Norway. A Flom Bridge embankment in Oslo experiences average 200mm settlement a year. SO, in 1972, some initiatives were taken by Norwegian Public Roads Authority (NPRA). They decided to use EPS geofoam as a compressible inclusion material to reduce this settlement. The result was satisfactory in using of geofoam rather than other fill material (Roald Aabøe, T. Frydenlund, 2011). Then from 1985 to 1987, in Japan over 130,000m^3 of geofoam was used in 2000 projects (Geofoam, n.d.). After this introduction of EPS many researchers conducted a lot of researches on this effective material beneath the earth behind retaining wall. In 1997, according to a research, geofoam should be placed to the entire height of the retaining wall. The creep loading is effective on EPS geofoam than the rapid loading (Murphy, 1997). In 2000, a study discussed about the real life application of EPS geofoam as cushion behind retaining wall, on roofs of underground, over pipelines, tunnels, under rail track and earthquake area (to reduce the counter effect of vibration). For geofoam's stability, durability, extremely low density & low weight, neutral behavior with different types of chemicals, it is used in those applications (Beinbrech & Hohwiller, 2000). In Japan, to analyze the behavior of two interfaces, a hybrid interactive system with soil, structure (NY & YA) and EPS was built. For NY wall model, using geofoam behind the wall can achieve 40-50% earth pressure reduction (Okuzono, 2004). A shaking table test was conducted on three types of EPS to evaluate the behavior of EPS as seismic buffer. And the result was so much satisfactory (Bathurst et al., 2007). A finite element study of lateral pressure on a stiff, non-yielding retaining wall using EPS geofoam as a compressible inclusion was performed in 2010. The authors found that the elastoplastic model of geofoam dominated in terms of simulating the progression of plastic stresses in the inclusion (Trandafir et al., 2010). Another study in 2011, two authors conducted a non-yielding wall model employing EPS geofoam to minimize the lateral earth forces on the wall (Ertugrul & Trandafir, 2011). In 2015, three researchers published a study on geofoam technologies for safeguarding subterranean pipelines and culverts. And utilization of EPS geofoam satisfied the result effectively (S. F. Bartlett et al., 2015). Four tests, flexural strength test, water absorption test, compressive strength test and the unconsolidated undrained test were completed in a study in 2017 on different types and shapes of EPS by two authors (Beju & Mandal, 2017). In recent years, two researchers of McGill University conducted a computational investigation of the function of various thicknesses and densities of EPS geofoam in mitigating ground pressure on retaining structures under dynamic loading (Khan & Meguid, 2021).

So, from the above discussions we can understand that, this lightweight fill material isn’t used or not so very popular in this south asian subcontinent. But Bangladesh, as a seismic active zone, the structures should be built with extra precaution to withstand against the uncertain lateral loads like earthquake. So, this backfill material can be used behind retaining structures. But this material can’t be used for every type of soil. EPS geofoam is effective for soft soil. So, determination of the soil is necessary. All the discussed study above was conducted for soft soil.

1.3. Objectives of the Proposed Topic:

EPS geofoam had been widely using all over the world in recent years. But in Bangladesh it wasn’t used or not so popular. So, this inclusion material is being tested as a backfill material behind retaining structures. The experiments are completed here on EPS geofoam with the soil of Dhaka and Chittagong.

The aim of the study is:

- By conducting numerical analysis to determine the impact of geofoam on retaining wall.

- To analyze the influence of geofoam density and thickness on deformation of retaining wall with static and dynamic loading.
- To analyze the effect of backfill soil properties on varying of static and dynamic loading with EPS geofoam.
- To evaluate the effect of excavation depth on varying of static and dynamic loading with EPS geofoam.

1.4. Significance of the Study:

Bangladesh is a very vulnerable country with its high risk of earthquake attack. Chittagong, Dhaka, Sylhet, Mymensingh, Rajshahi, Rangpur, Comilla, Bogra are extremely vulnerable to severe earthquakes. Depending upon the earthquake intensity in different area, Bangladesh has been divided into three main earthquake zones. In this study, we collected the soil of Dhaka and Chittagong of earthquake zone-2 to evaluate the earthquake effect on retaining wall with EPS geofoam. Bangladesh is severely affected by several major earthquakes. During last 150 years, seven major earthquakes (Magnitude >=7) attacked Bangladesh. For the reason of earthquake, ground rupture, soil liquefaction. landslides and many other damages happen. And these damages of soils affect the buildings, roads and different structures severely. As a result, the buildings and structures may collapse. The prevention of earthquake isn’t possible but sustainable structure can be built to withstand against these uncertain loads. To make a defensible structure, a compressible inclusion can be utilized between the retaining structure and the backfill soil. Among all the compressible material, EPS geofoam is so much effective in reduction of lateral earth pressure. This lightweight material is not so popular in our country. In this study, some numerical analysis have been conducted to supervise the effectiveness of different types of EPS geofoam in reducing lateral earth pressure with Dhaka and Chittagong soil.

CHAPTER TWO: LITERATURE REVIEW

2.1. General:

This chapter discusses about EPS geofoam, that is a lightweight material has been using for the load reduction behind the retaining wall. Now a days, it has been so popular all over the world. EPS material properties, applications behind retaining structures, in pavement structure & road construction upon culvert or pipeline, in rail track to reduce the vibrations, in earthquake zone etc. have been discussed here. As geofoam is a lightweight & compressible material, so when load applied on the geofoam from the backfill it absorbs some of the load and transfer the remaining portion of the load to the retaining structure. To build an economic structure geofoam can be a perfect material. It can be used in existing structure also. Besides of EPS geofoam properties, backfill soil frictional properties, height of the wall also affect lateral load on the retaining wall.

2.2. EPS Geofoam as a Backfill Material:

In 1997, a researcher conducted a research with creep and rapid loading on the retaining wall and determined a linear elastic geofoam between the wall and backfill soil, which is twice as compressible under 1000h of creep loading compared to rapid loading. The resultant lateral force of creep loading was 15% less than rapid loading. And the total force reduction for creep loading was 4% lesser than rapid loading. So, rapid loading events resulted in the largest lateral strains, which dropped over time as the geofoam creeped. So to achieve the best result need to use EPS geofoam under creep loading (Murphy, 1997).

A hybrid interactive system appeared with two interfaces when EPS geofoam was placed between backfill soil and retaining wall. One interface was EPS and backfill soil interface and another interface was EPS and retaining wall interface. In 2004, two researchers examined this hybrid interactive system to evaluate the behavior of the interface. They used Non-yielding wall & Yielding Active wall to recognize the best fit wall model. The outcome showed that geofoam behind NY wall reduced seismic earth pressure. The reduction of 40-50% in lateral ground pressure might be obtained using geofoam behind the NY wall concept (Okuzono, 2004).

A finite element analysis was conducted for four wall heights of 3, 6, 9 & 12 m with EPS thickness 1.2m. The observation stated that The plastic yielding of geofoam, the development of plastic stresses in the geofoam inclusion, and stress redistribution in the geofoam-backfill system were all well described by the elastoplastic model of geofoam. (Trandafir et al., 2010).

To sustain a pavement structure on a low bearing capacity soil, the soil shouldn't be overloaded. In this situation the engineers can use EPS as an ultra-lightweight fill material instead of other heavier fill material. As this material is available at a low cost and can be used in existing structure. As a result, the reduction in overall weight can be achieved easily. So to achieve sustainability in structure on poor soil, as a lightweight fill material, EPS geofoam can be employed (Huang & Negussey, 2011).

Furthermore, EPS geofoam can be used as a slope stabilization, building for compensatory foundation on compressible soils, rail embankments and other forms of embankment construction (Mohajerani et al., 2017).

2.3. Use of EPS Geofoam in Different Countries:

EPS geofoam was first introduced in the decade of seventy of last century. In 1972, Norwegian Public Roads Authority (NPRA) first established EPS geofoam to reconstruct the Flom Bridge embankment. This embankment experienced an average settlement of 200mm per year before it was rebuilt. So, the embankment was needed to reconstruct to avoid the settlement. By using EPS geofoam as a lightweight fill material the settlement was effectively terminated (Frydenlund & Aabøe, 2001). 24-year-old EPS was used in this reconstruction project. As being the old version of EPS blocks, these blocks didn't show any material deterioration effects. The results of the tests were observed for a long time loading. A long-term monitoring plan was implemented to track the changes in the material characteristics of EPS blocks over time. The testing included looking at the strength, density, and water absorption of EPS blocks, as well as looking into potential creep effects (Aabøe & Frydenlund, 2011).

In May 1997, The Utah Department of Transportation had begun work on a $1.5 billion project to rebuild Interstate I-15, Salt Lake City, USA. The goal of the project was to expand the embankments of a 27-kilometer stretch of road. In July 2001, the reconstruction work was finished. In this project, EPS geofoam was employed in two separate applications for pavement construction. It was utilized for two purposes: first, as a lightweight fill material, and second, to protect subterranean utilities such as buried pipes and high-pressure gas lines (S. Bartlett et al., 2012). The creep effect was also observed in this reconstruction project. The settlement for creep effect was negligible (15mm) and a total deformation for creep effect was 0.2 – 0.4% after observation of 10 years after the reconstruction (Bartlett Steven, Negussey Dawit, Farnsworth Clifton, 2011).

In Rotterdam on the Matlingeweg pavement reconstruction, surface deflection measurements and asphalt strain measurements are resulted by using double and single layer of EPS, in 1990. EPS30 with 10MPa elastic modulus and EPS25 with 8MPa elastic modulus were used to eliminate the settlement. Resulting settlements varied from a few tons of millimeters upto 200mm and more per year. EPS30 and EPS25 was used for upper and lower layer respectively. For the asphalt strain measurements, asphalt packages were laid in two phases at the top of the pavement structure with EPS sub-base. An open asphaltic concrete layer of 80mm thick and a dense asphaltic concrete layer of 50mm thickness was placed first. Then after one month of the reconstruction, crack was observed on the road base because of the displacements of EPS sub-base. So, in December of 1990, dense asphaltic concrete layer of 80mm thick was overlaid on the top of the pavement structure. Maximum deflection decreased more than 50% after the final overlaying (Dugkov, 1997).

2.4. The Material Properties of EPS Geofoam:

The effectiveness of geofoam behind retaining wall depends on the design parameters of the material. The design considerations can be the density, thickness, compressive strength, creep & durability, young's modulus & poisson’s ratio, chemical resistance, shear strength, moisture absorption, thermal resistance etc. Many researchers studied on all of these properties of EPS geofoam.

