STUDY ON IMPROVEMENT OF STABILITY OF RETAINING WALL REINFORCED WITH GEOGRID

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
IN
GEOTECHNICAL ENGINEERING

Submitted by:
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I, Sukriti Barman (2K20/GTE/19) of M. Tech (Geotechnical Engineering), hereby declare that the Project Dissertation entitled " STUDY ON IMPROVEMENT OF STABILITY OF RETAINING WALL REINFORCED WITH GEOGRID", which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi is submitted in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation entitled "STUDY ON IMPROVEMENT OF STABILITY OF RETAINING WALL REINFORCED WITH GEOGRID", which is submitted by Sukriti Barman (2K20/GTE/19) of M. Tech (Geotechnical Engineering), Delhi Technological University, Delhi submitted in partial fulfillment of the requirement for the award of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ACKNOWLEDGEMENT

I express my deep gratitude and indebtedness to **Prof. Anil kumar Sahu**, Department of Civil Engineering, DTU, Delhi, for his guidance, and valuable feedback throughout this project work. His able knowledge and supervision with unswerving patience fathered my project work at every stage, for without his encouragement, the fulfilment of task would have been impossible and difficult.

I express my sincere thanks to **Prof. Raju Sarkar**, Department of Civil Engineering, DTU, Delhi, for his cooperation, support and persistent efforts in guiding at each stage of the project work. I wish to express my gratitude towards our Head of Department, **Prof. V. K. Minocha**, Department of Civil Engineering, DTU, Delhi, for showing interest and providing help throughout the period of my project work.

I am genuinely appreciative of all my Friends for their support and suggestions during my work. Lastly, I would like to thank the Almighty GOD ,my parents and my husband, whose committed and untiring efforts towards me have brought me at this stage of my life.

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ABSTRACT

Mechanically stabilized earth (MSE) retaining wall is a distinctive structure which is used extensively in the recent days. Generally, there are various types of soil reinforcement can be used in mechanically stabilized earth retaining wall. Steel strip, welded steel grid, wire mesh, geogrids, and geotextile sheets are examples of modern soil-reinforcing elements. The adoption of a facing system minimizes soil erosion between reinforcing parts and enables for the safe construction of steep slopes and steep walls. Since the early 1970s, geosynthetic materials are produced and then used as reinforcement material in soil retaining structures. Geosynthetics have been increasingly popular in reinforced soil constructions, and they currently account for a considerable percentage of reinforced soil industry. Technological advances in the polymer sector have been regularly comprised into new geosynthetic products, improving the qualities of geosynthetic materials used in geotechnical applications. Geogrid is one of the main products of geosynthetic materials. Tieback anchors are developed to reach the optimum rigidity achievable within financial constraints in order to limit wall displacement and ground settlement. Horizontal deflection, vertical deflection and factor of safety under the effect of various stiffness of geogrids are studied. Geogrids are applied into varying height of wall too. Tie back anchor is coupled with geogrid and the effect on reducing horizontal deflection has been studied. The length of geogrid and the surcharge load are taken constant and comparison has been drawn between with and without geogrid structure. Significant improvement of stability of structure is shown after application of geogrid. While collaborating with tie anchors it gives better result in controlling horizontal deflection of structures. The combination of geogrid and soil effectively enhances the deformation of the retaining wall structure and the overall stability.

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CHAPTER 1

INTRODUCTION

A retaining structural element is designed and constructed to withstand the lateral pressure when a transformation in ground elevation surpasses the angle of inclination of the soil. Retaining walls are vertically or almost perpendicular structures intended to prevent material from falling, sliding, or degrading on one side.

A mechanically stabilized earth (MSE) retaining wall is a structure that consists of different thicknesses of compressed fill materials and soil reinforcement elements mounted on a wall facing. The friction and strain interaction between the fill material and soil reinforcing element is what provides the wall structure its stability.

During the building of an MSE wall, reinforcements are put in levels of the backfill soil, and this reinforced material resists the earth pressure caused by the retained material by using the relative movement between reinforcement and soil.

Figure 1.1 The geogrid supported soil retaining wall's front face has a cast-in-place concrete-rigid facing. (G. Yang et al. 2009)

There are various sorts of retaining walls, and we'll go through a few of them here.

- **Gravity Retaining Wall** - These walls are designed to withstand horizontal ground forces by their own weight. The major forces operating on these types of walls are vertical forces from the wall's weight, lateral earth pressure pressing on the bottom face, and seismic loads. Other forces, like as vehicle loads, are also present, must be considered if they are met. The Coulomb equation is commonly used to compute lateral earth pressure.
- **Cantilever Retaining Wall** – These kinds of walls are built of concrete and work on the principle of leverage. These have a much thinner stem and depend largely on the backfill soil's weight to keep it from sliding and overturning. A cantilever retaining wall is the most common type of earth-retaining structure. Ground slopes and ground retaining structures are utilised to maintain two different ground surface elevations. Cantilever walls have an L-shaped orreversed T-shaped foundation and are made of reinforced concrete. The foundation receives allvertical pressure behind the wall, protecting it from falling due to lateral displacement from thevery same soil mass. Since construction requires space behind the walls, they are not well suited to facilitating slopes until temporary support is provided during construction.
- **Counterfort Retaining Wall** - These types of walls resist all lateral loads by flexing action rather than mass. As a consequence, such walls have a huge foot structure, a vertical stem strengthened with bar, and thin transversal slabs called Counterfort Supporting it at regular intervals. The slab is designed for high tensile stresses stress since it is designed to be put inside the area in which the soil mass must always be maintained. A cantilever wall with a greater stem necessitates a large base, hence Counterfort walls are designed with transverse support to overcome this limitation. Because a big base is required for a cantilever wall with a large stem, Counterfort walls are constructed with transverse supports to overcome these limitations. The wing walls protrude upward from the heels of the footing into the stem of counterfort cantilevered retaining walls. The stems between counterforts are narrower (than cantilevered walls) and extends horizontally between the counterfort walls like a beam.
- **Gabion or Crib Wall** - A gabion wall has wire material cages which hold stones or rubble together. Steel barrels are packed with stone or debris in crib walls, which are a sort of gabion wall. Stacking timber grillages and filling the interior with earth or rubble is another alternative. Also popular are precast concrete crib walls.

- **Reinforced Earth Retaining Wall** – This kind of wall is designed and constructed to resist lateral pressure and to hold the soil laterally. The walls link soils between two different elevations, which is frequent in terrain with unfavorable slopes. These walls are a value option for roads and bridges, railways, and mass transit networks. These are also used to deal with difficult design challenges like very tall structures, lack of space, and the existence of obstructions inside the soil mass.

1.1 GEOGRID

Geogrid can be defined as a geosynthetic material mainly made up of polymeric material.
Example – Polyethylene, polyvinyl alcohol polypropylene etc. It is a very useful reinforcing material now a days.

Geogrid is generally fabricating by 3 ways: extrusion, knitting or welding. The coarse or fine substance that is put on top of the geogrids combines with it. The apertures interlocks with the ribs (flat straps/bars) to limit the overlying granular/soil material due to the stiffness and strength of the ribs. The aggregates are held in place by the geogrids' interlocking. It is easier than traditional approaches to achieve mechanical stabilization of any ground work.

1.1.1 Functions of Geogrid

- Its flexible and dynamic nature, makes it a appropriate choice for retaining walls, enabling them to become more robust and earthquake-resistant.
- The construction costs are found to be much cheaper when geogrids were used instead of standard concrete retaining walls.

1.1.2 Advantages of Geogrid

- The usage of geogrids allows for more cost-effective construction.
- It is harmless to the environment.
- Geogrids make members more resilient since they protect them from environmental threats.
- It helps to keep the soil from collapsing.
- Because the placement techniques are straightforward, geogrids ensure ease of construction.

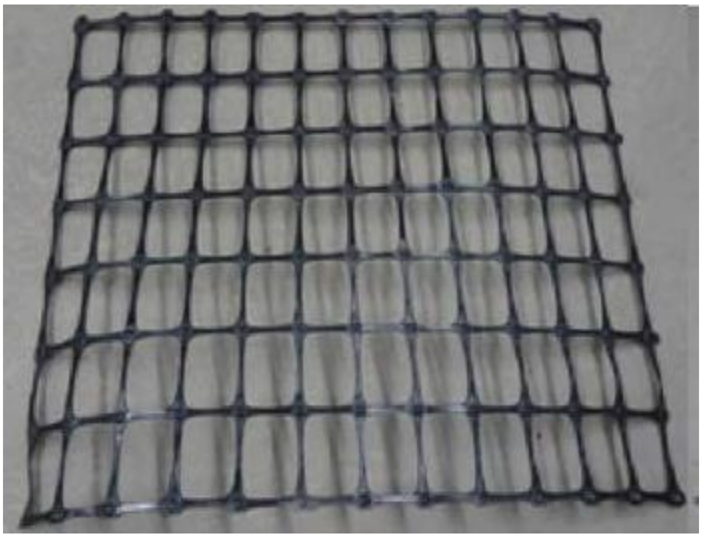

Figure 1.2 Geogrid before ribs cut off (Xiao et al., 2015)

1.1.3 Tie Anchor

A tie back anchor is generally used in soil or rock. It helps to carry and transmit the applied tension load into the earth. It is kind of a holding system widely used in conjunction with other retaining structures.

The tieback's bond length must reach outside the soil's possible critical slip surface. Otherwise, the tieback will not be able to prevent the ground material within the failure surface from collapsing.

1.2 OBJECTIVE

The goal of the present study is to observe the influence of the followings-

- To observe the impact of vertical spacing of reinforcement, stiffness of geogrid on the stability of reinforced retaining wall.
- The combined effect of geogrid and tie back anchor on the stability of reinforced retaining wall.

CHAPTER 2

LITERATURE REVIEW

The literature on MSE walls on weak soil is examined and given in the following paragraphs in this study.

Yang et al. (2009) observed the main line of Gan (Zhou)-Long (Yan) railway during the building of a cast-in-situ geogrid reinforced soil retaining wall. It was found that the upright foundation stress of a reinforcement retaining wall is not linear along its length, with the highest value in the center and decreasing value at the edges. It was also discovered that during building, the maximum horizontal displacement of the face of the wall is confined within a segment of the bottom wall, and that after construction, the maximum lateral forces ofthe wall face is kept within a portion of the top wall.

Leshchinsky et.al. (2004) reported the findings of parametric investigations in Geosynthetic Reinforced Multitiered retaining Walls. He studied utilizing two types of analyses: first one based on limit equilibrium (LE) another on continuum mechanics. When appropriately applied, in the case of stability of slope, limit equilibrium analysis produced nearly the same safety factors in multitiered MSE walls against failure as the study based on continuum mechanics. It was noted that Limit Equilibrium analysis could be used to find out the tensile strength. When the height of the multitiered retaining wall was risen up, the necessity of tensile strength of reinforcement was also grown. Poor quality fill demands more tensile strength and length of reinforcement whereas good quality fill requires less .

Hossain et al. (2012) reported a study of an MSE wall in Lancaster, Texas, on State Highway 342. A rigorous field and lab research testing program was conducted to determine the potential causes of the wall movement. The site research included soil boring and resistivity imaging (RI). At a few locations in the backfill region, RI was utilised to detect perched water zones. Some elements that contributed to the uncontrolled movement of the MSE wall were discovered. When backfill contains a significant percentage of fines, the likelihood of excessive MSE wall movement increases. The poor drainage capabilities of the backfill soil added to the strain, and the formation of a water zone caused by water infiltration into the material of the backfill could be a major contributor in movement. Apart from these factors, a critical problem may be aroused due to an insufficient length of retaining wall reinforcement.

Chiang et al. (2021) reported a number of finite element simulations to examine the efficiency and reinforcing mechanisms of GRS foundation due to normal fault movement. The computational and experimental results of reinforced and unreinforced foundation were initially compared for model validation. The impact of soil and reinforcing parameters on the performance of reinforced foundations was investigated using parametric methods. The deformation behavior of reinforced and unreinforced foundations exposed to normal fault movement were predicted by FE analysis. The two key reinforcing mechanisms revealed in this study were the shear rupture interception effects and tensioned membrane.

Linhares et al. (2021) used experimental studies and numerical simulations to explore the effectiveness of Geosynthetic Reinforced Soil (GRS) walls based on the effect of surcharge width under working stress conditions. Experiments using blocks and wrapped-face walls were conducted at Laboratory. There were four kinds of Geosynthetic Reinforced Soil walls studied, with different facing varieties and surcharge widths considered. The numerical model of GRS walls was carried out using the two-dimensional computer application PLAXIS .As per the conclusions of the physical and numerical tests, maximum surcharge width might impact the reinforcement loads. According to the numerical analysis, backfill compaction predicted building movements and increased reinforcement loads, in the reinforced soil wall creating a type of compressive stress and lowering post-construction motions.

Guler et al. (2007) examined the failure process of reinforced soil segmented walls with extendable reinforcements using a numerical analysis availing the finite element method. The findings of three experimental test full-scale constructions earlier reported in the literature were then compared to the numerical method. The failing plane of a GRS-retaining wall approaches a straight sliding type , which originates from the structure's toe with a quite low slope.

Hatami et al. (2001) investigated the structural behavior of reinforced-soil RS wall systems with different reinforcement types using a computational technique which is a nonuniform reinforcement. To simulate wall models, a finite difference approach was utilized, which included the building the wall in steps and the installation of reinforcement in the wall at periodic intervals of vertical spacing, followed by a sloped surcharge. The lateral earth pressure coefficient and horizontal wall movement behind the facing in all non uniform reinforcement walls are clearly dependent on the stiffness value of reinforcement layers of the wall at various heights. In non uniform reinforced wrapped faces, such as those investigated in this paper, walls with certain backfill types, and reinforcing configurations, a formula is proposed for estimating the maximum reinforcement load.

Fonseca et al.(2014) analyzed assumptions from numerical analysis to measurements in an instrumented geogrid reinforced soil construction on a foundation soil which is collapsed, where recycled construction and demolition wastes (RCD) were employed as backfill. The porous collapsible foundation soil was evaluated by means of reinforcing strains, horizontal and vertical earth pressures, wall face displacements, settlements, and horizontal displacements. It was showed from both the field measurements as well as the numerical predictions that in geosynthetic retaining wall RCD waste could be an useful backfill material in the place of general conservative materials.

Xiao et al. (2015) studied a number of model retaining walls. The effects of various parameters of the strip footings on the GRS walls was analyzed. The offset distance, the width of the strip footing on the GRS wall, the size of geogrid, and the relationship between geogrid and concrete wall facing were incorporated. To detect prospective failure surfaces appearing in the walls, In the backfill a narrow pigmented sand layers were put. It was also found that the contour of the lateral displacement of the wall face was affected by offset distance of footing. The failure surface began at the footing's one-side edge. The mechanical connection tests revealed three potential slip surfaces exists. Two-part wedge method provided by Spencer had factors of safety lesser than Bishop's slip circular surface method, as specified by the limit equilibrium studies.

Song et al. (2018) used the FEM software plaxis to study the failure process of a GRS wall numerically. The failure mechanism was investigated based on the investigation of the construction layer and the impact of strength of soil, strength of geocell, and location of geocell. As per the findings, the slope was curvy and went through the bottom of the wall and connected with the wall. Moreover, the mode of failure of the high-strength geocell-built wall in the bottom half was essentially equal to the complete high-strength geocell-built wall.

Sadat et al. (2018) looked into the performance of an MSE wall and the impact of different parameters on its efficiency when the wall face stabilized with respect to the reinforcement zone. The study was carried out with the use of a numerical method that was tested using triaxial testing and then MSE wall tests. Differential settlement would generate considerable lateral and vertical displacements, and an elevation in active earth pressure and geotextiles reinforced strain, according to the numerical calculations. The highest horizontal displacement happened around 1.0 m above the toe.

Lawson et al. (2010) found that when the reinforced fill zone was confined, reinforced segmental block retaining walls could be built utilizing a mix of geogrid reinforcement and anchor reinforcement. The design theory for reinforced soil walls wass presented in this study. Anchors were deployed to distribute the reinforcement in a limited reinforced fill zone. There was also a case study where this method was employed effectively.

Kong et. Al. (2021) investigated performance of curved and straight sections which are reinforced with different length of reinforcements. Lengths were taken 1m, 3m, 5m and 7m. Three dimensional numerical analysis was performed. Wall height was taken constant whereas the length of reinforcements were varied which effected wall behavior divergently. It was found that curved section demanded more reinforcement than straight section. Reinforcement lengths should be individually applied. So, instead of utilizing the same length of reinforcement in the curved and straight parts, it is more cost effective to use separate lengths.

Yu et. Al. (2016) introduced thorough numerical modelling of a geogrid reinforced incremental concrete panel earth retaining wall in this study, which uses the finite difference method (FDM) to predict the behavior of the wall. The backfill soil was examined using two different constitutive models (linear and nonlinear elastic-plastic model). Large variances in facing displacements can be caused by the magnitude of compaction pressure used near the facing. The paper also shows that the building approach, including the placement, sequence, and stiffness of the stand in supports used to build the wall, has a significant impact on measured and anticipated wall performance.