2.4.1. Density of EPS Geofoam:

In 2007, a study discussed about the effect of density of EPS on the reduction of seismic load on the retaining wall. The researchers determined an elasticized EPS geofoam of 14Kg/m^3, a Type I (16Kg/m^3) EPS geofoam and a 57% cored EPS geofoam of Type XI (12Kg/m^3- after coring 6Kg/m^3) for the shaking table test. Here these three types of EPS acted like a seismic buffer material. The generated hysteric response curve showed that Type I and the elasticized EPS was in the elastic range. On the other hand, the cored EPS geofoam exceeded the elastic limit. Another curve was generated on the basis of time and displacement. This curve showed that with decreasing of density, both the vertical and horizontal load of the seismic thrust induced by the shaking table reduced significantly (Bathurst et al., 2007).

A study was conducted with micro and macro mechanical structure of EPS. The macro mechanical cylindrical structure of EPS density of 17-30 Kg/m^3 with confining stress of 0, 30 & 60 KPa showed that initial elastic modulus, plastic modulus and yield stress increased with density under compression, but the poisson's ratio decreased. Because of increasing density resulted in thicker walls of the closed cellular structure, the stress-strain correlations of EPS varied considerably with density. As a result, the compressive strength of EPS increased as well as, initial elastic modulus, plastic modulus and yield stress also increased (Ossa & Romo, 2009).

In the same year of 2009, an experiment was supervised on the effectiveness of connectors between the interfaces of EPS geofoam. EPS15 and EPS30 was used in the experiment under normal pressure of 14.8 KPa, 29.6KPa, 74.1KPa. Both of the EPS were tested with and without a barbed connection. When tested with EPS15 and EPS30, the monotonic loading test and repeated loading test with barbed connection, plates did not enhance shear resistance. Under all typical loads, the higher density foam showed greater interface shear resistance (Barrett & Valsangkar, 2009).

Zarnani and Bathurst conducted a parametric study with EPS19, EPS22 & EPS29 against dynamic loading with different frequencies. For 9m wall height, the maximum isolation efficiency was 55% when construct with a 3.6m thick buffer layer of EPS19, which is the most compressible EPS used in the study. The authors used different wall heights in the research. The practical implementation of the data observed in the study proved that for low-height walls excited below the fundamental frequency of the system, the choice of EPS type may not be important (Zarnani & Bathurst, 2009).

On EPS specimens with densities of 24, 30 and 32 kg/m^3 and confining stress levels of 0, 30, and 60 KPa, a series of resonant column tests and strain-controlled cyclic tri-axial tests were performed. The specimens were shaped like cylinders. This experiment discovered a relation between density of EPS and shear moduli of EPS. The outcome of the experiment showed that shear moduli increased with density. The damping ratio didn't affect by the density of EPS geofoam (Ossa & Romo, 2011).

In 2017, two researchers carried out water absorption tests, compressive strength tests, flexural strength tests & unconsolidated undrained test on EPS12, EPS15 & EPS20 with different sizes. The water absorption tests showed that the absorption of water of EPS is so much less but the absorption decreased with increasing of density. The outcome of the compressive strength test was with increasing of density compressive stress and elastic modulus increased. The flexural strength test presented that flexural strength increased and deformation of failure decreased with increasing of EPS density. The unconsolidated undrained test revealed that elastic modulus, compressive strength and deviator stress increased with density. Shear stress also increases with increasing of density (Beju & Mandal, 2017).

In the last year of 2021, two researchers experimented the effectiveness of EPS density on minimization of lateral earth pressure. Four types of EPS with density 15, 22, 29 & 39 Kg/m^3 were used in the experiment. The outcome displayed that for given backfill soil with internal friction angle of 40° and EPS thickness ratio to wall height of 0.3, the peak seismic force amplified from 10.6-12.7 KN/m, with the increasing of density from 15 – 39 Kg/m^3. Softer geofoam absorbed more energy (Khan & Meguid, 2021).

Furthermore, Xiaoodng Huang and Dawit Negussey showed in their research that EPS blocks of density between 16 to 32 Kg/m^3 was effectively used in pavement construction. As a result, low density geofoam blocks appear to be more successful in this application than high density geofoam blocks (Huang & Negussey, 2011).

2.4.2. Thickness Ratio of EPS to Wall Height:

In 1997, a professor of University of Bahrain utilized EPS geofoam with expanding soil that was numerically modelled. He determined three thicknesses of EPS. The thickness ratios of EPS to wall height were 0.05, 0.1 & 0.2. He also tested the model with granular backfill instead of EPS and the thickness ratio of the granular backfill to wall height was 0.2. The outcome of the test exhibited that EPS geofoam worked much more effectively than the granular backfill soil and with increasing of the thickness of EPS geofoam the lateral earth pressure reduced significantly. So, with higher EPS thickness behind retaining wall can achieve more lateral earth pressure reduction instead of same thickness of granular backfill material (Aytekin, 1997).

A rigid NY wall model with four different conditions of EPS panels were utilized in uniaxial model test. EPS15 with three different thickness ratio to wall height of 0.07, 0.14 & 0.28. Another one test condition of the described four conditions was without geofoam behind retaining wall. The small scale test and numerical modeling proved that with compressible inclusion of EPS geofoam the lateral wall pressure mitigated significantly and the reduction increases with increasing of the thickness of the EPS geofoam (Ertugrul & Trandafir, 2011).

The role of EPS geofoam in decreasing ground pressure on retaining structures under dynamic stress was investigated numerically. Different thicknesses ratio of EPS to wall height from 0.1 to 0.3 was installed in three different tests. For a given backfill of friction angle 40° and EPS density of 15Kg/m^3, the seismic peak force reduced from 14.30KN/m to 10.62KN/m, with increasing of EPS thickness ratio from 0.1 to 0.3. So, with increasing of EPS thickness ratio from 0.1 to 0.3, 26% seismic force reduction could be achieved on the wall. So, thicker geofoam can compress more and can absorb more energy (Khan & Meguid, 2021).

A numerical parametric study of EPS19, EPS22 & EPS29 with buffer thickness ratio of 0.025, 0.05, 0.1, 0.2 & 0.4 to wall height was conducted against dynamic loading induced by a shaking table. The excitation frequency ratio of 0.3, 0.5, 0.85, 1.2 & 1.4 to fundamental frequency was determined to excite the system. For a wall height of 6m with EPS19 and excitation frequency of 30% of the fundamental frequency, the total forces on the wall reduced by 23% with buffer thickness of 0.3m and this attenuation increased to about 40% for increased geofoam thickness of 1.2m. The outcome showed that the wall forces were attenuated when a geofoam seismic buffer is placed against the back of the rigid wall compared with the no geofoam backfill case and the magnitude the peak wall force decreased with increasing buffer thickness (Zarnani & Bathurst, 2009).

2.4.3. Compressive Strength of EPS Geofoam:

In 1995, a study stated that the compressive strength of EPS doesn't give any insight on creep behavior. As a result, the design of EPS should be designed within the elastic limit of EPS to maintain the long-term compressive strain within acceptable limits. In a rapid loading test, it was characterized as 1% compressive strain. Creep effects are minor in this range (Horvath, 1995).

According to ATSM standards, the compressive strength of EPS was determined by the compressive stress at a strain of 10%. This scenario was only applicable when EPS geofoam didn't break under compression; it instead collapses into solid polystyrene in one dimension (Horvath, 1999).

In 2004, some researcher conducted some guidelines and recommended standard for implementation of geofoam in highway embankments. In geotechnical applications, the most common method of loading EPS is compression. As a result, compressive strength is a crucial characteristic to consider (Stark Timothy, D.David Arellano, John S. Horvath, 2004).

Compressive strength test and unconsolidated undrained test were conducted with EPS12, EPS15 & EPS20. This two tests stated a relation of compressive strength with density of EPS. For compressive strength tests, three cubic sample of 50mm^3, 100mm^3 & 150mm^3. The compressive stresses were proportional upto 1.5% strain. Between the strain level of 1.5-4%, the yield point was developed. Outcome of the 9 tests of compressive strength was with increasing of density of EPS, the compressive strength of EPS increased. But the parameter of size of the cubic samples didn't much affect the compressive strength. The unconsolidated undrained test was conducted with a cylindrical EPS with 75mm diameter & height of 150mm. Different cell pressure of 50KPa, 100KPa &150KPa were applied in the test. Here also the stress-strain curve was linear upto 1.5% for all densities of EPS geofoam and thereafter a very little increase in deviator stress was observed with increase in axial strain. Compressive strength was also affected by density. The increment of EPS density, amplified the compressive strength of EPS, as well as, the deviator stress (Beju & Mandal, 2017).

2.4.4. Young's Modulus and Poisson's Ratio of EPS Geofoam:

A numerical modeling was established in 1997 with block molded EPS geofoam, applied as a compressible inclusion between expansive soils and retaining structures to determine the reduction of transmitted lateral earth pressures on the structure. Different thicknesses EPS geofoam were used for the modeling. The outcome form the modeling showed that with increasing of elastic modulus, the compressive strength of EPS increased (Aytekin, 1997).

A tabletop servo-hydraulic test and a free standing servo-hydraulic test was performed on EPS with densities of 15 & 29 Kg/m^3. 0.05m^3, 0.6m^3 & a cylindrical shape with 0.08m diameter and 0.15m height of EPS were used to investigate the possible effects of size and shape of the samples on the evaluation of parameters related to elasticity for geofoam by laboratory testing. The tabletop servo-hydraulic test was performed for the 0.05m^3 and for the cylindrical sample. The results of this test defined a relation between the height and density with elastic modulus of EPS geofoam. Enhancement in height and density of EPS geofoam, intensified the elastic modulus of EPS geofoam. For the 0.6m^3 sample, the free standing servo-hydraulic test was performed to evaluate the elasticity parameter. Cell damage and crushing occurred due to loading at the upper and lower boundaries that are adjacent to the metal loading plates and the maximum elastic modulus were found at the mid height of the cubic sample. So, young's modulus values determined by deformation observation over the middle of the cubic sample provide improved estimates of such parameters for geofoam application (A. Elragi et al., 2000).

Three types of EPS geofoam were used for a shaking table test to evaluate the reduction of dynamic loads against retaining wall. Different densities of EPS geofoam resulted in different modulus of elasticity. The hysteric response curve showed that the strain amplitude of geofoam with density of 6kg/m^3 (cored from 12Kg/m^3) was recorded of about 2.2%, which exceeded the elastic limit of the material. But the EPS with density of 16 &

$14Kg/^3$ were in the elastic limit of 1%. With time the horizontal peak force decreased with EPS geofoam of lower elastic modulus (Bathurst et al., 2007).