Yang et. Al.(2012) examined a 6.0 m high reinforced retaining wall for 2 years during and after construction with the goal of identifying the behavior of the structure where lime treated soil was used under working-stress conditions . The lime-treated soil absorbed the most of the gravity load, while the geogrid reinforcement also helped to maintain the embankment's integrity. Deformation of backfill was mostly elastic under gravity loading. Compaction of backfill during construction was a key factor determining lateral earth pressure and deformation of reinforcement at the rear of the face, which decreased over time as strength of backfill and facing displacement increased.

Bilgin et. Al. (2009) looked into the controlling failure mode when evaluating theminimum required reinforcement length, as well as the possibility of lowering the prescribed minimum reinforcement lengths. The impact of various design parameters on the necessary minimum length of reinforcement and the failure mode of reinforced retaining walls was investigated. According to the findings, depending on the properties associated with a certainwall, both external and internal failure mechanisms can be ruling criteria in establishingthe minimum required reinforcement length. The findings of parametric experiments, such as the effect of various factors on the minimum required reinforcement length, ruling failure criteria are presented in this study.

Wang et. Al (2019) studied horizontal displacement of the wall face, vertical and horizontal soil stresses, and geogrid strains in the geogrid reinforced soil retaining wall . Model tests and numerical simulations were used to better understand the structural behavior of geogrid reinforced retaining walls under static loads with a deformation buffer zone . The lateral displacement of geogrid reinforced soil retaining walls with deformation buffer zone decreased .The increase in horizontal soil pressure occurred acting on the face plate of geogridreinforced soil retaining wall. The horizontal and vertical soil pressures had a nonlinear patternalong the length of the reinforcement, with a reduced value towards the face panel. The geogrid's cumulative strain had a single peak distribution over its length; the highest strain was 0.45 percent, and the peak tension was around 29.12 percent of ultimate tensile strength.

Rowe et. Al. (2001) studied a geosynthetic reinforced retaining wall which was analyzed by finite element method. For this scenario, the friction angle here between backfill and the wall facing was estimated to be somewhere between 30 and 45°. When relative to a rigid foundation, a very compressible and weak foundation layer can substantially increase deflections at the wall's face and base, reinforcement layers' strain, and, to a minor extent, vertical stresses at the wall's toe. The horizontal stresses were the only characteristic that was unaffected by strength or the stiffness of the foundation.

Chen et.al.(2013)examined the efficiency and sustainability of a geocell-reinforced retaining structures using a numerical model in this research. For the analysis, a built in model was used which incorporated Mohr-Coulomb yield criterion for nonlinear elastic stress strain relation. Corresponding results in potential slip surfaces and evaluating critical loads under which the wall is on the verge of failure indicate good agreement in the validation of the numerical model. The lateral deflections of the walls are similarly comparable between the model and the analytical results. the lateral earth pressures, In Rankine's active state, against the rear of the wall facing were slightly greater than the horizontal stress, but those at the rear of the reinforced region remained similar to the earth pressures at rest.

Holtz et.al.(2017) reviewed evolution of a geosynthetic reinforced soil slopes and wall. The resulting reinforcement tension must be assessed directly for soil–geosynthetic interaction behavior; else, the interaction parameters are only a suggestion. In plane strain, the Unit Cell Device is the only instrument that can do this. Because of the strength of both the geosynthetic and the sand are utilized more or less equally, geosynthetics are a far more effective reinforcement material than steel. Creep of GRS structures is not a concern at working stresses, which is not the case with geosynthetic reinforcement. When the loading stops, the geosynthetic releases, causing GRS to distort.

Latha et.al.(2006) investigated the geocell reinforcement benefits on the efficiency of earth embankments through laboratory model experiments, built on deficient foundation soil and suggested a straightforward approach for designing geocell-supported embankments. For the introductory design of embankments supported by geocells, a easy method depended on slope stability analysis was presented, substituting the geocell layer with a surface soil of equal properties in the study. according to stability analysis of the experimental prototype embankments with respective observed surcharge capacities, the empirical approach is comparatively better in representing the secant modulus and geocell dimension effect.

On the basis of literature review, following research gaps are observed –

1) The development of lateral deflection and vertical deflection
2) Geogrids along with other structures for improvement of deflections of retaining wall

An attempt has been made to work in this direction in order to fill the observed research gap. The study on numerical modelling on retaining wall on many aspects is described in the following chapters, keeping the aims in mind.

CHAPTER 3
MATERIALS AND METHODS

In this study, a retaining wall reinforced with geogrid is analyzed in Plaxis 2D software. Then, it is again analyzed along with tie anchor to testify its stability in the soil possibly. Plaxis is a finite element software. To investigate different stability, deformation, ground water flow etc. this software has been developed and used exceptionally in geotechnical, structural engineering.

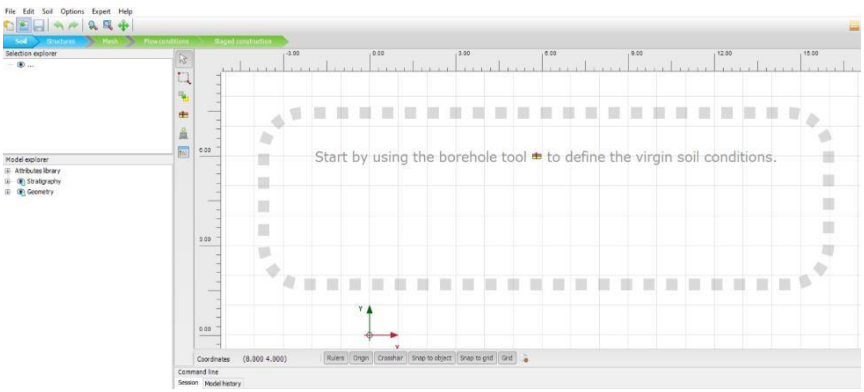

Figure 3.1 Basic Layout of Plaxis 2D

Plaxis software version v20 is used in the study. Total 45 test models have been examined and analyzed. For simulating the soil clusters plane strain model of 15 node elements were used.

3.1 FINITE ELEMENT RETAINING WALL MODEL

All the models were made in Plaxis software. The height of the wall varies from 4m and 5m. The standard geometry of the retaining wall of height 4m is shown in the figure 3.2.

3.2 FINITE ELEMENT MATERIAL PROPERTIES

Mohr Coulomb Model - This specific model generally requires five input parameters. They are Modulus of elasticity, Poisson’s ratio, angle of friction, cohesion and dilatancy angle. There is no consideration of water table and Mohr coulomb model is applied in this study to investigate the stability of walls. Loading is 20 kN. It is not varying. With the Mohr Coulomb failure criterion, the MC model depicted a linearly elastic–perfectly plastic material; the characteristics for this model are stated in Table 3.1.

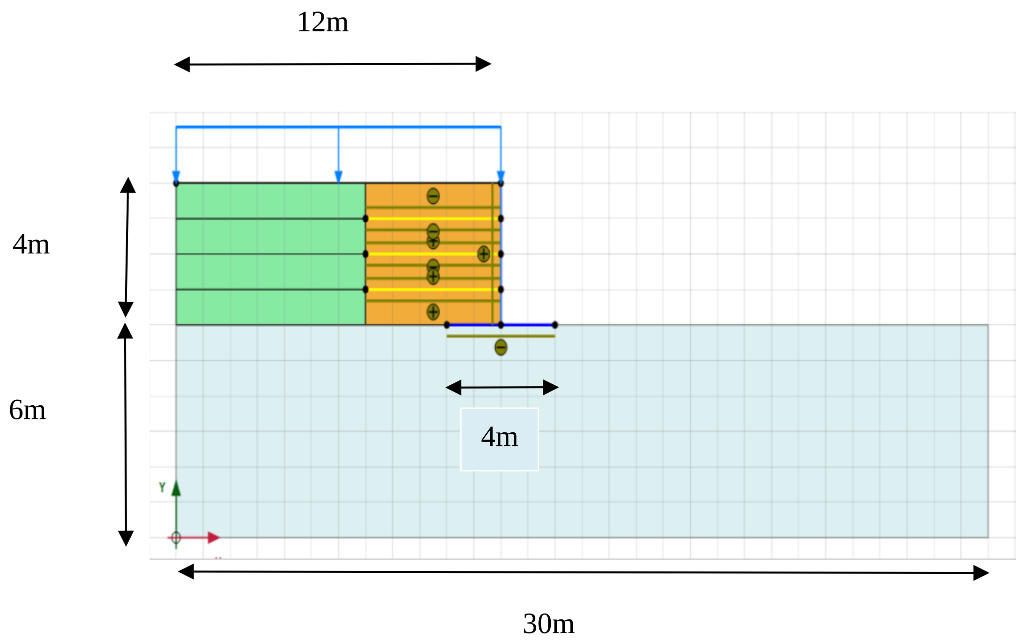

Figure 3.2 Geometry of MSE wall

Table 3.1 Finite Element Material Properties (Kibria et al. 2014; Kong et al. 2013)

Material	Mass Density $\gamma_{unsaturated}$ (kg/m^3)	$\gamma_{saturated}$ (kg/m)	Elastic Modulus E (kN/m^2)	Cohesion (kN/m^2)	Internal Angle of Friction φ (°)	Angle of Dilation ψ(°)
Geogrid soil	19	20	30,000	1	34	-
Backfill Soil	19	20	12,500	1	34	4
Found Soil	16	16	5500	8.45	27	0

Table 3.2 Finite Element Plate Properties (Kibria et al. 2014; Kong et al. 2013)

Material	Flexural Rigidity EI (kN m^2/m)	Normal Rigidity EA (kN/m)	Weight W (kN/m/m)
Foundation block	370000	18000000	0.15
Concrete facing	11000	5000000	38

Table 3.3 Finite Element tie anchor properties (Muhammed et. al. 2017)

Material	Flexural Rigidity EI (kN m^2/m)	γ (kN/m^3)	Dia (m)	Normal Rigidity EA (kN/m)
Grout body	2500000	24.90	0.0250	-
Anchor	-	-	-	200000

3.3 METHODS

The study has been conducted to investigate improvement of the stability of the retaining wall. So here we have taken 3 different heights of the wall which are 4m, 5m and 6m.

Along with varying height there are some difference in the properties of geogrids have been made too. First of all the stiffness of geogrid has been compared then the vertical spacing of the geogrid has been changed too. These studies have been done by FE model prepared in plaxis 2D software.

Tie anchors are also known as a good support to reduce deflection of retaining structures. So when we are combining it with geogrids, what happens is also checked here. After studying the geogrids behavior node to node anchor was combined with the geogrid and investigated.

3.4 MECHANISM OF GEOGRID

The geogrid's desired reinforcing effect is achieved by a variety of techniques.

3.4.1 LATERAL CONFINEMENT

By interconnecting with soil, it restricts horizontal bulk movement and provides lateral confinement. It improves rigidity allowing a higher load to be applied at the same deformations. It reduces vertical stresses imparted to the sub soil and increases horizontal stress.

3.4.2 INCREASE OF LOAD DISTRIBUTION ANGLE

The use of geogrid provides for a greater load distribution angle beneath the rails, reducing the pressure exerted to the subgrade and therefore reducing settlements and deformations.

3.4.3 TENSION MEMBER EFFECT

A loading capacity is created, which is an upward vertical force and helps to sustain the imposed load, reducing the stress on the soil.

CHAPTER 4

RESULTS AND DISCUSSION

In total, 45 simulations were processed. At first without providing any geogrid stability of retaining wall was examined, after that geogrid was applied and by changing stiffness of geogrid, vertical spacing of geogrid and varying height of wall simulations were done. Overall deflections of wall laterally and vertically, factor of safety were observed. Tie anchor has been attached with the geogrids and again lateral and vertical deflections were examined along with factor of safety. Figure 4.1 to Figure 4.54 give lateral and vertical deflection pictures of 2-D models with geogrids.