Cylindrical specimens of EPS with 10cm diameter and the height of 17cm, different densities were tested under compression at displacement rates of 0.5, 1 & 10mm/min with confining stress of 0, 30 & 60KPa. The findings of the tests evaluated relations between density, displacement rate and confining stress with elastic modulus of EPS. Here with increasing of density and displacement rate, the modulus of elasticity increased; but the confining stress decreased with the increment of elastic modulus of EPS. These tests results also stated that the poisson’s ratio decreased with the increment of density of EPS. Due to viscous properties of EPS geofoam, poisson’s ratio was not affected by displacement rate and confining stress (Ossa & Romo, 2009).

The exposing of a material to a vertical stress, poisson's ratio compared the lateral and longitudinal strains it experienced. When the stress-strain behavior is linear, it increases linearly with the density of the block, but it decreases fast for larger strains (E.L.Santiago, 2018).

The statement in the guideline and recommended standards described previously for the application of geofoam in highway embankments was about the poisson's ratio, that was roughly 0.12 for EPS geofoam when its behavior was in the elastic range (STARK et al., 2004).

2.4.5. Creep Behavior of EPS Geofoam:

In 1997, a research was conducted on the creep behavior of EPS geofoam on the performance as a compressible inclusion. The linear elastic geofoam is twice as compressible under 1000h of loading (creep loading) was compared to rapid loading. From the comparison researchers stated that stress increased 11% on above and below of the specimen for both rapid and creep loading; the total resultant lateral force was 15% less for the creep loading than the rapid loading; so, the total force reduction had happened for the creep loading, that was 4%. So, lateral stress are highest under rapid loading conditions and decrease with time as the geofoam creeps (Murphy, 1997).

Creep behavior was caused by the constant load applied to the EPS geofoam blocks in the pavement structure after construction, which was of key significance to the designer. This constant force, which originated from the pavement structure's dead load, caused the gaps between the EPS geofoam blocks to close, potentially causing the pavement structure's time-dependent creep to begin. The severity of this creep was proportional to the size of the constantly applied load (Xiaodong, 2006).

Utilizing exhumed samples from ancient EPS geofoam (24 years old) in the projects were tested in Norway and revealed no symptoms of material breakdown. The compressive strength tests performed on these materials revealed no overall drop in compressive strength, and the creep readings observed were considered modest. The suggestion of the study was that by taking into account the buoyancy forces, 100-year lifetime of EPS blocks in implementation could be achieved. The dissolving agents (such as petrol/diesel fuels) couldn’t affect the EPS blocks. The applied dead loads did not exceed 30–50 percent of the material's strength (Aabøe & Frydenlund, 2011).

The durability of an EPS geofoam product can be harmed by continuous UV exposure. The EPS blocks will discolor and become chalky and brittle if exposed to UV radiation for several months or even years. This may be readily avoided by limiting the material's exposure to UV rays to no more than a month, or by covering the EPS if longer exposure is expected (John S. et al., 2004).

2.4.6. Thermal Resistance:

Only 2% of expanded polystyrene is polystyrene, with the remaining 98% being air. Expanded polystyrene is an effective insulating material because trapped air is a poor thermal conductor. It has a R value of 0.5–0.8 cubic meter degree Celsius per Watt (m3 C/W), which is a measure of a material's thermal resistance. This is far higher than the R-value of soil, which is generally approximately 0.1 m3 C/W. Furthermore, it has been found that the R-value of expanded polystyrene rises with density, peaking at 35 kg/m3 density (A. F. Elragi, 2000).

2.4.7. Chemical Resistance:

A variety of substances can degrade EPS geofoam, and motor vehicle fuels are the main source of concern in pavement construction. When spilled fuels, such as diesel and petrol, might disintegrate the EPS blocks. This problem may be readily solved by covering the EPS with a geo-membrane or other appropriate material for protection (Horvath, 1994).

2.4.8. Moisture Absorption:

Despite its closed cell structure, expanded polystyrene can absorb some water, which can be attributed to a variety of circumstances. The thickness of the EPS geofoam, its density, the phase of the water (liquid/vapour), the presence of water only in the vapour phase, the presence of water only in the liquid phase, and, lastly, time are all elements to consider (Horvath, 1994).

2.5. Application:

EPS geofoam can be applied in various types of development. It can be applied behind retaining wall to support the retaining wall to withhold the structure. It can be used in pavement and road construction to protect the underground gas line or pipe, in vibration reduction of rail track, earthquake etc.

2.5.1. Behind Retaining wall:

Two researchers published a study on the observation of the retaining wall with EPS geofoam in underground garages, cellars and support walls. With EPS geofoam the researchers found out an impressive result. The soil pressure on the wall reduced by installing EPS geofoam. They used the EPS geofoam in increasing sustainability of a supporting wall situated in increasing traffic roadway embankment. The cushion foundation was installed between the wall and the backfill soil. The opposite side of the EPS construction is stepped down below the slope of the adjacent soil, resulting in significantly reduced soil pressure acting on the wall. To fix the remainder of the slope and the topsoil layer, a row of angled stones was set on the EPS surface. Mineral plaster is used to protect the freestanding section of the EPS construction that is exposed to the air (Beinbrech & Hohwiller, 2000).

2.5.2. Protecting Buried Pipelines:

In Norway, Underground pipelines were observed under coarse clay and longitudinal cracks were shown at the apex of the pipe; where the concentration of the loads were happened. So, cushion foundations were needed to apply, which material can attract the loads to themselves and relieve the pressure on the surrounding soil. EPS geofoam were used as a deforming layer to rearrange the stress line over the pipeline. The internal shearing forces of the underlying soil were mobilized by the stresses in the deformed layer, causing the load to be displaced to the sides and relieving pressure on the pipe. With EPS deforming layer the pressure over the pipelines decreased by almost half. The pressure on the base and the side walls was followed the previous reduction (Beinbrech & Hohwiller, 2000).

This application took usage capacity of expanded polystyrene to compress substantially more than the other materials, it came into contact with. The expanded polystyrene could deform more easily than the other components beneath it because of this (Murillo et al., 2009).

To protect the underground buried pipelines with EPS geofoam, light-weight cover or embankment system, imperfect trench method, slot-trench light-weight cover system, EPS post and beam cover system these four methods had been used. The lightweight embankment system was similar to the construction of embankments with EPS geofoam. The EPS blocks were utilized to lower the total strains operating on the subterranean utilities. But the problem was that it needed more right-of-way space, which is not always available. In imperfect trench method, the type of soil around the geofoam largely affected the performance. For slot-trench cover system, the EPS-pipe interaction was highly non-linear. At first it compressed linearly, then it yielded and at last densification happened. The last and final method of post and beam cover system was used effectively for non-ductile pipe. EPS29 showed an impressive result in this method. 50 – 60KPa pressure was on the post of the EPS and 10 - 20KPa on EPS capping beam, which was in acceptable limits for EPS29 (S. F. Bartlett et al., 2015).

2.5.3. Reducing Vibration of Rail Tracks, Earthquakes:

The structures in the rail track zone experienced the dynamic loads, which could make damages to the structure. So in Grenoble in 1987, EPS geofoam was used against the damping action. In order to absorb the vibrations an elasticated rigid expanded foam of 16Kg/m^3 was installed. It was feasible to meet the demands of continuous and traffic loads while also achieving a satisfactory vibration-damping effect. Measurements of structure-borne noise insulation along parts of the route with and without an EPS cushion layer found a 24 dB improvement in the crucial frequency range of 20 to 40 Hz, confirming the theoretical predictions (Beinbrech & Hohwiller, 2000).

When utilizing EPS as a deforming layer to mitigate earthquake effects, the goal was to intercept horizontal ground movements caused by earthquake shock waves and only pass them on to the building structure in a greatly attenuated form. Because earthquake stresses occurred often, the EPS deformations must be in the elastic portion of the pressure strain curve. It was recommended to utilize elasticated EPS and to design for a maximum compressive strain of 10% (Beinbrech & Hohwiller, 2000).

The ability of EPS geofoam barriers to reduce ground wave vibration was explored by Itoh et al. They discovered that low-impedance materials, such as EPS geofoam, are particularly good in reducing wave amplitude (Itoh et al., 2005).

Observation of depth, width and location of EPS barrier proved that these parameters had influence on the performance of vibration attenuation (Murillo et al., 2009).

Alzawi and El Naggar reported that when the trench barrier was relocated closer to the source of the vibration, the barriers performed better in stiff soils and deeper trenches were necessary for considerable vibration dampening (Alzawi & Naggar, 2011).

In all of the soils tested, the depth, breadth, and length of the wave barrier were critical criteria that determine its effectiveness. Variations in length and depth increased the wave barrier's dampening capacity, whereas changes in breadth dampened or amplified ground vibrations. The vibration dampening of the EPS wave barrier was lowest when the wave barrier was closest to the driven pile or existing pile. When $E_{geofoam}/E_{soil}$ was less than 0.1, the attenuation ability of EPS dramatically rose (Liyanapathirana & Ekanayake, 2016).

CHAPTER THREE: STUDY AREA & DATA COLLECTION

3.1. Introduction:

Deep excavation in the metropolitan areas of Bangladesh are frequently close to critical infrastructure, such as buildings, deep foundations, and subterranean pipes. Under these circumstances, the design and construction of deep excavations must take into account the excavation's potential negative effects and keep them to a minimum. The more constrained deformation requirements, rather than failure, drive the excavation design. Bangladesh is a big fan of the bottom-up building approach. We choose two major cities in Bangladesh for our research: Dhaka and Chittagong, because both towns have seen a significant increase in tall building construction in recent years.

Geological characteristics, retaining structures, construction techniques, and craftsmanship all impact deep excavations in Dhaka and Chittagong soil. Finite element analysis is a powerful technique for investigating excavation behavior. The geological and geotechnical engineering features acquired from the soil tests on Dhaka and Chittagong soil will be presented in this chapter.

3.2. Field Test:

Standard Penetration Test (SPT) was performed as field test. Wash boring technique was used to collect disturbed sample with SPT N value calculated every 1.5m for 39m in case of Dhaka site and 30m for Chittagong site. The test procedure is according to ASTM D 1586 (ASTM 1989).

3.3. Laboratory Test:

Tri- axial test was performed as laboratory test to determine the strength and stress-strain relationship. Cylindrical specimen of undisturbed sample was used to perform the test. The test was performed till failure or 20% axial strain of the specimen. According to ASTM D4767 04, the tri- axial test was performed.

3.4. Geological and geotechnical engineering properties of study areas:

We chose two venues for our research: one in Dhaka and the other in Chittagong. Based on the sub surface soil investigation and the laboratory tests, geological and geotechnical properties of soil is found. That is given below.

3.4.1. Parameters of the Soil of Dhaka for Mohr-Coulomb Model:

The site of colleting the soil was the Mohakhali area of Dhaka. SPT tests were conducted for the collection. Table 1 is showing the parameters of the soil of Dhaka achieved from the field and laboratory test.

Table 1: Summary of input parameters for Mohr-Coulomb model of Dhaka soil

Properties	Unit	Stiff Silt Clay	Medium Dense Fine Sand	Very Dense Silty Fine Sand
Unsaturated Unit Weight, Υ_{unsat}	kN/m^3	18	16	17
Saturated Unit Weight, Υ_{sat}	kN/m^3	20	18	20
Modulus of Elasticity, E	kN/m^2	26000	27000	28000
Poisson’s ratio, v		0.3	0.3	0.3
Shear Modulus, G	kN/m^2	10190	10385	10770
Cohesion, C’	kN/m^2	31	0	0
Dilation Angle, Ψ	Degree	0	1	3
Angle of Friction, φ	Degree	14	31	33
Interface factor, R_{int}		0.7	0.7	0.7

3.4.2. Parameters of the Soil of Chittagong for Mohr-Coulomb Model:

The site of collecting the soil in Chittagong was Agrabaad. Table 2 is showing the data of the soil of Chittagong.

Table 2: Summary of input parameters for Mohr-Coulomb model of Chittagong soil

Properties	Unit	Stiff Silt Clay	Medium Dense Fine Sand	Very Dense Silty Fine Sand
Unsaturated Unit Weight, Υ_{unsat}	kN/m^3	16	17	15
Saturated Unit Weight, Υ_{sat}	kN/m^3	17	20	17
Modulus of Elasticity, E	kN/m^2	27500	31000	31000
Poisson's ratio, v		0.3	0.3	0.3
Shear Modulus, G	kN/m^2	10577	11924	11924
Cohesion, C'	kN/m^2	5	0	0
Dilation Angle, Ψ	Degree	0	4	1
Angle of Friction, φ	Degree	30	34	31
Interface factor, R_{int}		0.7	0.7	0.7

CHAPTER FOUR: NUMERICAL MODELING

4.1. Introduction:

Numerical modeling means using mathematical equations to define the physical condition. Using numerical models, numerical analysis is performed to obtaining solution involving multiple variables. We use PLAXIS2D, a finite element package, to determine the effect of geofoam in reducing the effect of earthquake. PLAXIS2D can analyze deformation and stability for projects like excavation, embankments, foundation to tunneling. It was discussed by Duncan (1992) that, due to conservation estimation of safety factor 2D analysis is more appropriate for slope design (Stark, T. D. THREE-DIMENSIONAL SLOPE STABILITY METHODS IN GEOTECHNICAL PRACTICE). For this reason, PLAXIS2D was used instead of PLAXIS3D, even though it is more accurate due to presenting deformation on all three axis.

In the following section, the modelling process using Mohr-Coulomb model at different depth for different foundation type is discussed. It is also discussed the derivation procedure for the geotechnical parameters used in Mohr-Coulomb model.

4.2. PLAXIS2D Modelling:

Plain strain was selected as the finite element model. It is suitable for geometries with uniform cross section. Also plain strain model is best suited for earthquake simulation which is done by applying load at the bottom of the structure. 15 node triangular elements were selected. It provides high quality test result due to fourth order interpolation and involves 12 gauss/ stress points.

The soil behavior is modeled as Mohr-Coulomb model. It is a well-known model based on Hook’s law of isotropic elasticity and generalized form of Coulomb’s failure criterion. According to Mohr-Coulomb model soil behaves linearly. Undrained A is used as the drainage mode for all soil levels.

Athanasopoulos (2012) found that EPS geofoam behaves more like linear elastic (Athanasopoulos - Zekkos, A., Lamote, K., & Athanasopoulos, G. A. (2012). Use of EPS geofoam compressible inclusions for reducing the earthquake effects on yielding earth retaining structures. Soil Dynamics and Earthquake Engineering, 41, 59–71). Due to this reason linear elastic model was selected for EPS geofoam for this paper.

The diaphragm wall was model as plate element. Strut was modeled as beam element whereas pile raft was modeled as embedded beam element. Mesh was generated setting the element distribution to medium. An example of numerical model of one and two storied basement with 2 different basements is shown below-

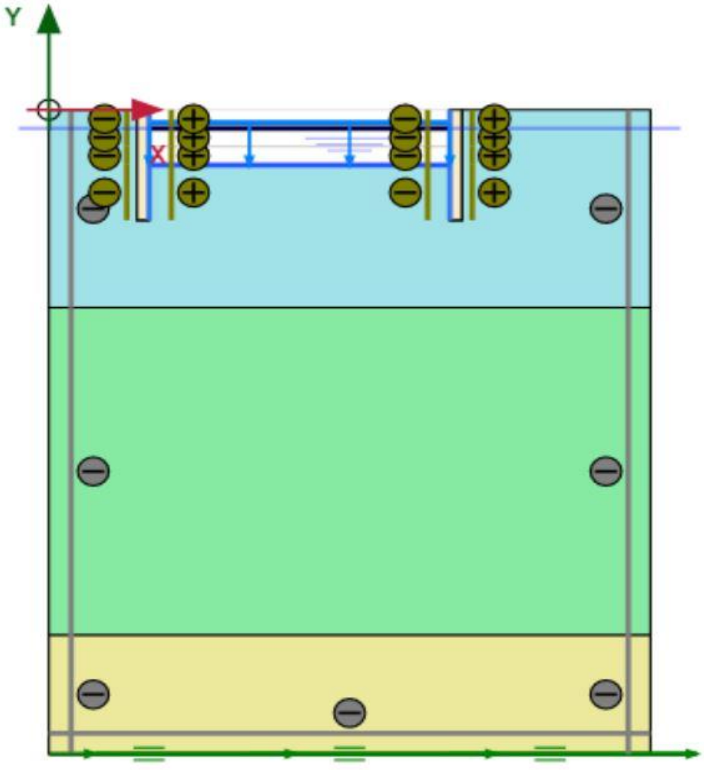

Figure 1: Numerical model of one storied basement with raft foundation

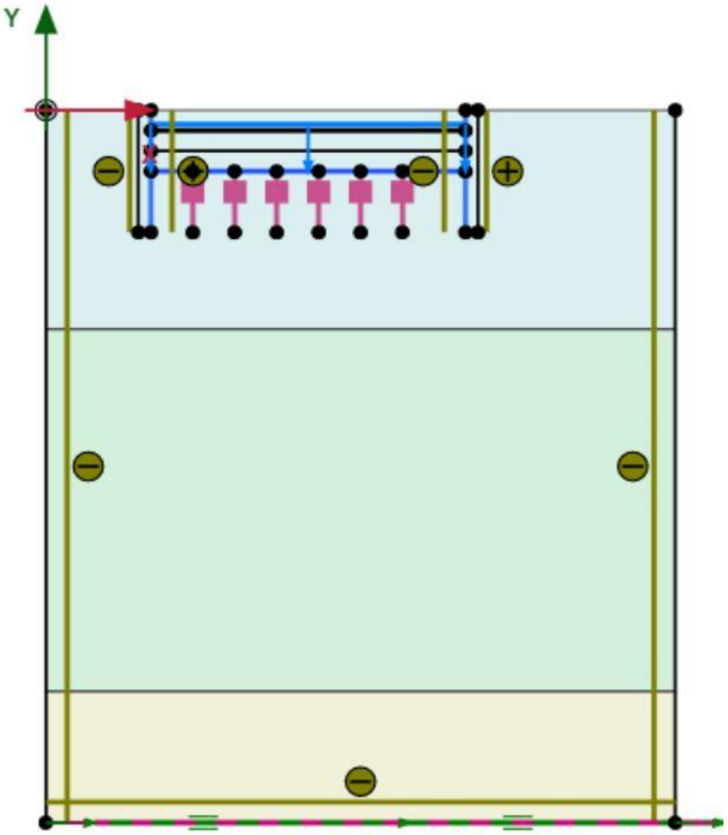

Figure 2: Numerical model of single storied basement with pile raft foundation

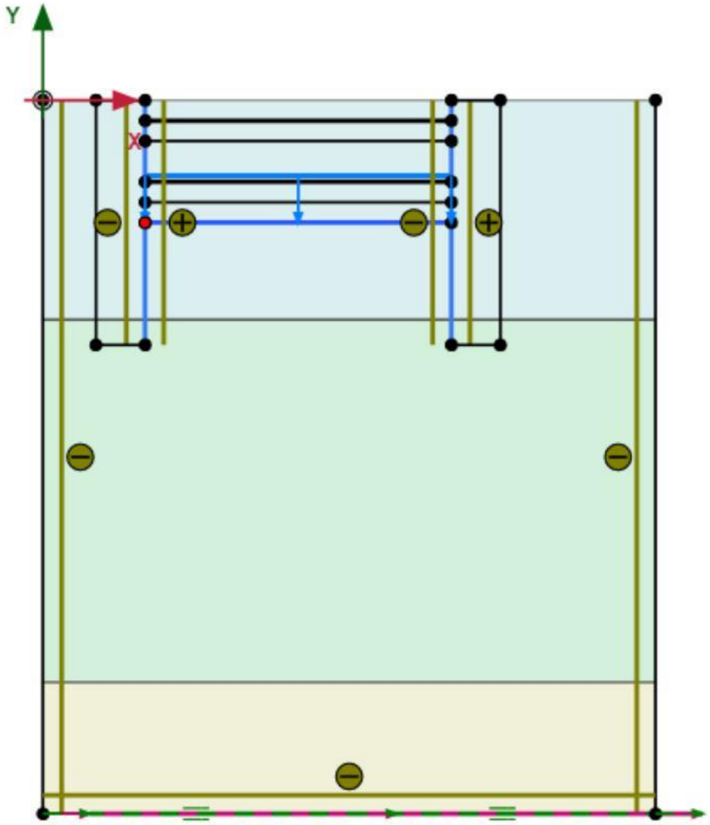

Figure 3: Numerical model of two storied basement with raft foundation

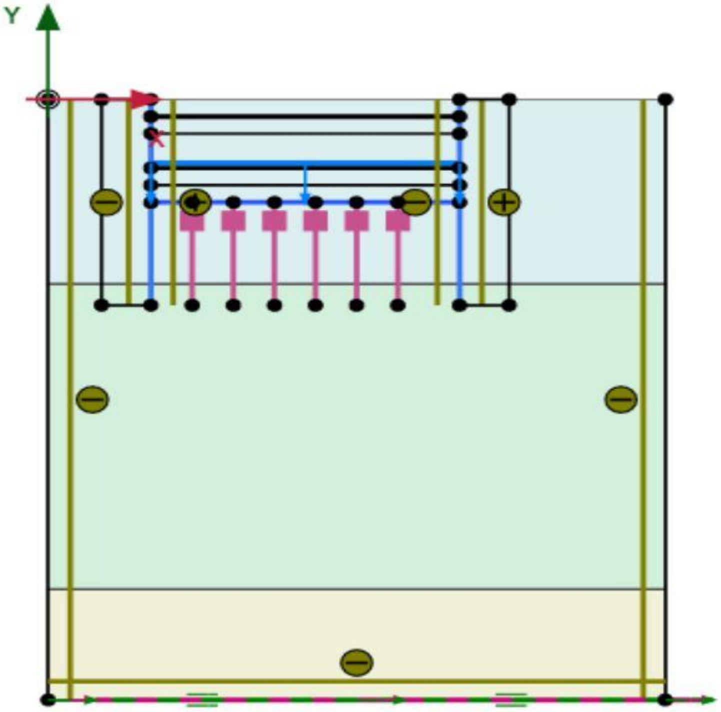

Figure 4: Numerical model of two storied basement with pile raft foundation

4.3. Design Parameters:

4.3.1. Introduction:

In this section the design parameters for linear elastic model of EPS geofoam, diaphragm wall, raft foundation, strut are discussed below.