4.1 CASE 1: WITHOUT GEOGRIDS

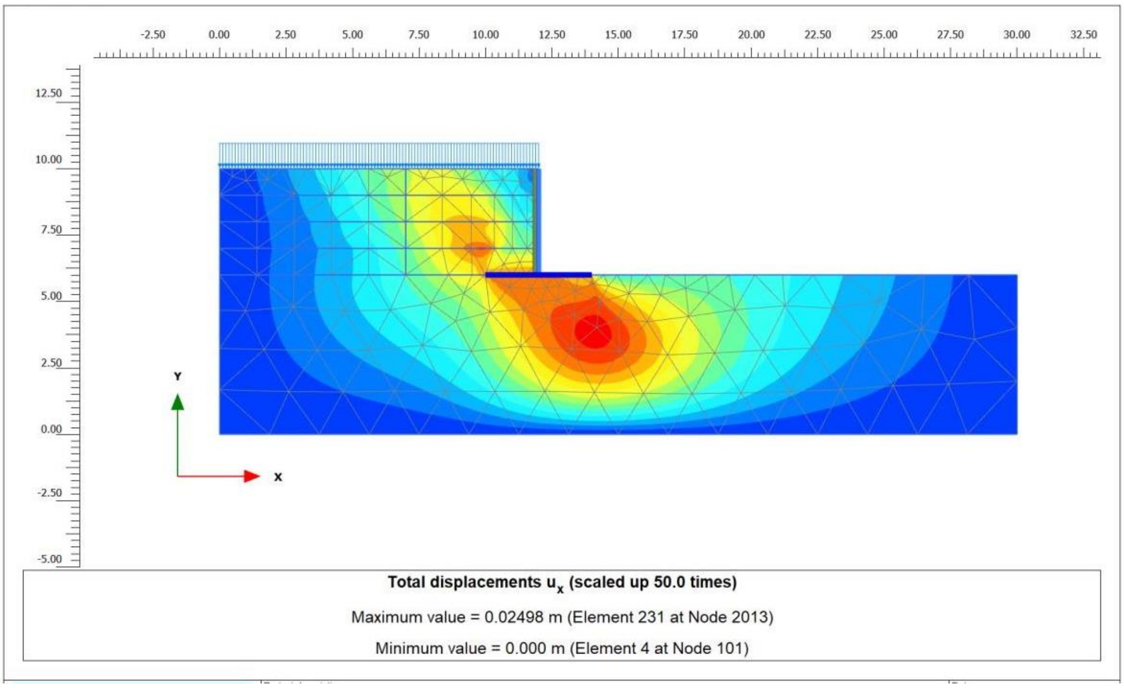

Fig. 4.1 Lateral deflection of 4m high retaining wall without geogrid

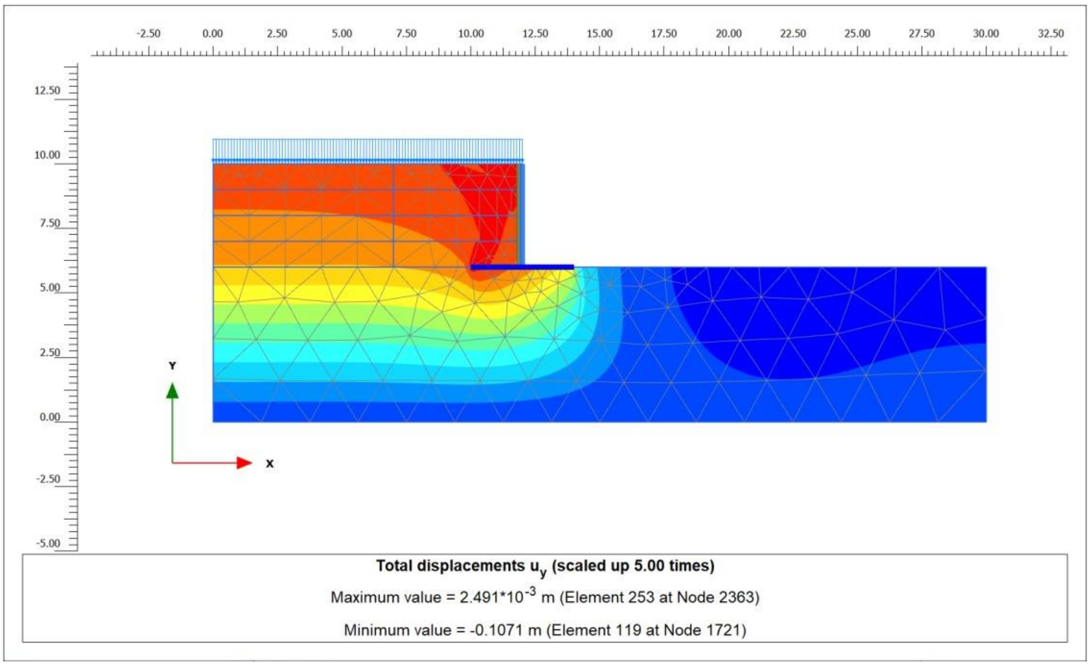

Fig. 4.2 Vertical deflection of 4m high retaining wall without geogrid

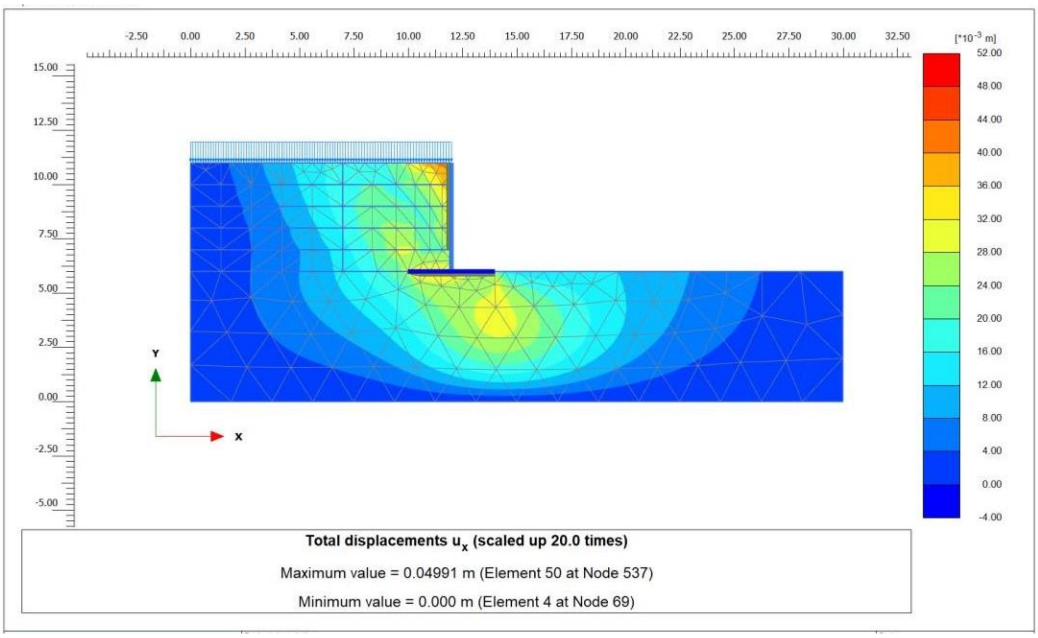

Fig. 4.3 Lateral deflection of 5 m high retaining wall without geogrid

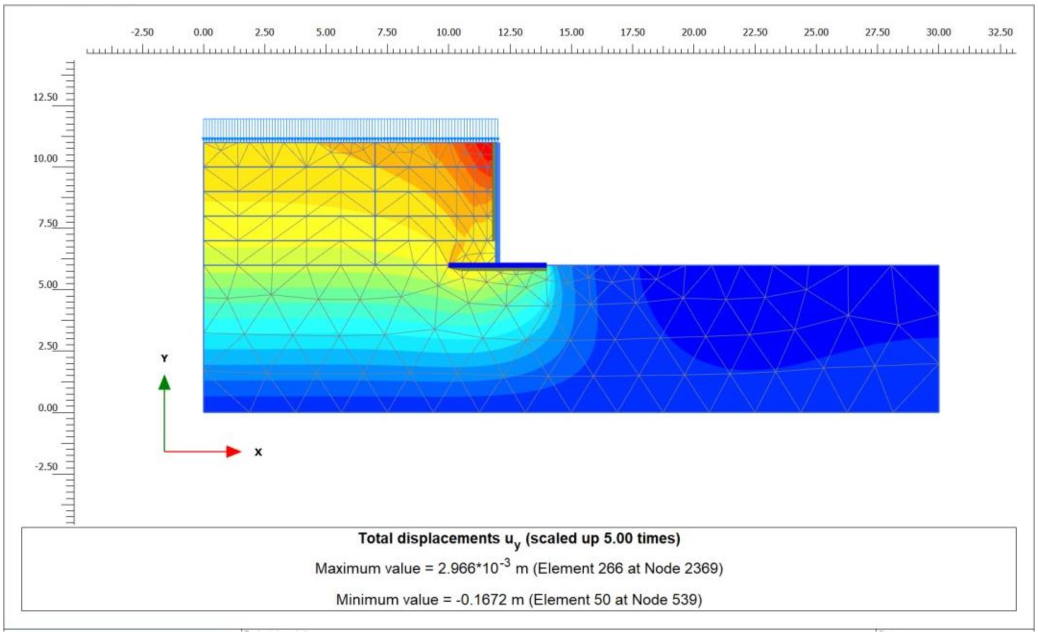

Fig. 4.4 Vertical deflection of 5m high retaining wall without geogrid

4.2 CASE 2: VERTICAL SPACING BETWEEN TWO GEOGRIDS ARE 1M

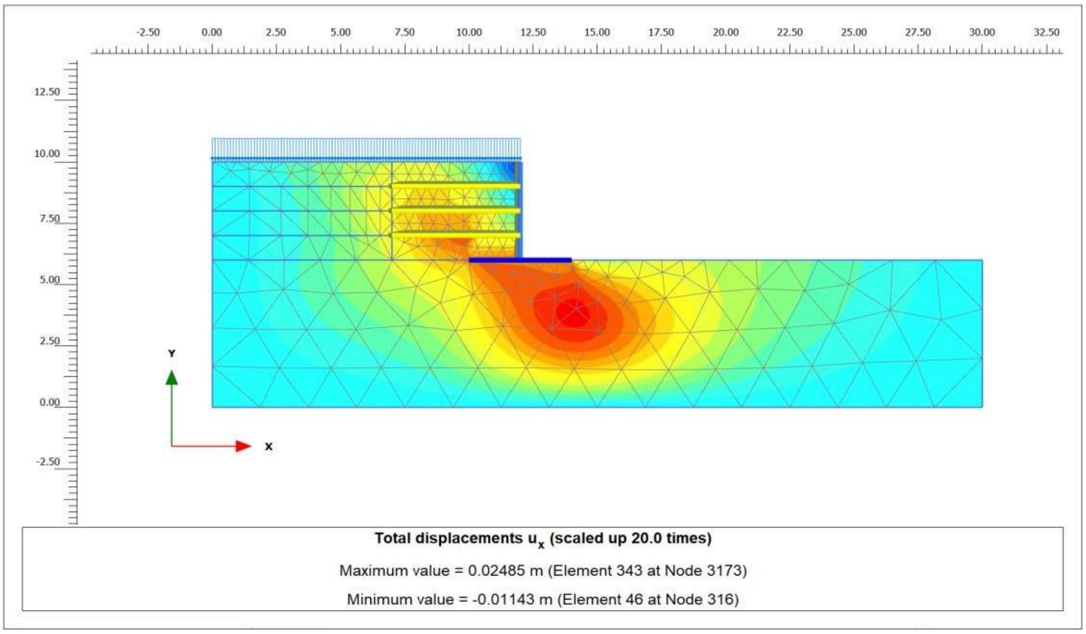

Figure 4.5 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 1m

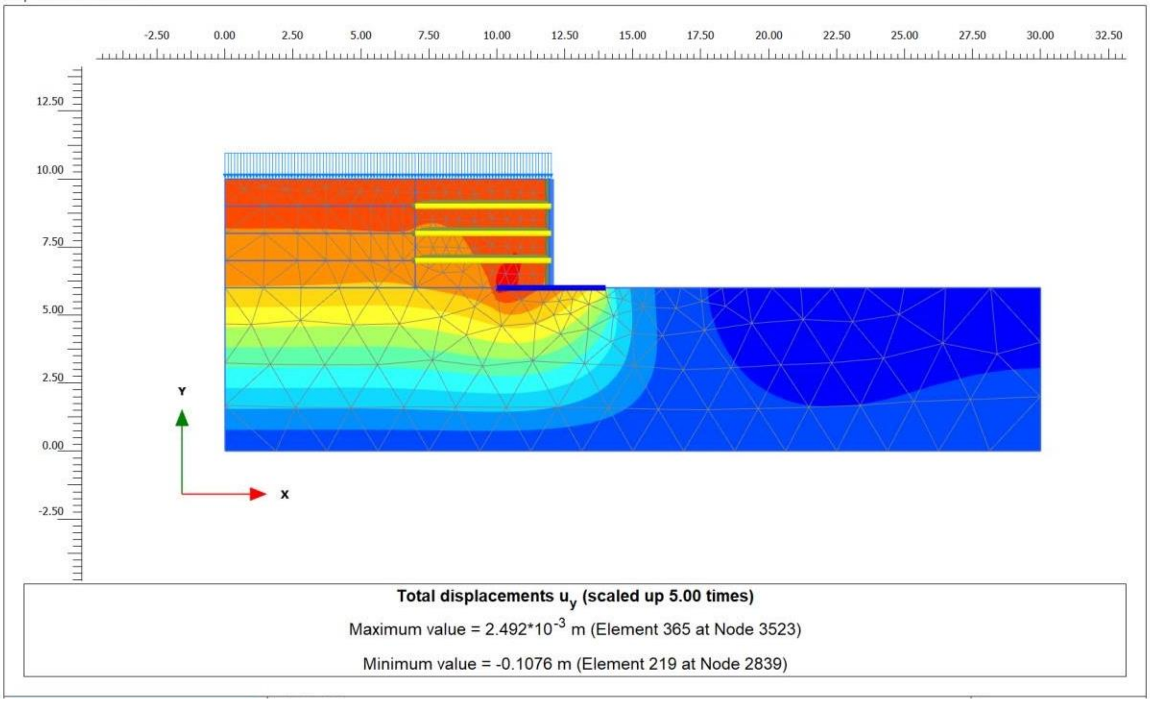

Figure 4.6 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness 7000(kN/m)) with vertical spacing 1m

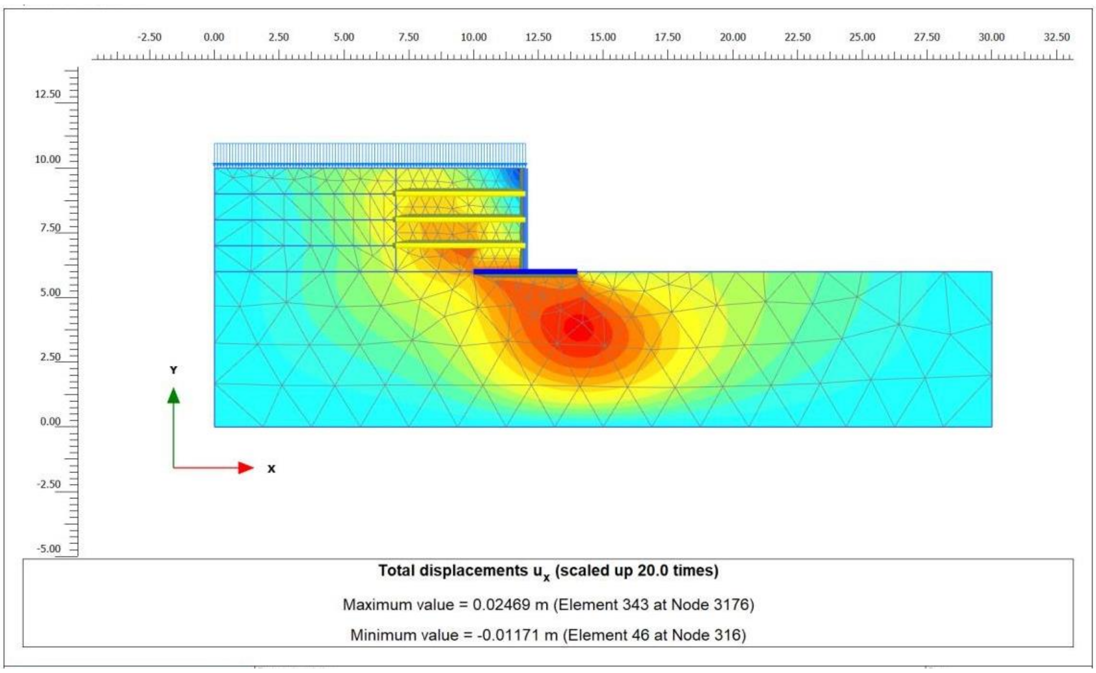

Figure 4.7 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness 9000(kN/m)) with vertical spacing 1m

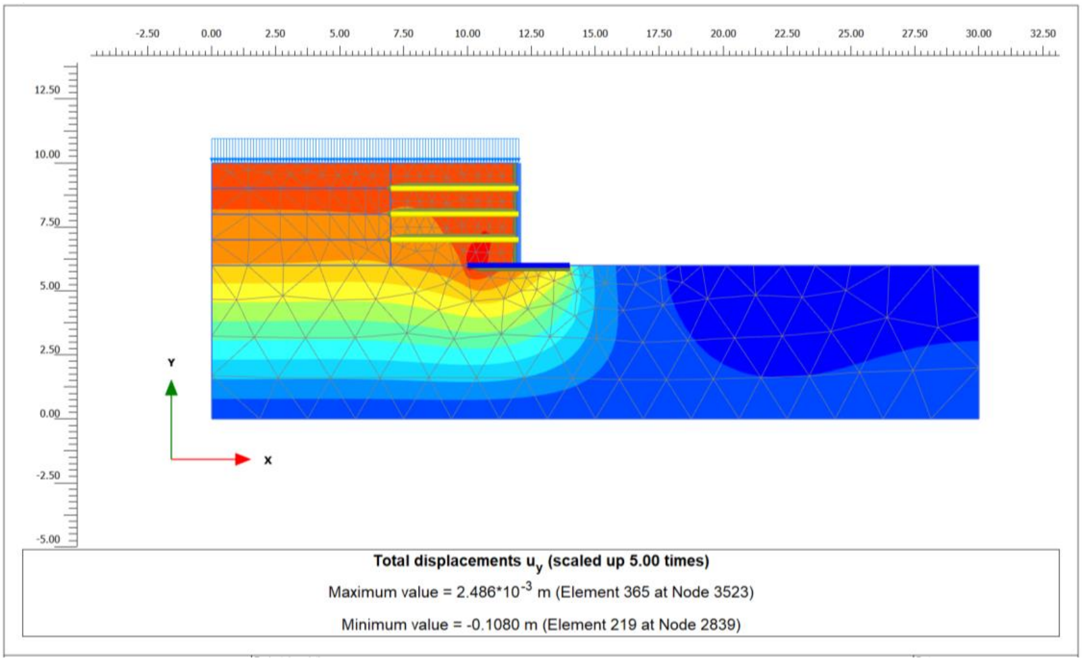

Figure 4.8 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 1m

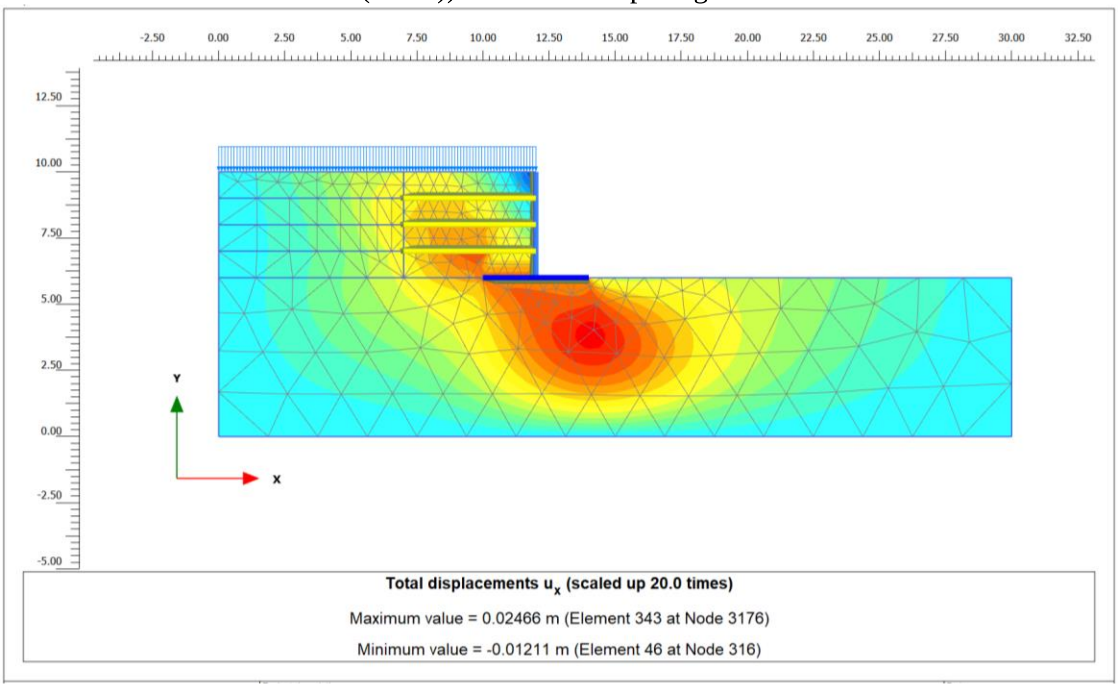

Figure 4.9 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness12,000 (kN/m)) with vertical spacing 1m