4.3.2. Design Parameters of EPS Geofoam:

Three different types of EPS geofoam are used to evaluate the effect of different thicknesses. The thickness ratios of the EPS are o.1 and 0.2 to wall height. Table 3 shows the parameters of EPS geofoam.

Table 3: Summary of input parameters of EPS geofoam

Property	EPS15	EPS22	EPS29
Material model	Linear Elastic	Linear Elastic	Linear Elastic
Unit weight (KN/m^3)	0.15	0.22	0.29
Young's Modulus (KN/m^2)	4,200	6,910	10,000
Poisson's ratio	0.11	0.12	0.13

4.3.3. Design Parameters for Structural Elements:

Table 4 is a summary of input parameters used in modeling the diaphragm wall, strut & raft foundation. Table 4 is a summary of input parameters of pile element. Both positive and negative interfaces are implemented during modeling. The retaining wall (diaphragm wall) was modeled as plate element along with raft foundation. The steel strut was modeled as beam element whereas the pile as embedded beam element.

Table 4: Summary of input parameters of structural elements

Parameters	Unit	Diaphragm Wall	Raft Foundation	Strut
Material Type		Elastic	Elastic	Elastic

Axial Stiffness	kN/m	$7.5 * 10^6$	$5 * 10^6$	$2 * 10^6$
Bending Stiffness	kNm^2/m	$1 * 10^6$	8500	-
Poisson’s Ratio		0	0	-
Weight	kN/m/m	10	0	-

Table 5: Summary of input parameters of embedded pile

Parameters	Unit	Embedded Pile
Unit weight	kN/m^3	24
Modulus of Elasticity	kN/m^2	$30 * 10^6$
Diameter	M	0.5
Material Type	-	Elastic

4.4. Excavation Sequence Modeling:

PLAXIS2D divides finite element calculation into several sequential calculation point known as “Phases”. Each phase represent a type of loading or construction stage. The phases of the numerical model used in this paper are based on actual construction sequence to perform numerical analysis. Table 5 outlines the phases used in the model.

Table 6: Summary of phases & their activity

Foundation Type	Basement Type	Phase	Activity
Raft Foundation	Single Basement	1	Install diaphragm wall
		2	Geofoam Insertion
		3	-2m Soil excavation

		4	Install Strut at -1m
		5	-3m soil excavation
		6	Cast Base Slab
		7	Activate 288kn/m/m load applied on foundation
		8	Simulate earthquake
	Double Basement	1	Install diaphragm wall
		2	Geofoam Insertion
		3	-2m soil excavation
		4	Install strut at -1m
		5	-5m soil excavation
		6	-4m strut installation
		7	-6m soil exaction
		8	Cast Base Slab
		9	Activate 288kn/m/m load applied on foundation
		10	Simulate earthquake
Pile Raft Foundation	Single Basement	1	Install diaphragm wall
		2	Geofoam insertion
		3	-2m soil excavation
		4	Install strut at -1m
		5	-3m soil excavation
		6	Install bored pile
		7	Cast base slab
		8	Activate 288kn/m/m load applied on foundation
		9	Simulate earthquake

Pile Raft Foundation	Double Basement	1	Install diaphragm wall
		2	Geofoam insertion

		3	-2m soil excavation
		4	Strut installation at -1m depth
		5	-5m soil excavation
		6	Strut installation at -4m depth
		7	-6m soil excavation
		8	Install bore pile
		9	Cast base slab
		10	Activate 288kn/m/m load applied on foundation
		11	Simulate earthquake

4.5. Dynamic Loading:

Bangladesh has no history of high magnitude earthquake. But it is situated between three tectonic plate which are Indian plate, Eurasian plate, Burmese Plate. Due to this reason Bangladesh is prone to earthquake of high magnitude. For this reason it is compulsory to construct earthquake resistant structure and one of the reasons of this study.

As there no recent history of major earthquake in Bangladesh, Kashmir 2005 earthquake was selected as dynamic loading. The earthquake occurred in 8th October with a magnitude of 7.6. Fig 5 shows time vs acceleration graph:

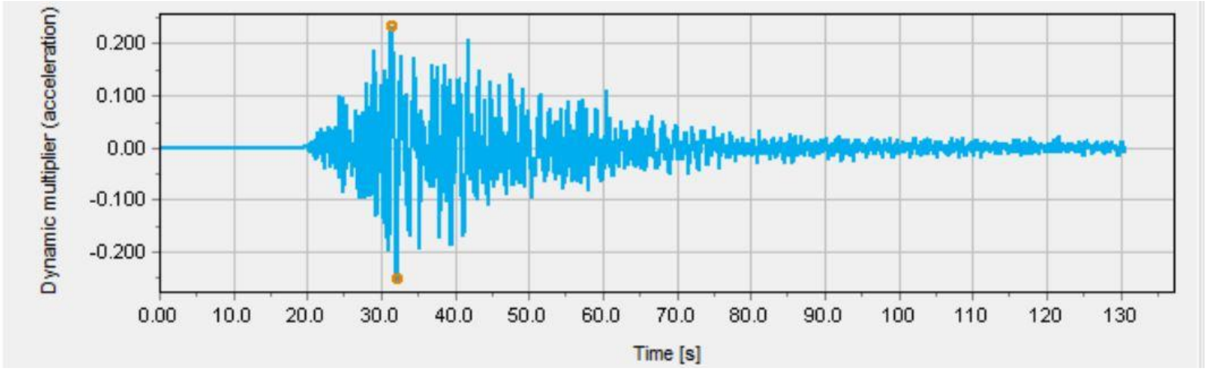

Figure 5: Time Vs Acceleration graph

CHAPTER FIVE: RESULTS & DISCUSSION

5.1. Introduction:

Diaphragm wall is a reinforced concrete wall used in deep excavation and also work as permanent foundation wall. Deformation due to constant earth pressure is a major parameter used to determine the performance of the diaphragm wall. During earthquake the earth pressure increases significantly effecting the stability of the retaining wall. The depth of insertion of diaphragm wall is 2 times the excavation depth. As a result for a single storied basement the diaphragm wall used was 6m, whereas for double storied basement it was 12m.

This chapter discusses the effect of 3 different densities of geofoam with 2 different width ratio (geofoam width/ height of retaining wall) on the retaining structure both on static and dynamic loading. Finally a comparative study will be done to determine which type of geofoam is best suited for different condition.

5.2. Stiff Soil Vs Loose Soil:

This section will exhibit the effect of geofoam when used with stiff soil or loose soil at dynamic condition. The graphs shown below will represent depth in y axis and total displacement U_x in the x axis. The foundation type selected was pile raft with double basement for both Chittagong and Dhaka soil.

From fig 6, it can be seen that without geofoam the total displacement U_x is around 95mm. But when geofoam inclusion of 3 different density (EPS15, EPS22, EPS29) is used with 0.2 thickness ratio the maximum total displacement reduces to around 76.5 mm.

Observing fig 7, it can be stated that without geofoam the total displacement U_x is around 305mm. But when we use geofoam with varying density the total displacement U_x reduces down to around 255 mm. It is around a 50mm decrease. It is a significant decrease when compared to Dhaka soil.

The change in total displacement U_x is due to the fact that the sample collected from Dhaka has higher SPT value representing stiffer soil, whereas the sample of Chittagong has lower SPT value representing looser, less dense soil. So, it is evident that geofoam can play an important role in reducing the effect of earthquake as much as twice for loose less dense soil compared to stiffer, high density soil.

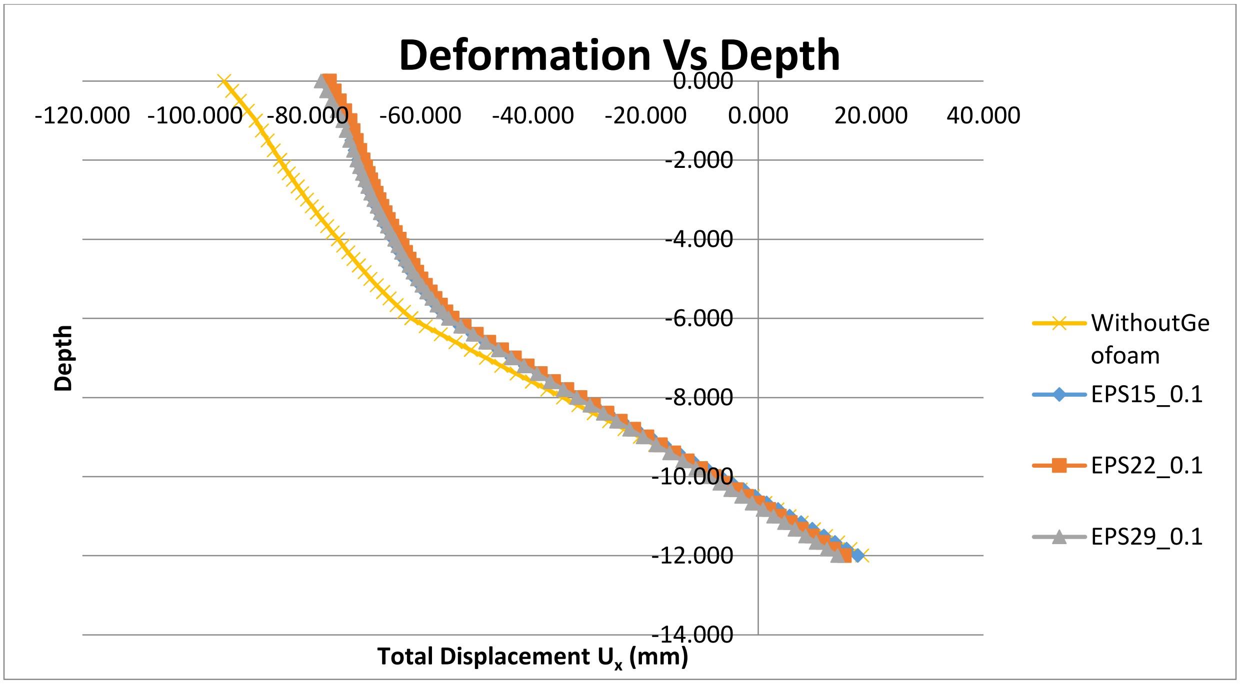

Figure 6: Total Displacement U_x Vs Depth (Dynamic analysis for 2 storied basement using Dhaka soil)

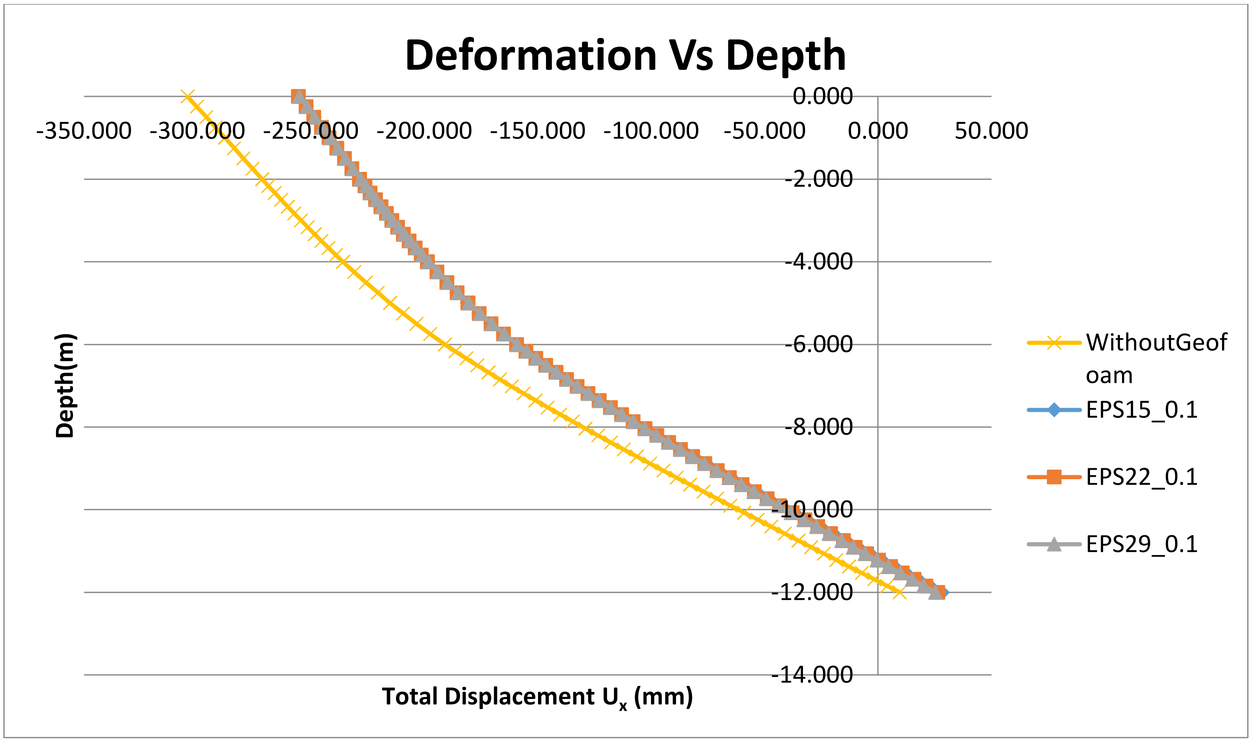

Figure 7: Total Displacement Ux Vs Depth (Dynamic Analysis for a 2 storied basement using Chittagong soil)

5.3. Effect of Density & Thickness:

From previous section it can be seen that geofoam performs better in loose, less dense soil therefore further investigations were done in Chittagong soil.

Geofoam density plays an important role in reducing the effect of earthquake. For this reason three densities of geofoam was used which are EPS 15, EPS22, EPS29. Besides density, the thickness of the geofoam plays a also vital role. For thickness, width to height ratio is used. Here height is the vertical length of retaining wall and width is geofoam thickness. Two different thickness ratios was used which were 0.1 & 0.2.

From fig. 8 & 9, it can be seen that for 3 different density of geofoam there is very slight difference in reducing the earth pressure acting on the diaphragm wall. Observing fig. 8, it is apparent that, without geofoam total displacement U_x is 269mm but with geofoam is 223mm. whereas if thickness ratio of 0.2 is used, from graph fig. 9 the total displacement U_x noticeably reduces down to 181mm which is a significant decrease. It is evident that EPS geofoam with higher thickness performs better in reducing deformation.

It is clear from fig. 8 & 9 that different type of geofoam density has very few effects in reducing the total displacement U_x. But if fig. 10 & 11 is observed, where total displacement (both x & y axis) is considered instead of total displacement U_x there is a difference in reducing deformation. From graph fig. 10, it can be seen that without geofoam maximum total displacement is 585mm. But for EPS15, EPS22, EPS29. It reduces down to 427, 416, 409mm accordingly.

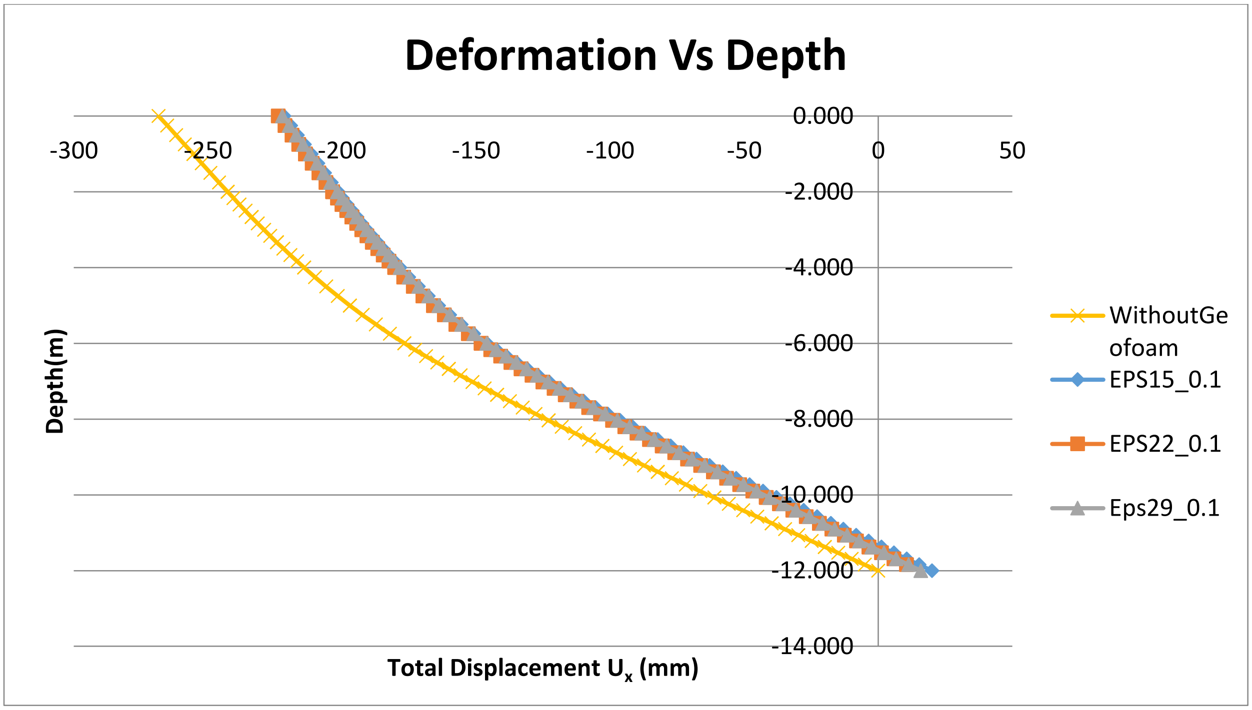

Figure 8: Total Displacement U_x Vs Depth (Dynamic Analysis for a 2 storied basement Using Chittagong Soil with 0.1 thickness ratio)

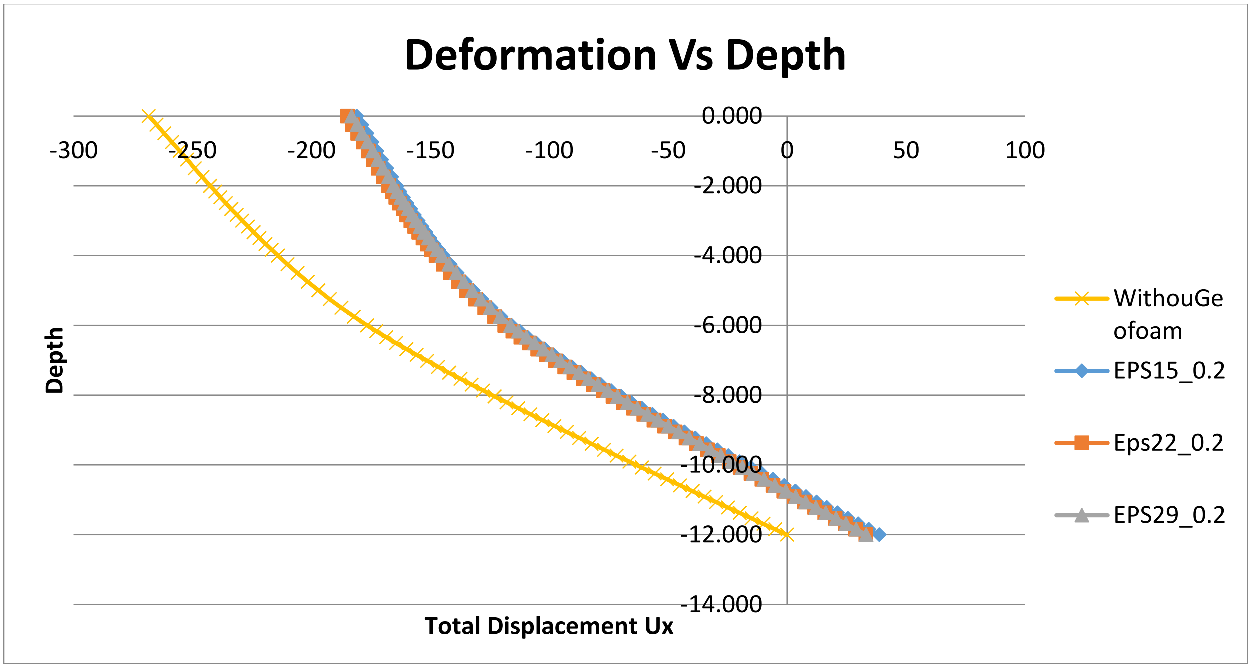

Figure 9: Total Displacement U_x Vs Depth (Dynamic Analysis for a 2 storied basement Using Chittagong Soil with 0.2 thickness ratio)