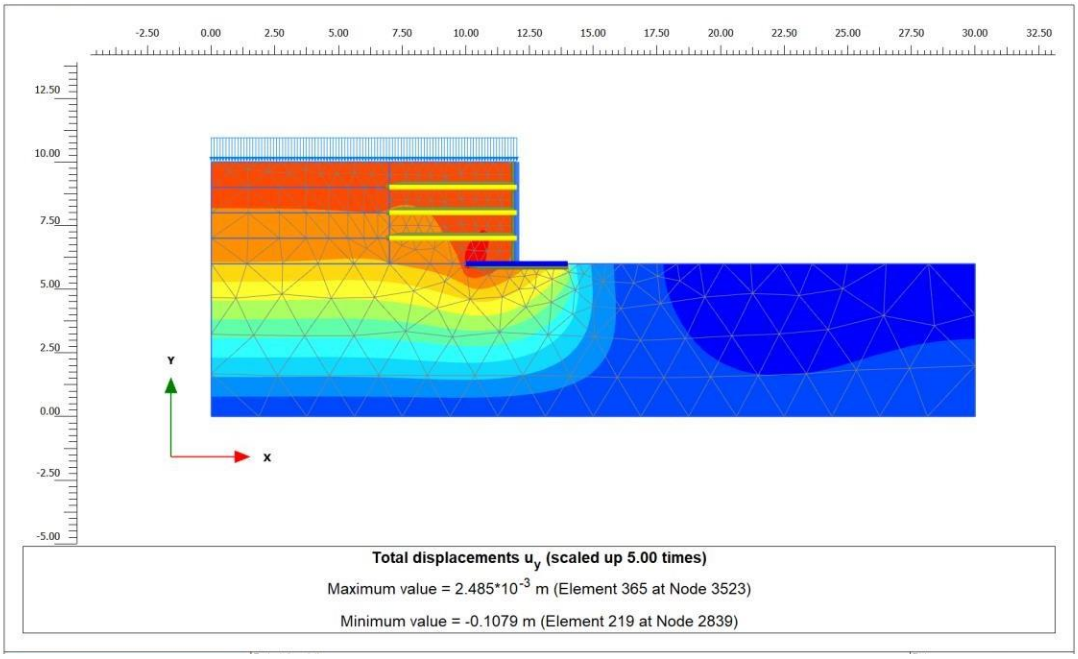

Figure 4.10 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 1m

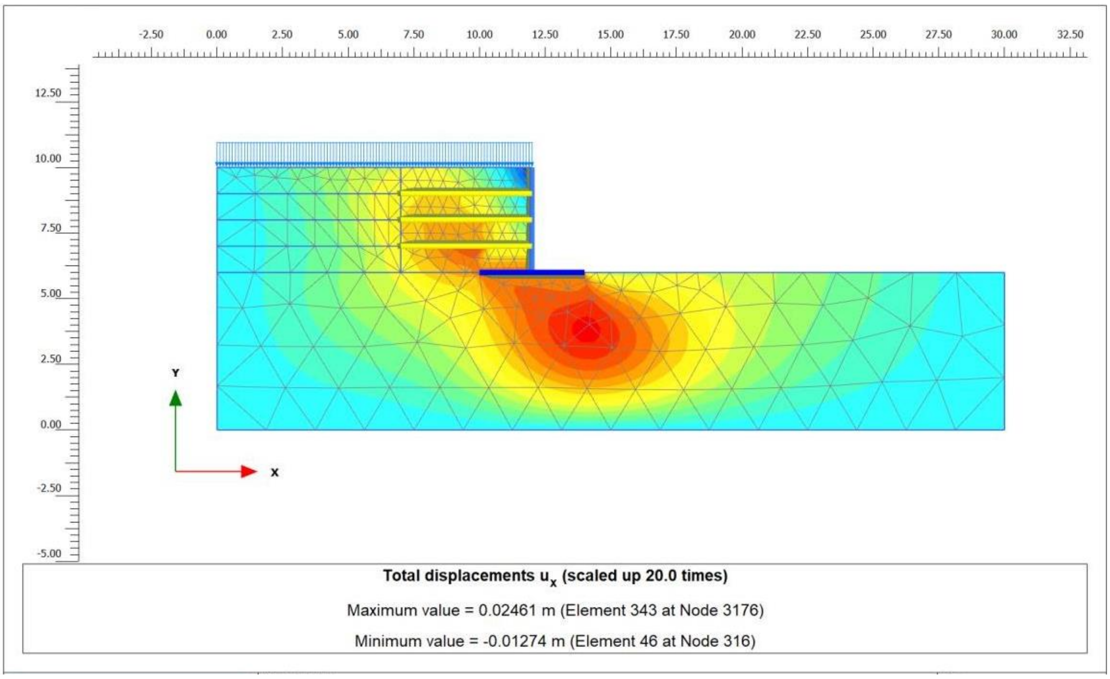

Figure 4.11 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 1m

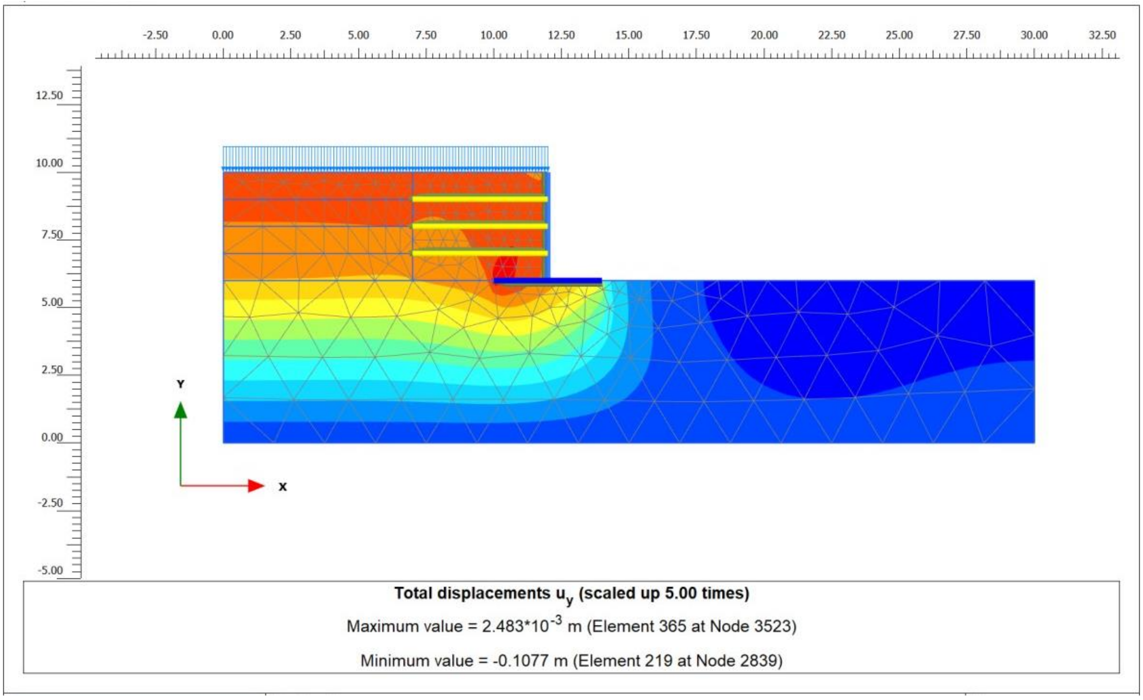

Figure 4.12 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 1m

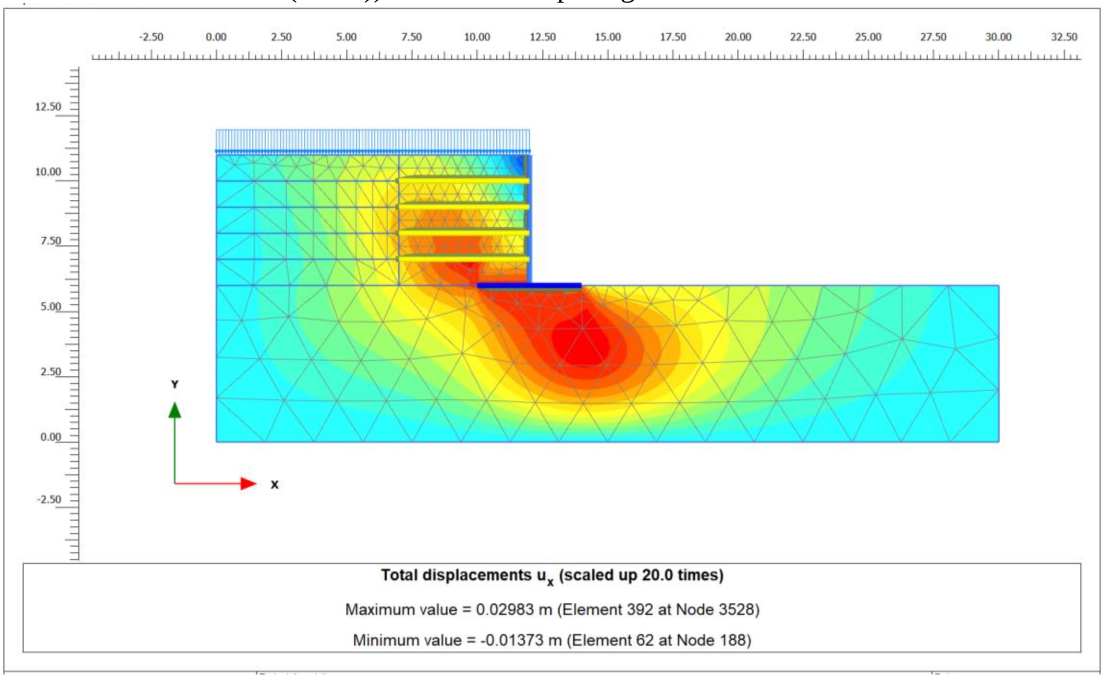

Figure 4.13 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 1m

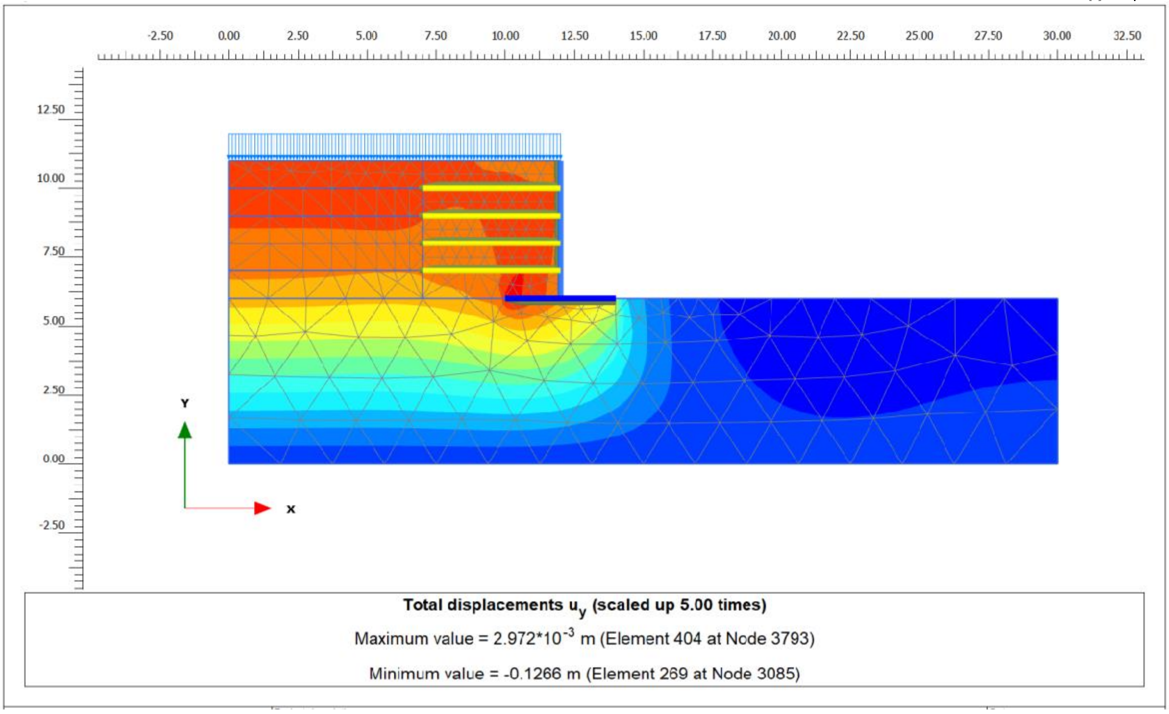

Figure 4.14 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 1m

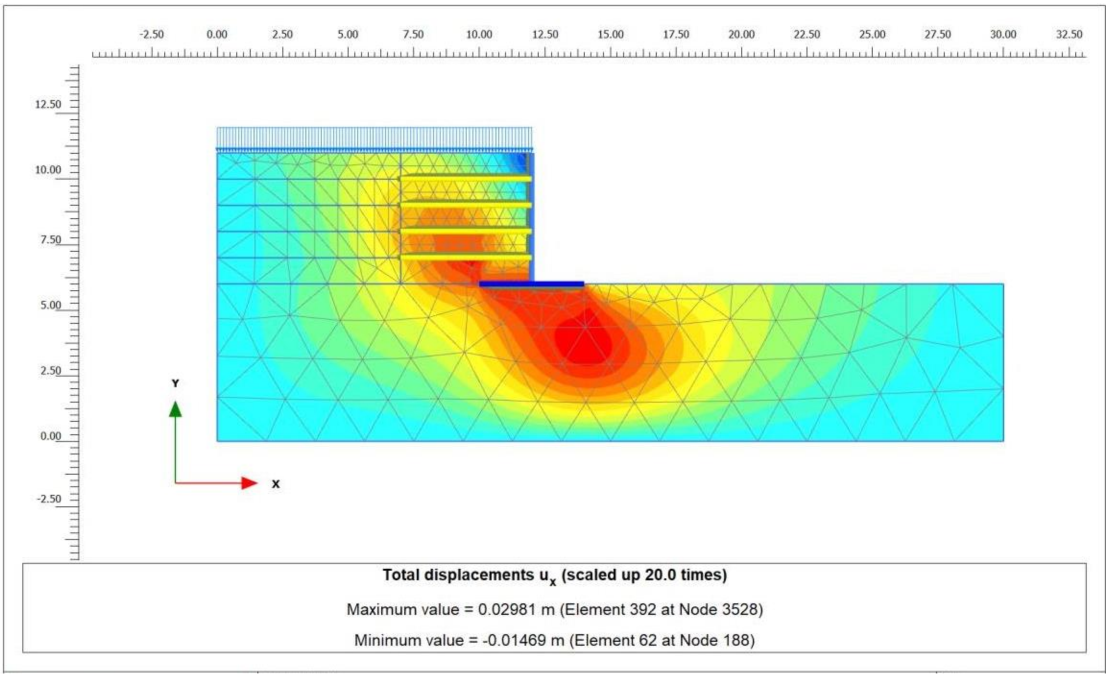

Figure 4.15 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 1m

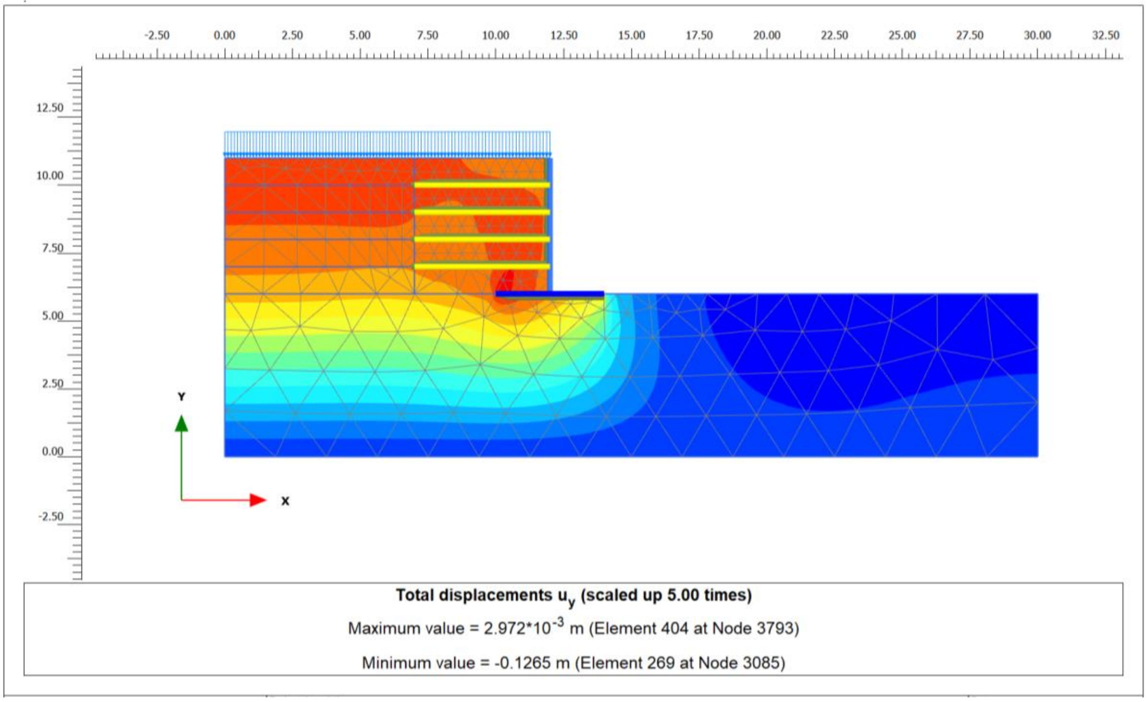

Figure 4.16 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 1m

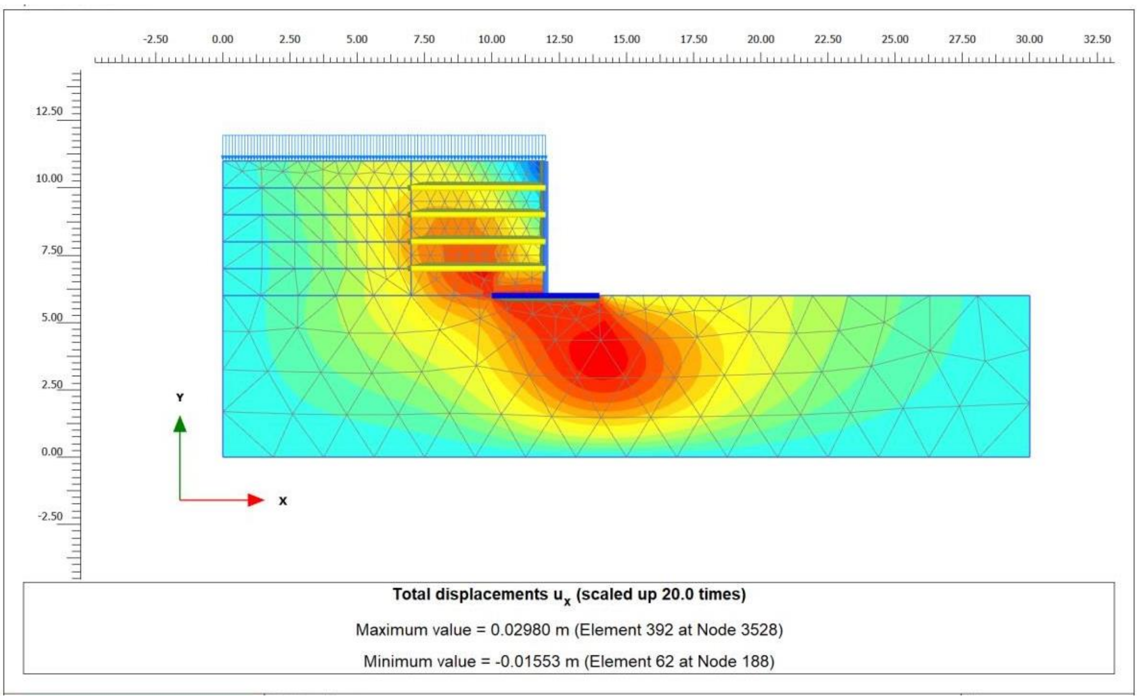

Figure 4.17 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 1m

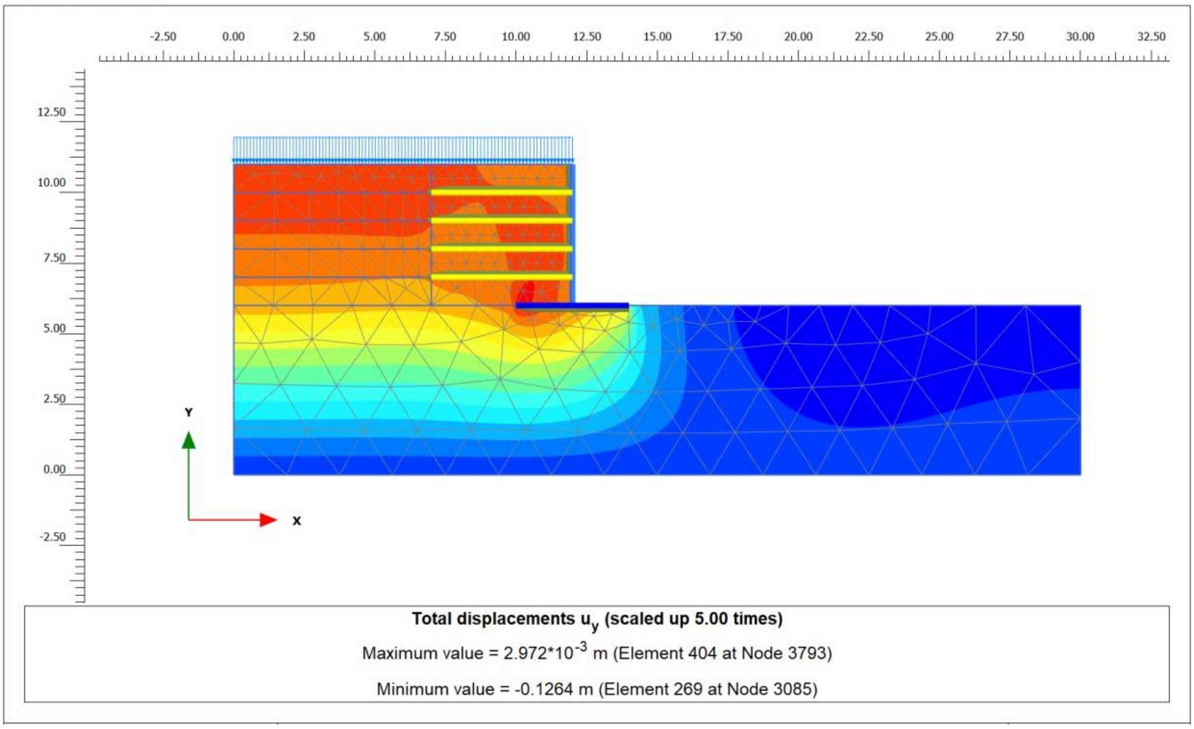

Figure 4.18 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 1m

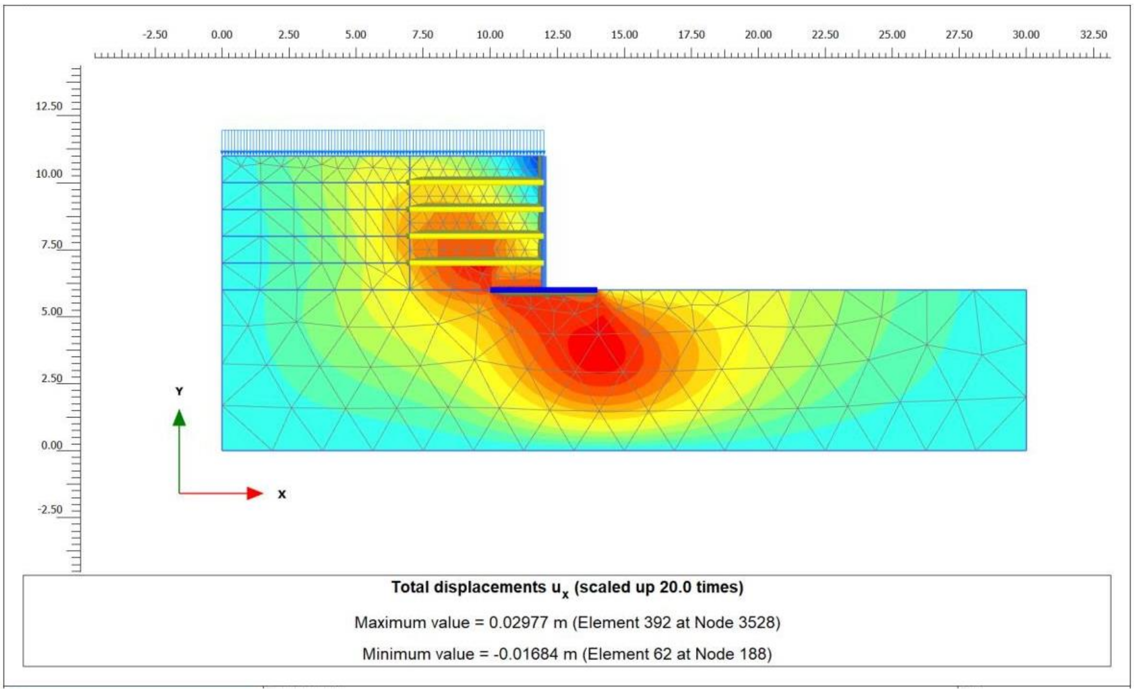

Figure 4.19 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 1m

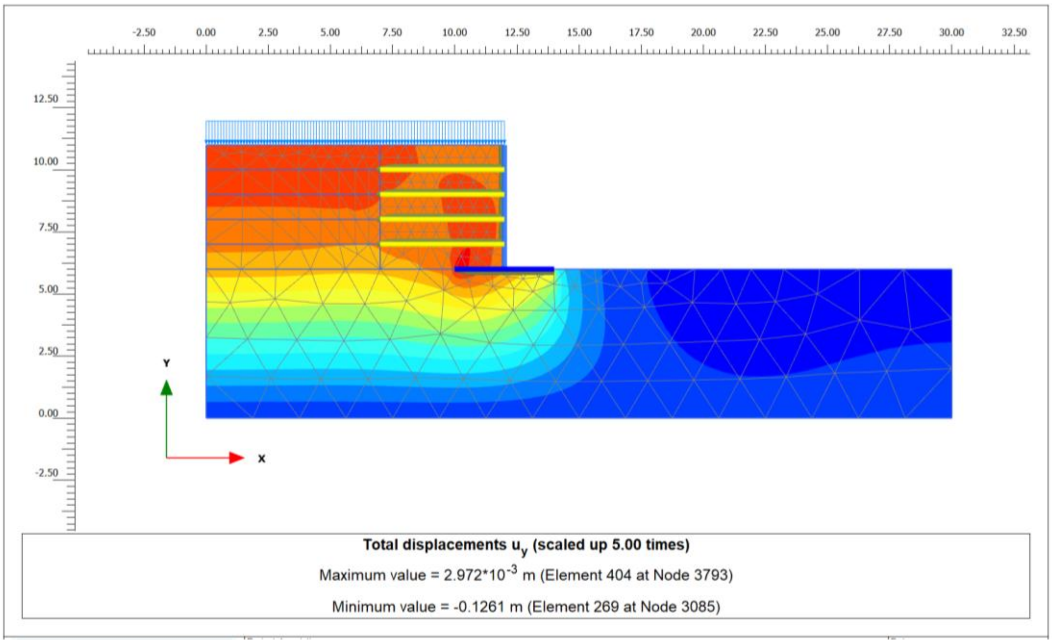

Figure 4.20 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 1m

4.3 CASE 3: VERTICAL SPACING BETWEEN TWO GEOGRIDS ARE 0.5 M

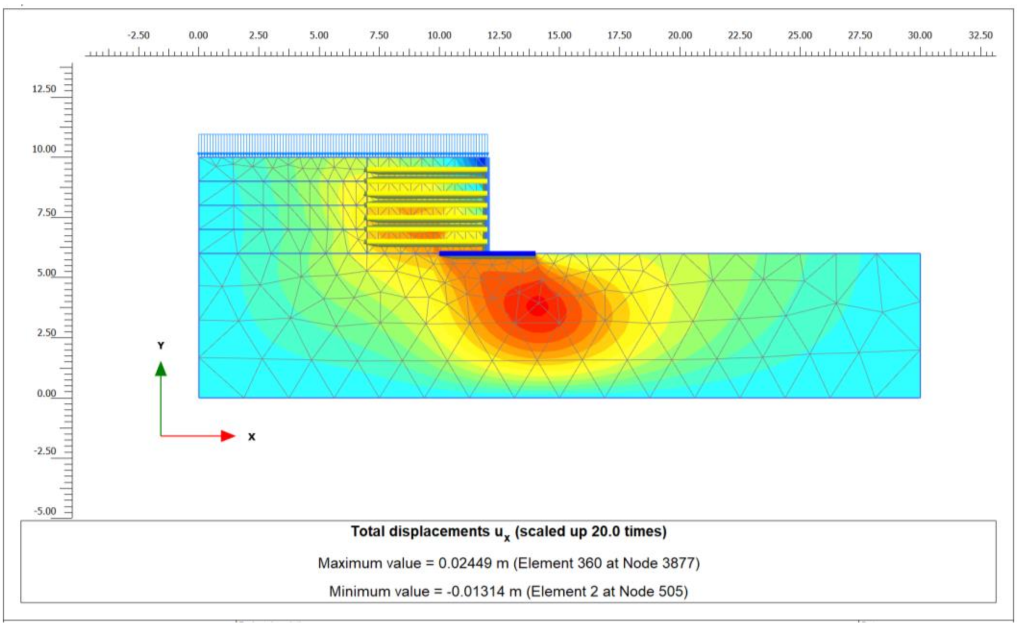

Figure 4.21 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.5m

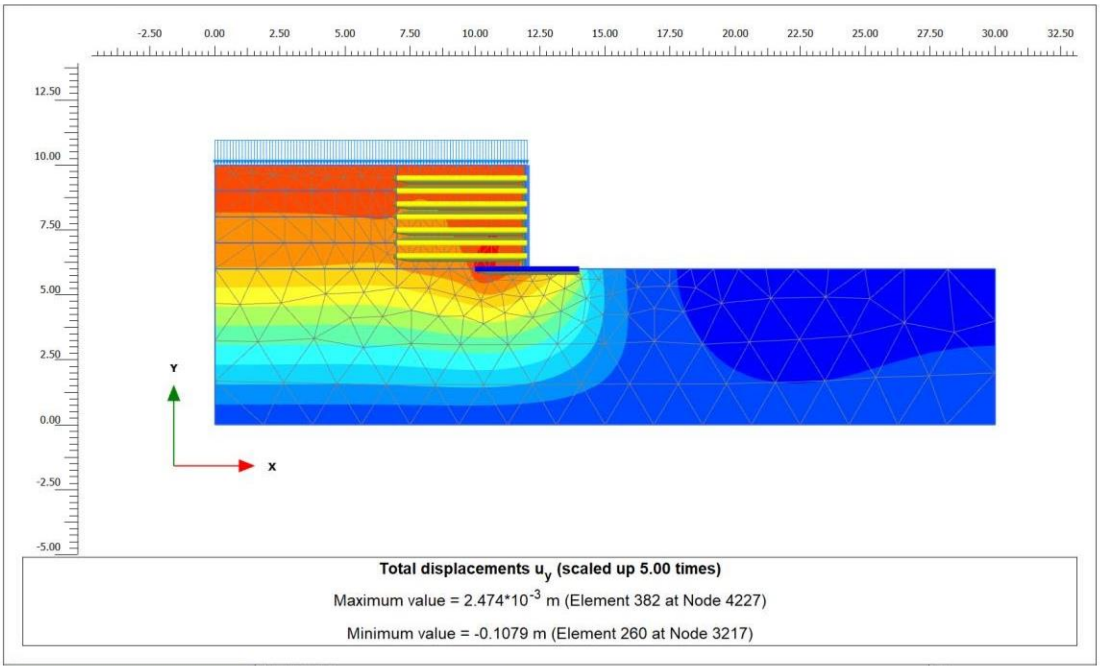

Figure 4.22 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.5m

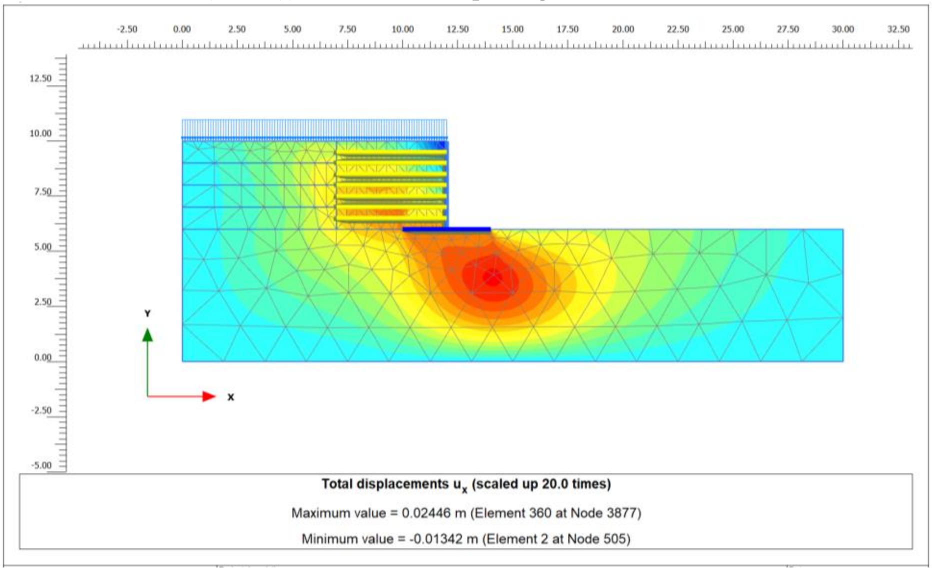

Figure 4.23 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.5m

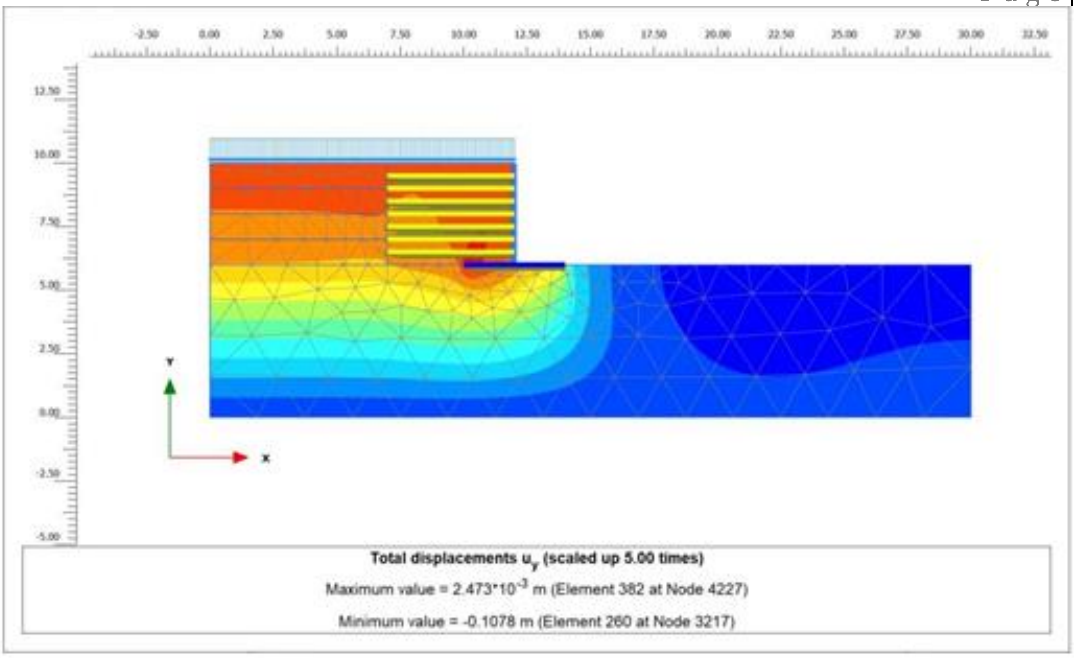

Figure 4.24 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.5m