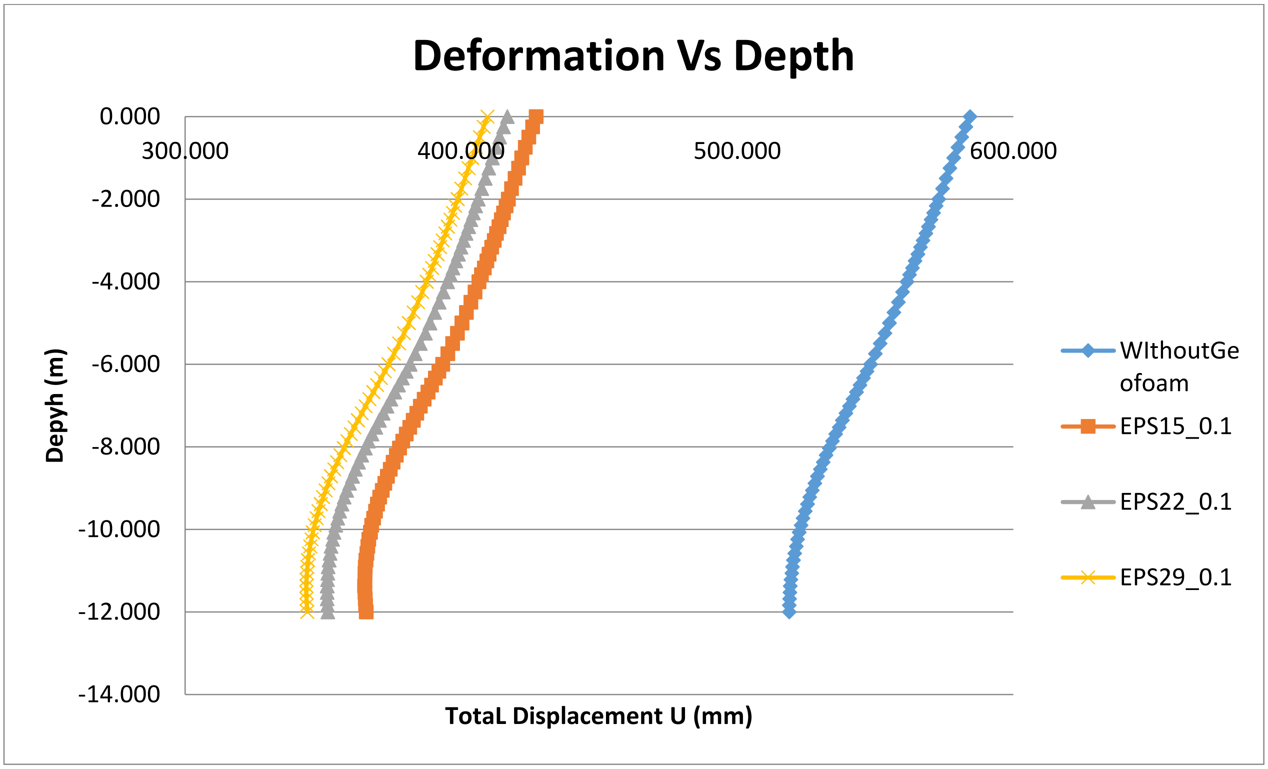

Figure 10: Total Displacement U Vs Depth (Dynamic Analysis for a 2 storied basement using Chittagong soil with 0.1 thickness ratio)

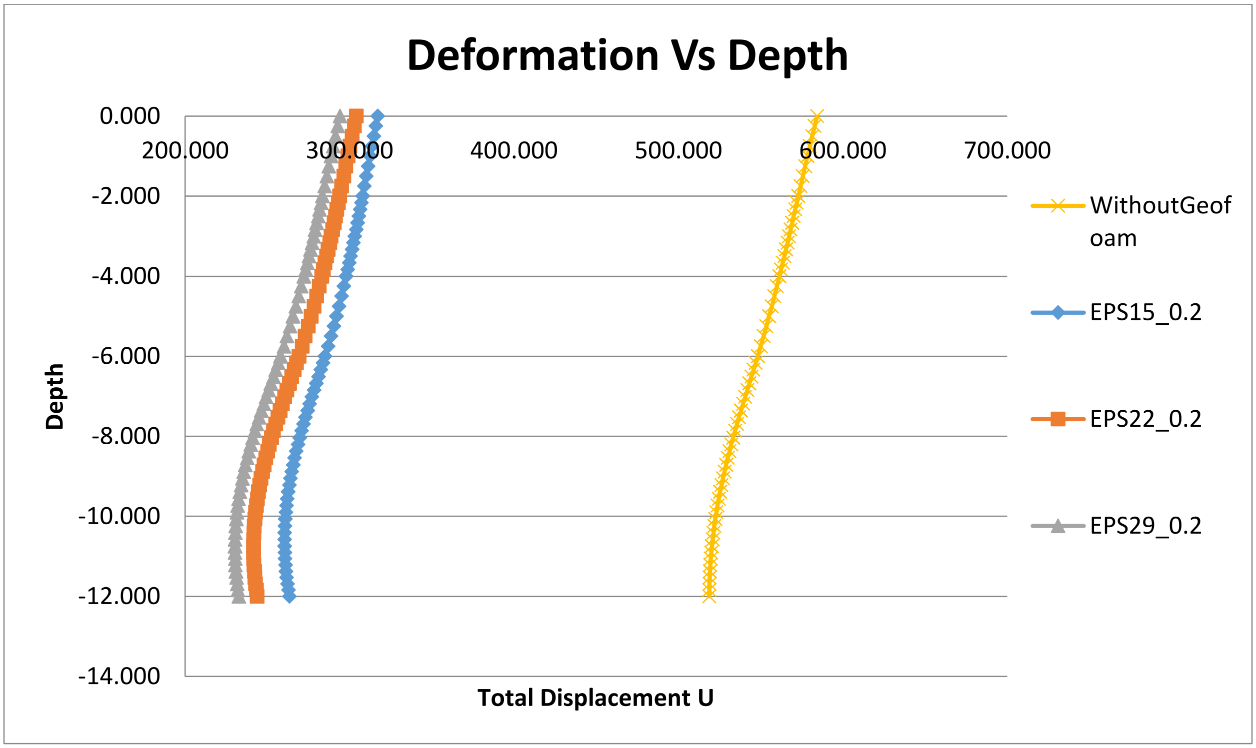

Figure 11: Total Displacement U Vs Depth (Dynamic Analysis for a 2 storied basement using Chittagong soil with 0.2 thickness ratio)

5.4. Effect of Depth:

Graph 5.4 clearly indicates that the use of higher density geofoam does result in higher reduction in total displacement. Numerical analysis was performed to determine if similar reduction occurred for single storied basement. Fig. 12 shows the effect of EPS geofoam EPS15, EPS22, EPS29 using 0.1 & 0.2 thickness ratio when used for single storied basement. As total displacement U shows better difference than total displacement U_x (fig. 10 & 11), the data was collected in total displacement U.

Observing fig. 12, it is clear that for single storied basement the effect of EPS geofoam is opposite of fig 10 & 11. Here geofoam with lower density is able to reduce the effect of earth pressure during earthquake. Without geofoam total displacement is 633mm. But for EPS15 at 0.1 and 0.2 thickness ratio is 339 and 454mm accordingly. EPS22 and EPS29 don’t perform well at 0.2 thickness ratio and increases deformation at 0.1 thickness ratio.

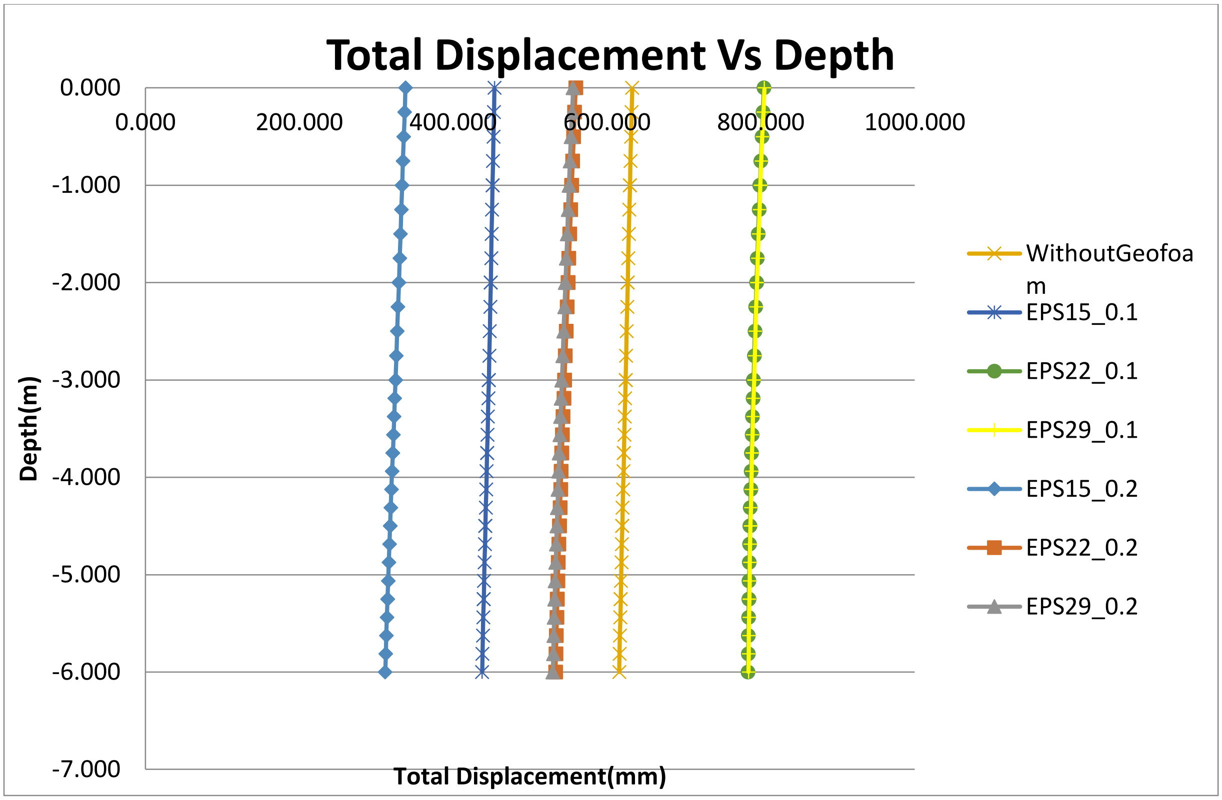

Figure 12: Total Displacement Vs Depth (Dynamic analysis for a single storied basement using Chittagong soil)

5.5. Effect of Static Loading:

Previous sections of this chapter discuss the results obtained from PLAXIS2D during earthquake simulation or dynamic loading. Although the earth pressure acting on any retaining structure is higher during an earthquake but occasionally occurs. Therefore this section discussed the effect of geofoam in reducing earth pressure during static loading.