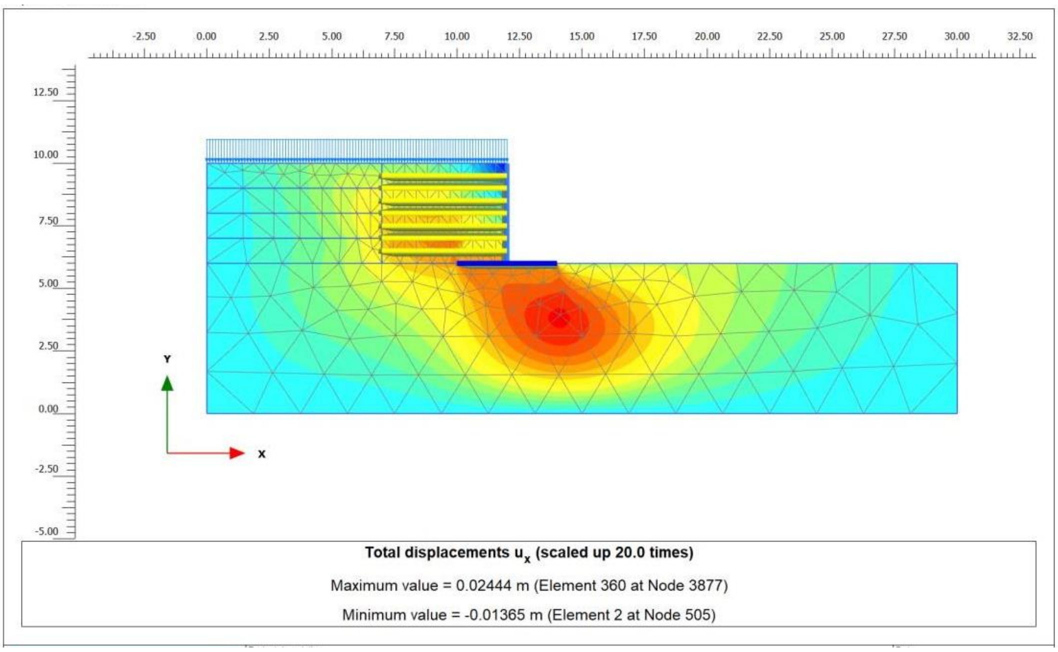

Figure 4.25 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 0.5m

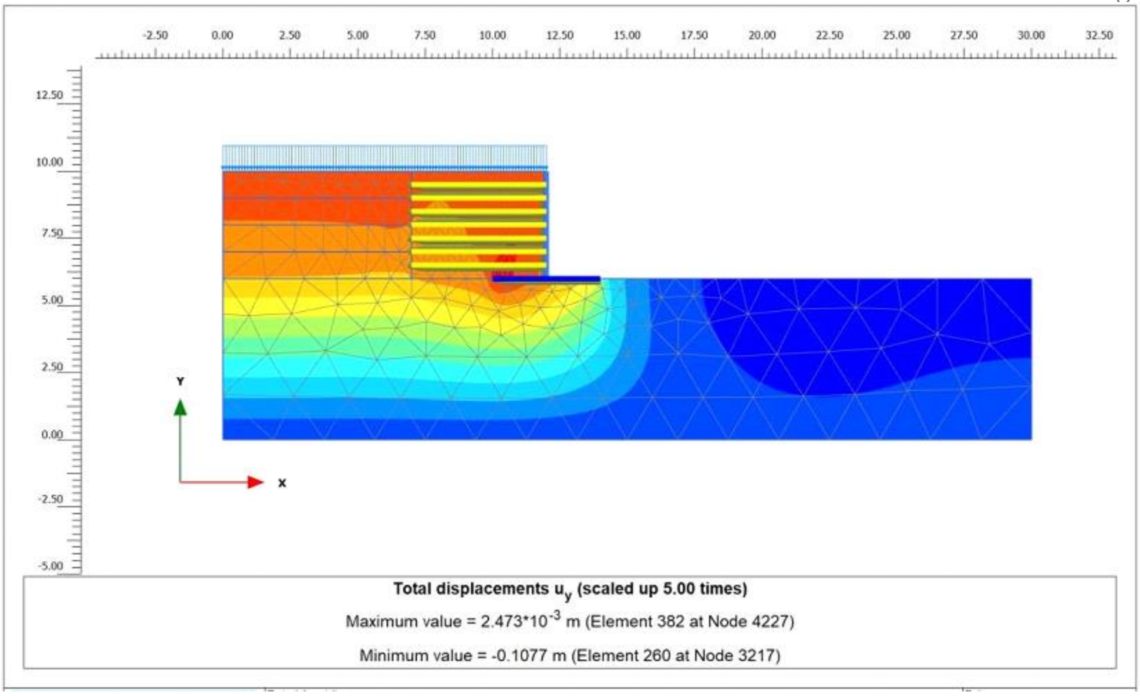

Figure 4.26 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness 12000 (kN/m)) with vertical spacing 0.5m

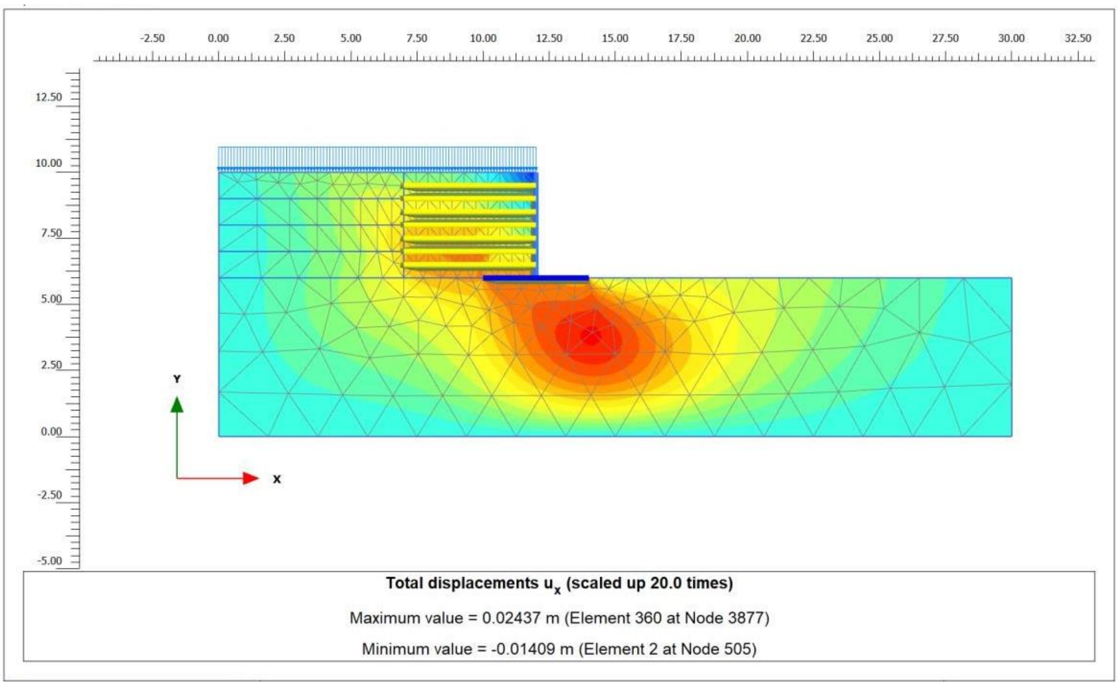

Figure 4.27 Horizontal deflection of 4m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.5m

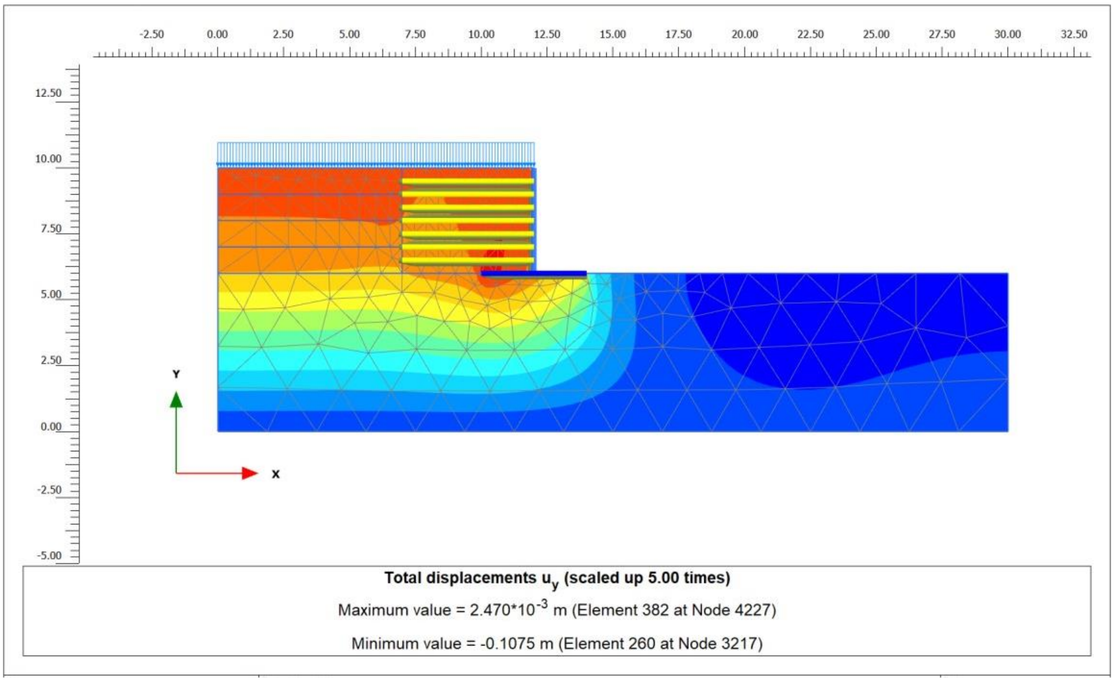

Figure 4.28 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.5m

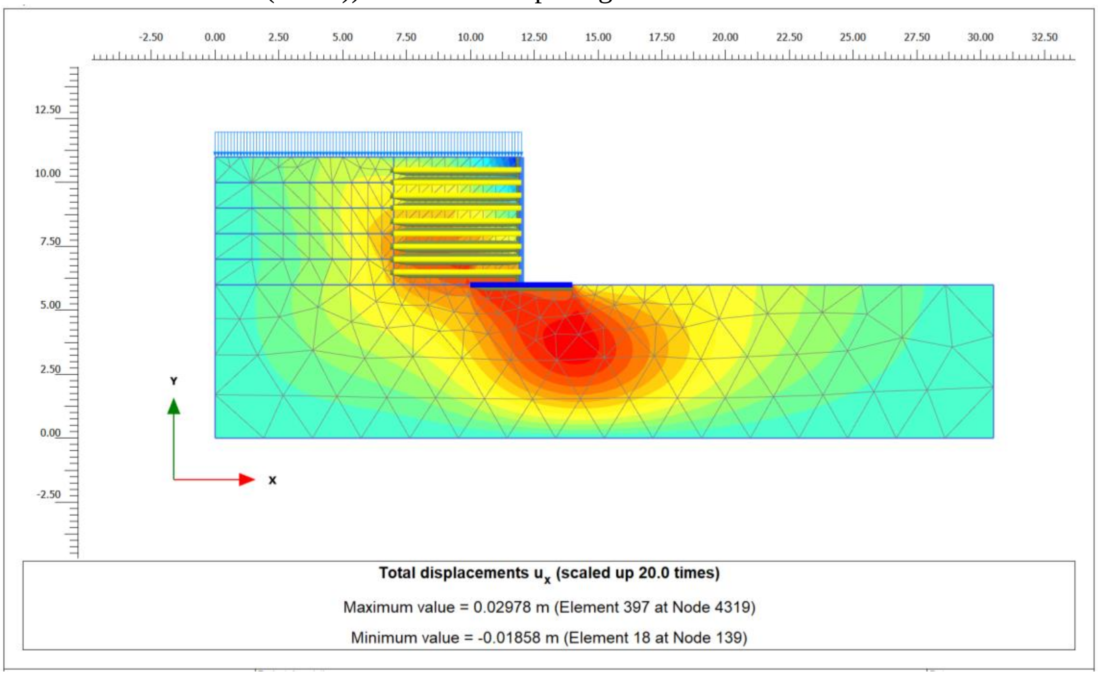

Figure 4.29 Horizontal deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.5m

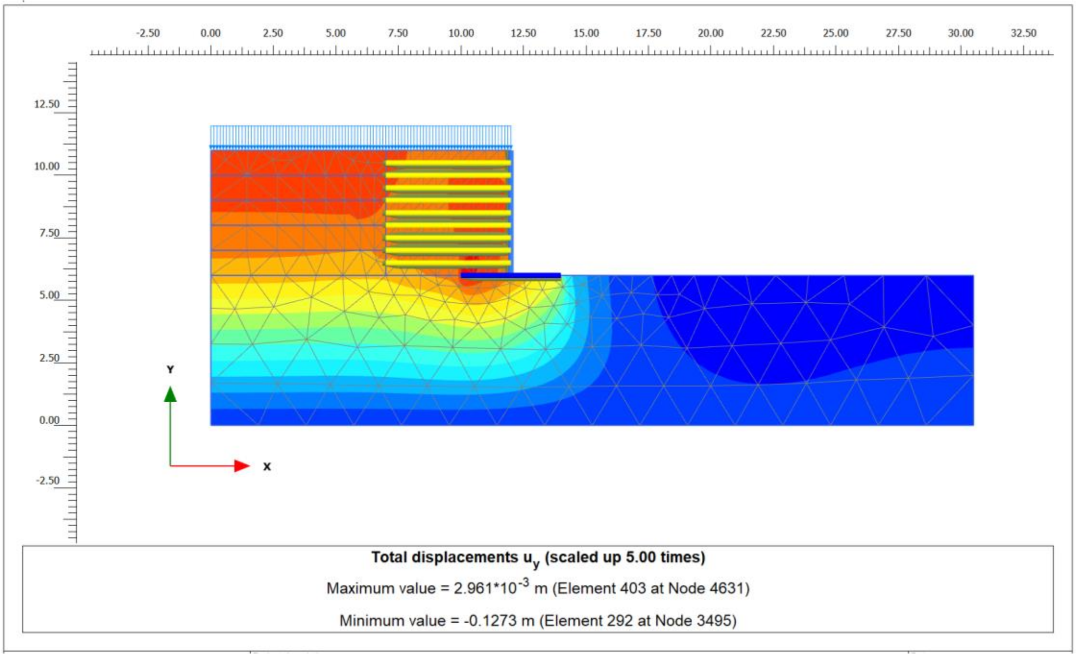

Figure 4.30 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.5m

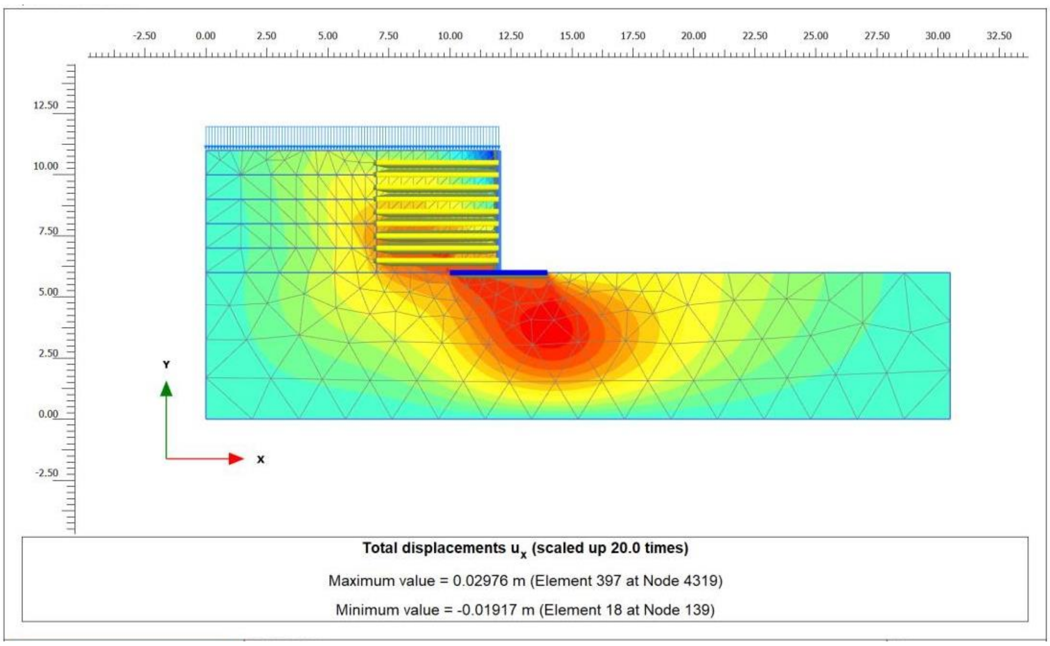

Figure 4.31 Horizontal deflection of 5m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.5m

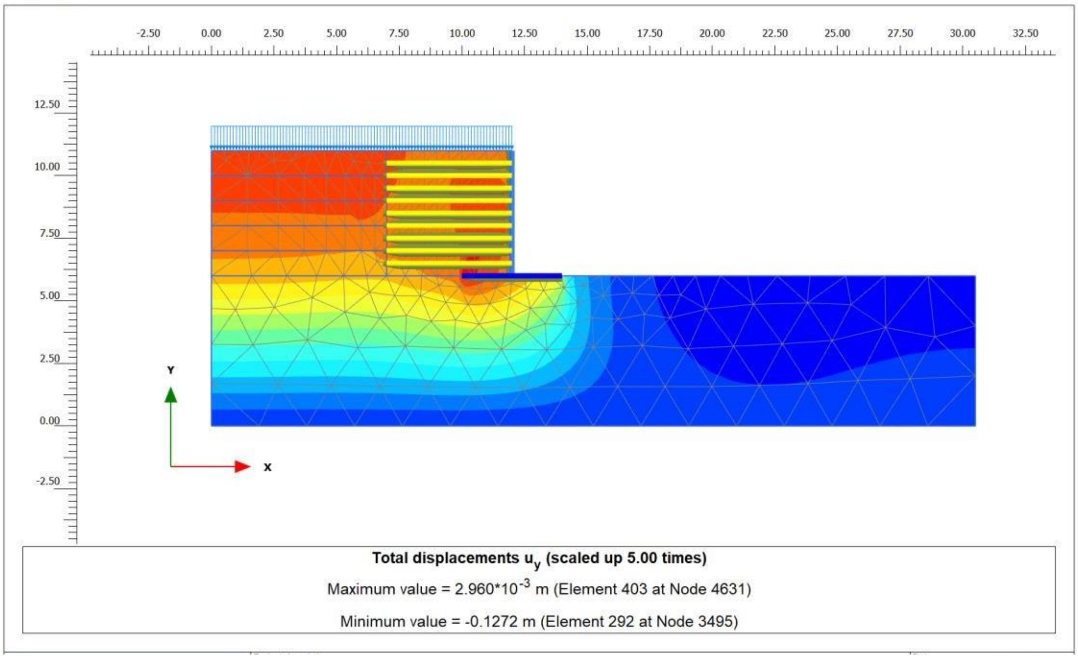

Figure 4.32 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.5m

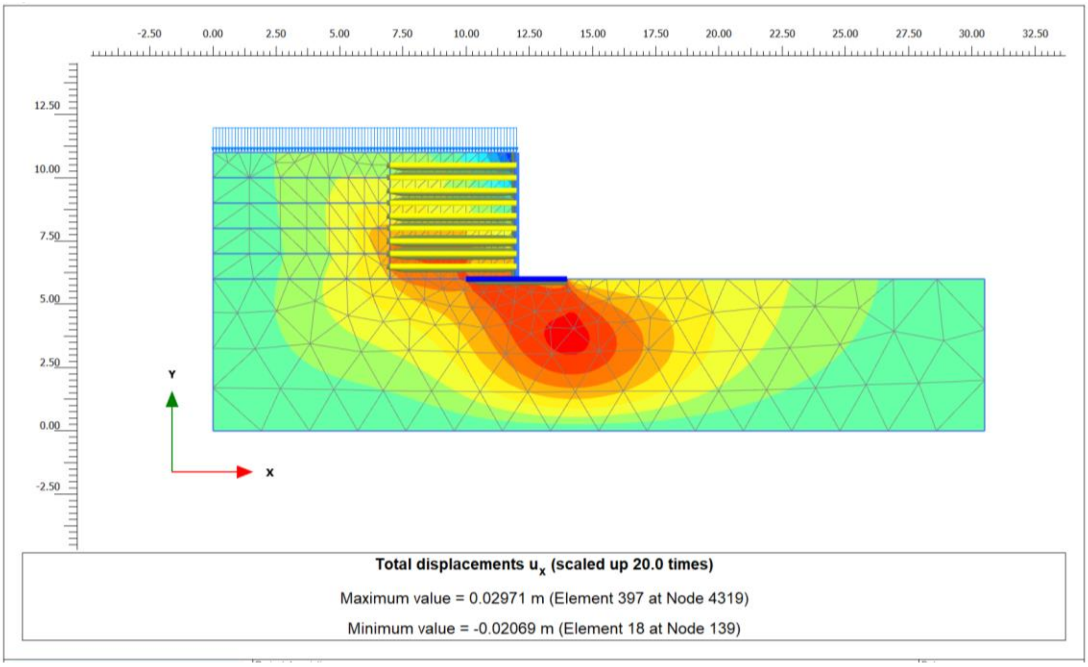

Figure 4.33 Horizontal deflection of 5m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.5m

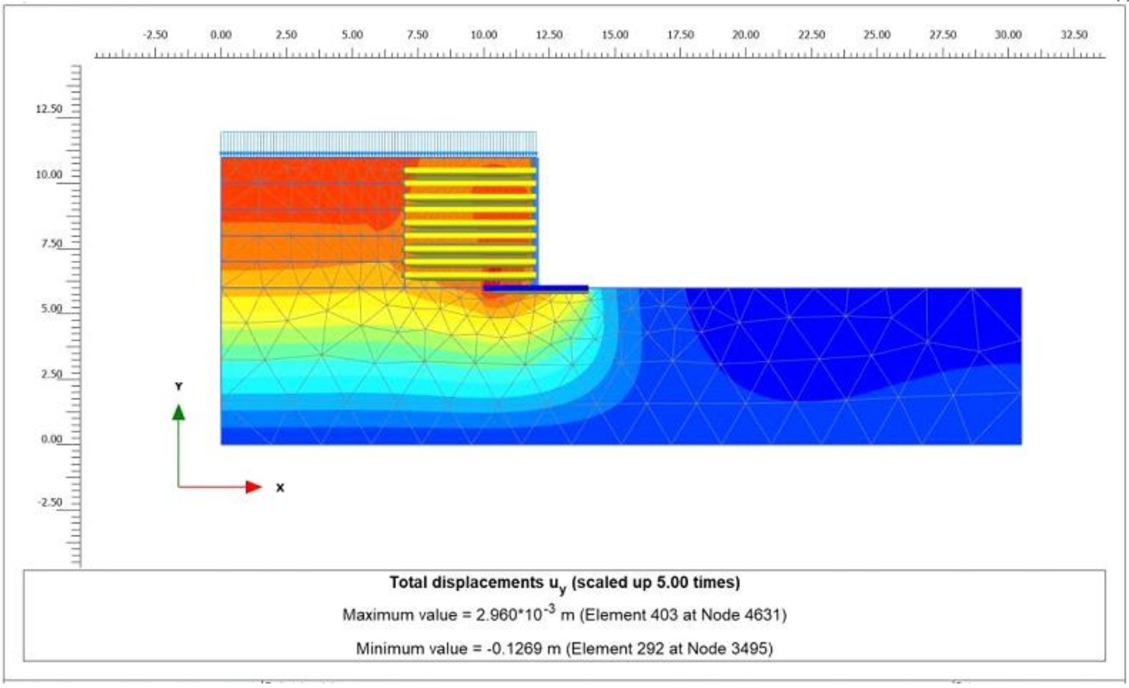

Figure 4.34 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.5m

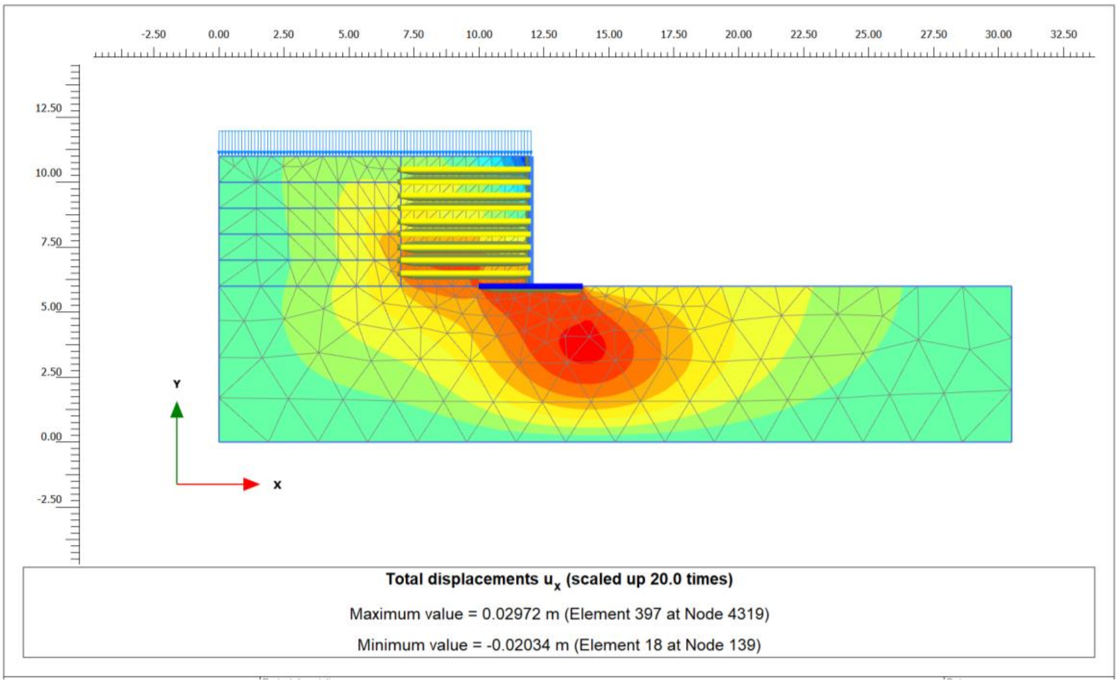

Figure 4.35 Horizontal deflection of 5m high retaining wall reinforced with geogrid (stiffness12000 (kN/m) with vertical spacing 0.5m