Observing fig. 13 & 14, it can be stated that the use of geofoam does play a role in reducing the effect of geofoam. But unlike dynamic analysis it is very small and sometimes geofoam does contribute in increasing the deformation. From fig. 13, it can be seen that the total displacement U (without geofoam) is 34mm and inclusion of geofoam reduces it to around 24-26mm. Similar can be said for fig. 14, where the reduction is around 8-10 mm.

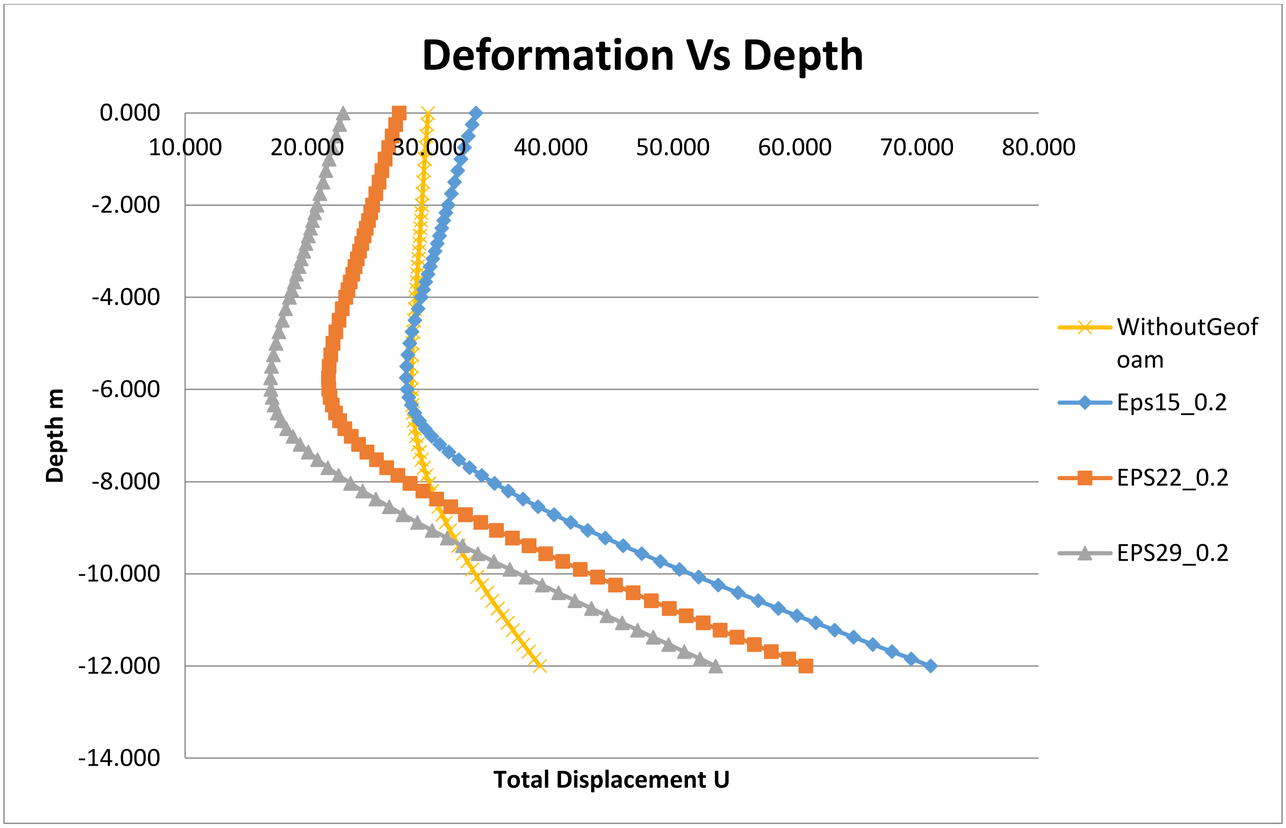

Figure 13: Total Displacement Vs Depth (Static analysis for a 2 storied basement using Chittagong soil)

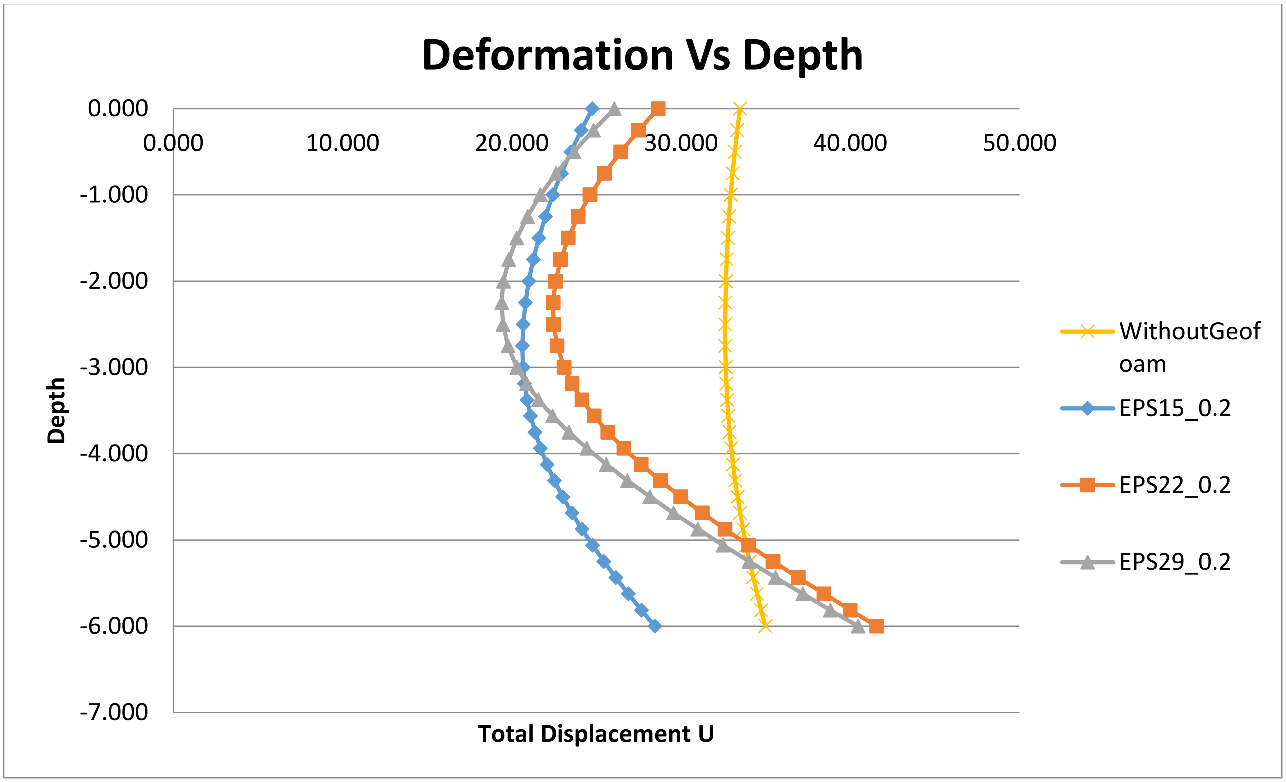

Figure 14: Total Displacement Vs Depth (Static analysis for a single storied basement using Chittagong soil)

CHAPTER SIX: CONCLUSION

Conclusion:

This research paper is about determining the effect of EPS geofoam inclusion during static and dynamic analysis in context of Bangladesh using numerical modeling. PLAXIS2D, a finite element package was used to perform the numerical analysis. The analysis was done using both Dhaka and Chittagong soil for raft and pile raft foundation.

In the previous chapters it is discussed in detail the background of the project, methodology, numerical modeling and results after numerical analysis. This section is a brief and synthesized summary:

- Finite element analysis is a computerized method using mathematical equations to determine and predict real world behavior. Finite element analysis is a complex procedure which is discussed in chapter 4 which includes (i) Soil modeling (ii) Retaining structure modeling (iii) Geofoam modeling (iv) Define construction sequence. This chapter also describes the testing procedure to determine the soil properties.
- It is seen in chapter 5 that geofoam performs better in loose, less dense soil. Sample of Dhaka soil has a SPT value higher than Chittagong soil making it stiffer than the other. As a result the displacement is lower compared to Chittagong. Total displacement U_x of diaphragm wall for Dhaka is 95mm, whereas for Chittagong it is 305mm. And the use of geofoam reduces the displacement significantly.
- Thickness ratio plays a vital role in reducing the effect of earth pressure. For 2 storied basements, using EPS29 with thickness ratio 0.2 results in 19% more decrease of total displacement U_x compared to that achieved with thickness ratio 0.1 and a decrease of 33% compared to without geofoam.
- Density of geofoam also has impact in reducing displacement. But it is best observed in total displacement U (both x & y axis) rather than total displacement U_x . In this research paper 3 different varying density of geofoam resulted in a reduction of 46%- 50% (higher density will results in higher reduction of total displacement).

- Retaining structure depth also plays a role in the performance of geofoam. For this reason 2 types of basement- one storied and two storied was used. For 2 storied basements, higher density does result in higher reduction. But in case of one storied basement, lower density geofoam performs significantly better. A reduction of

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