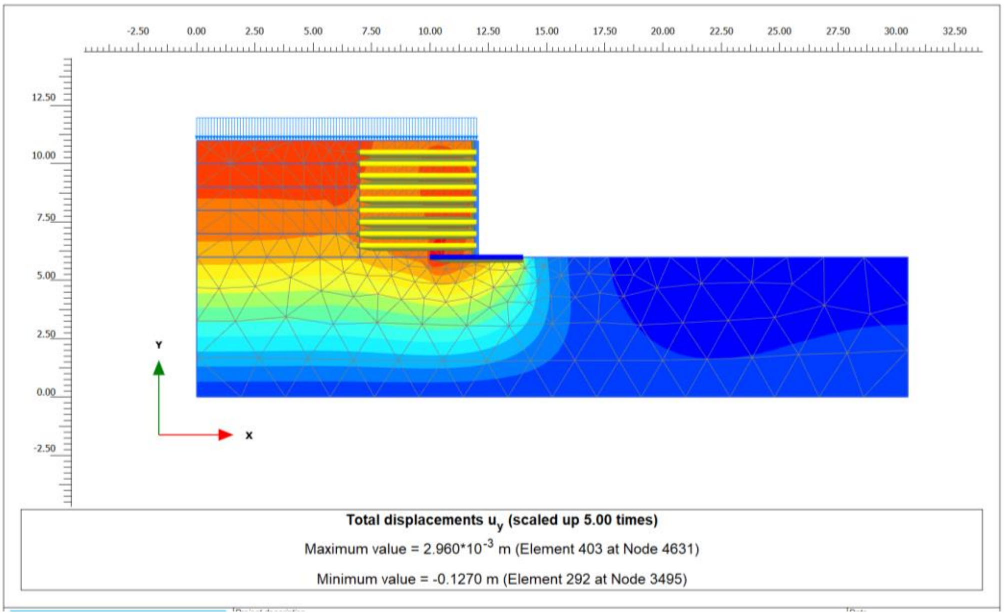

Figure 4.36 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 0.5m

4.4 CASE 4: VERTICAL SPACING BETWEEN TWO GEOGRIDS ARE 0.25 M

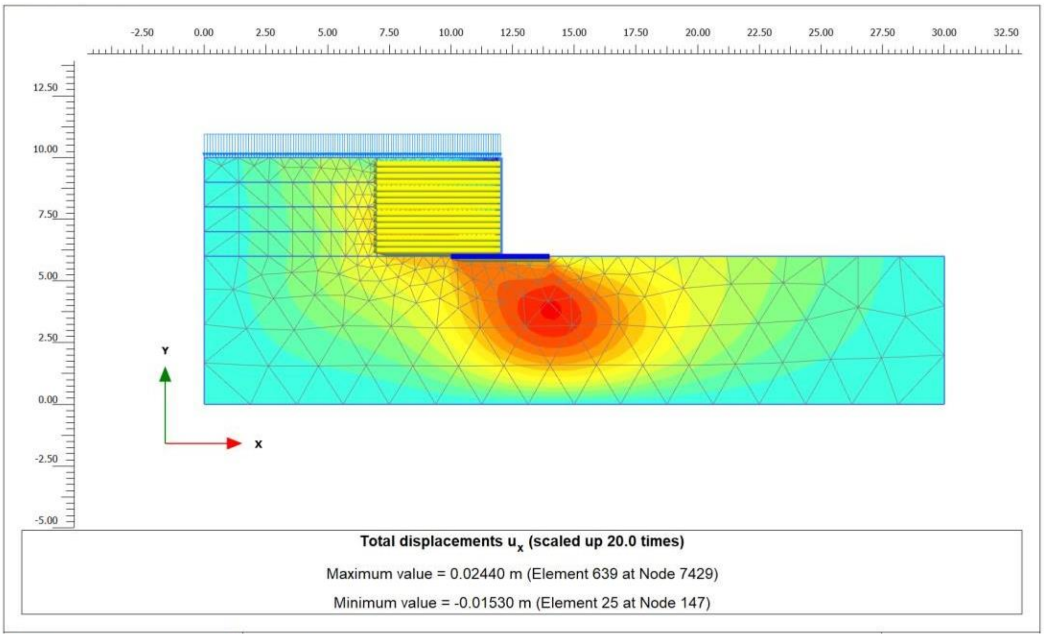

Figure 4.37 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.25m

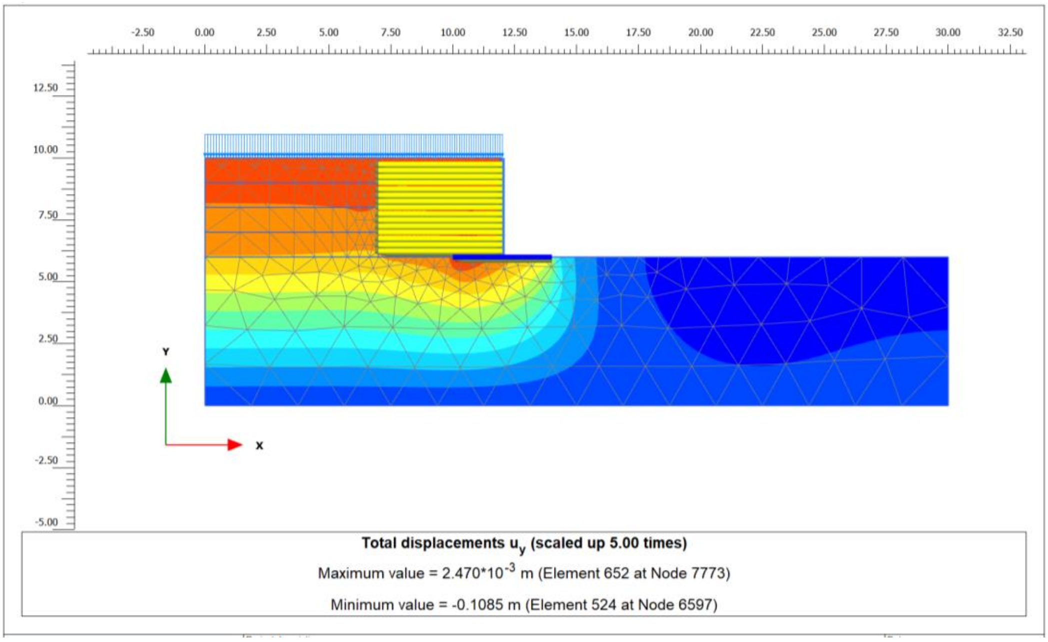

Figure 4.38 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.25m

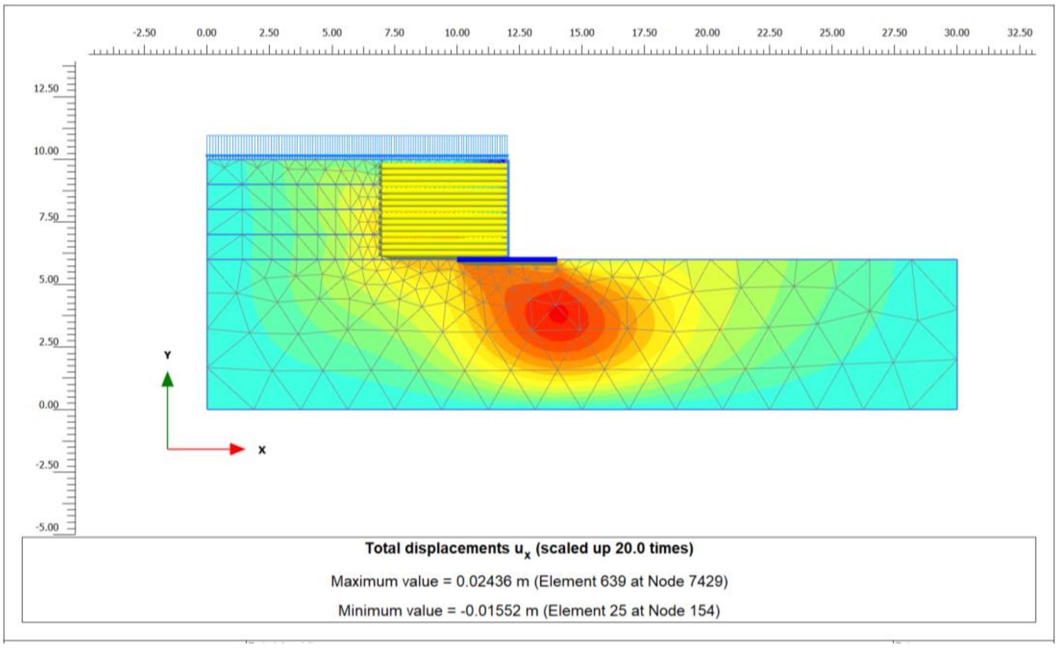

Figure 4.39 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.25m

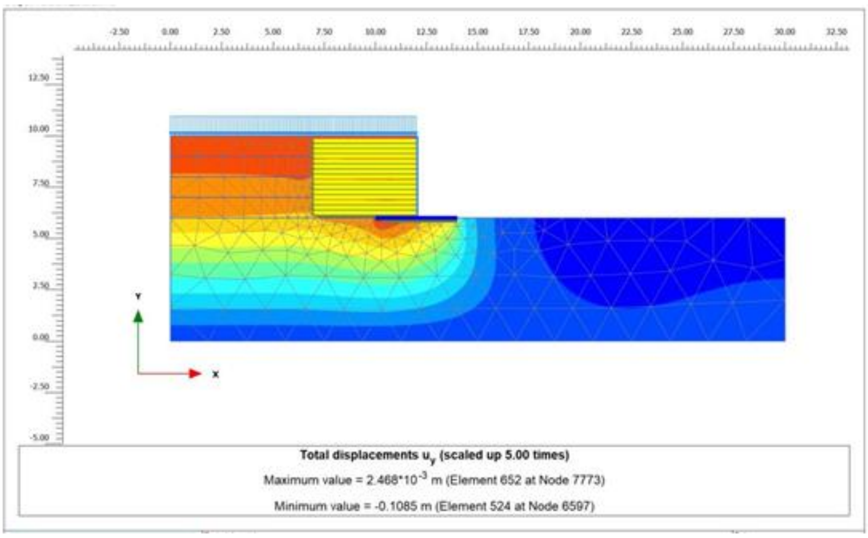

Figure 4.40 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.25m

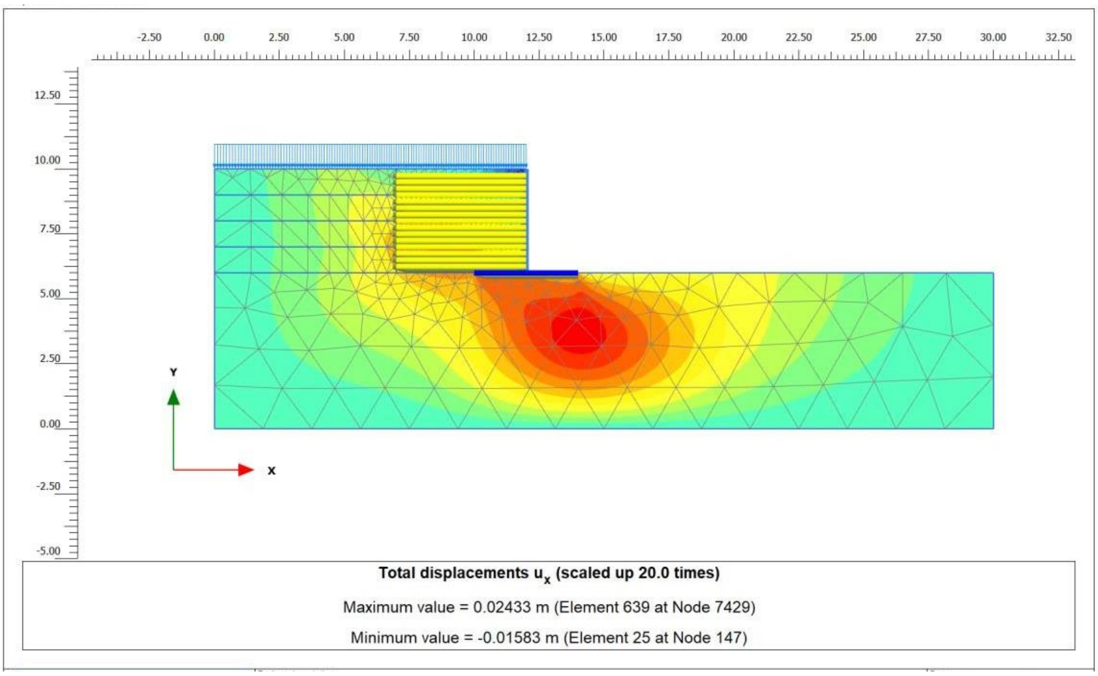

Figure 4.41 Lateral deflection of 4m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 0.25m

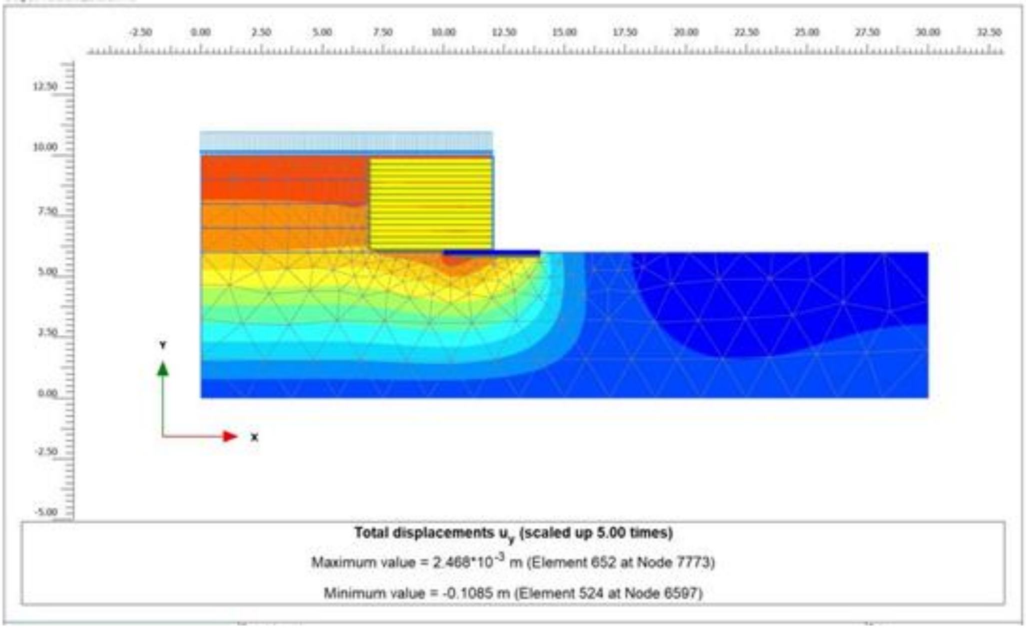

Figure 4.42 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 0.25m

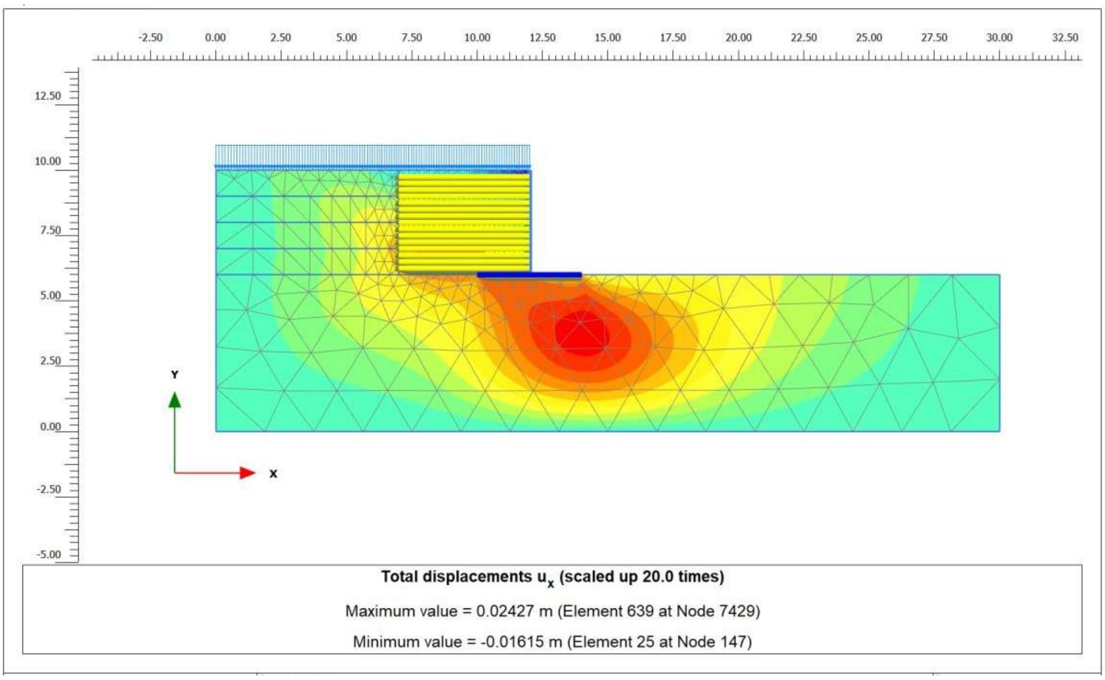

Figure 4.43 Horizontal deflection of 4m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.25m

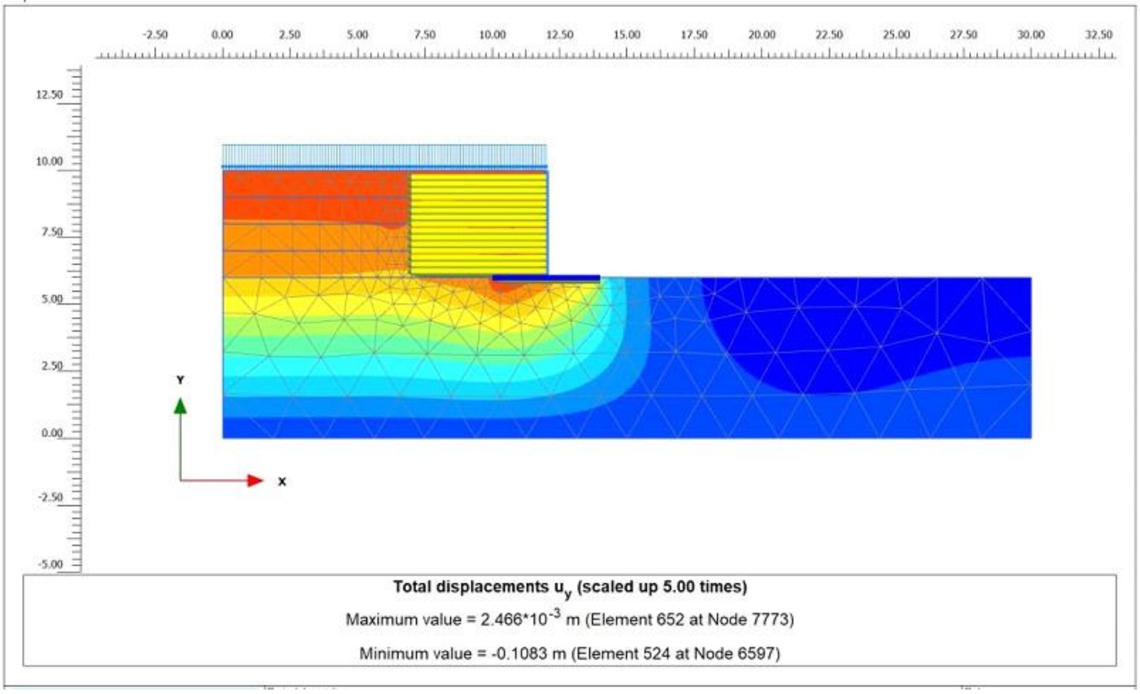

Figure 4.44 Vertical deflection of 4m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.25m

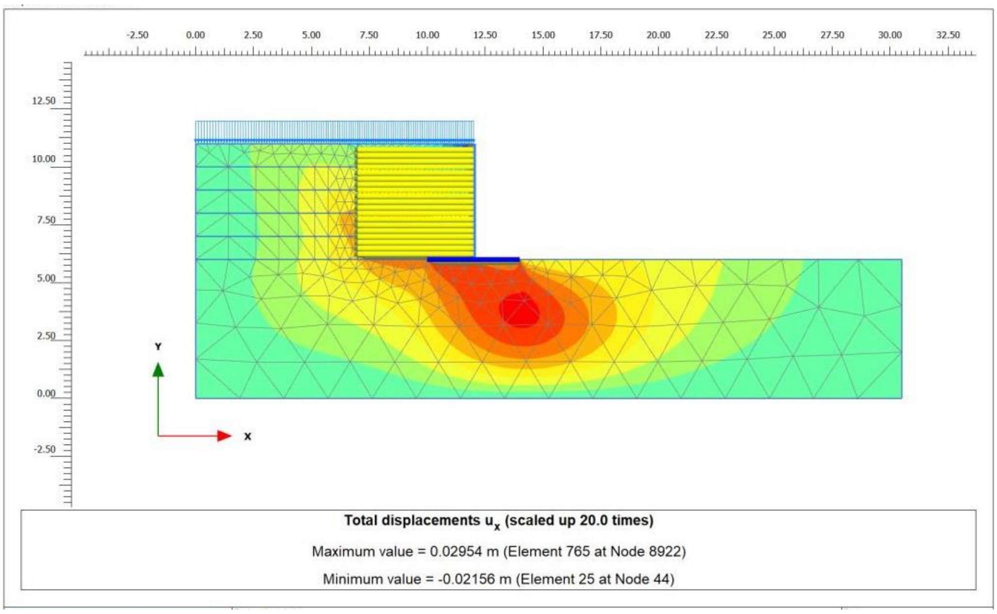

Figure 4.45 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.25m

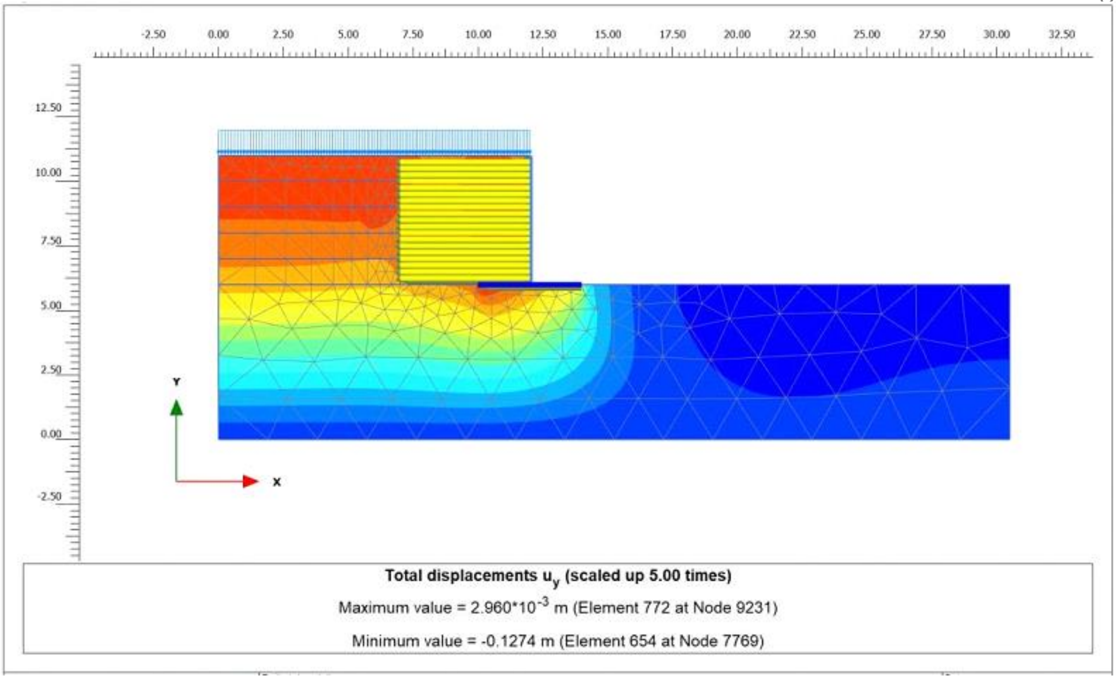

Figure 4.46 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) with vertical spacing 0.25m

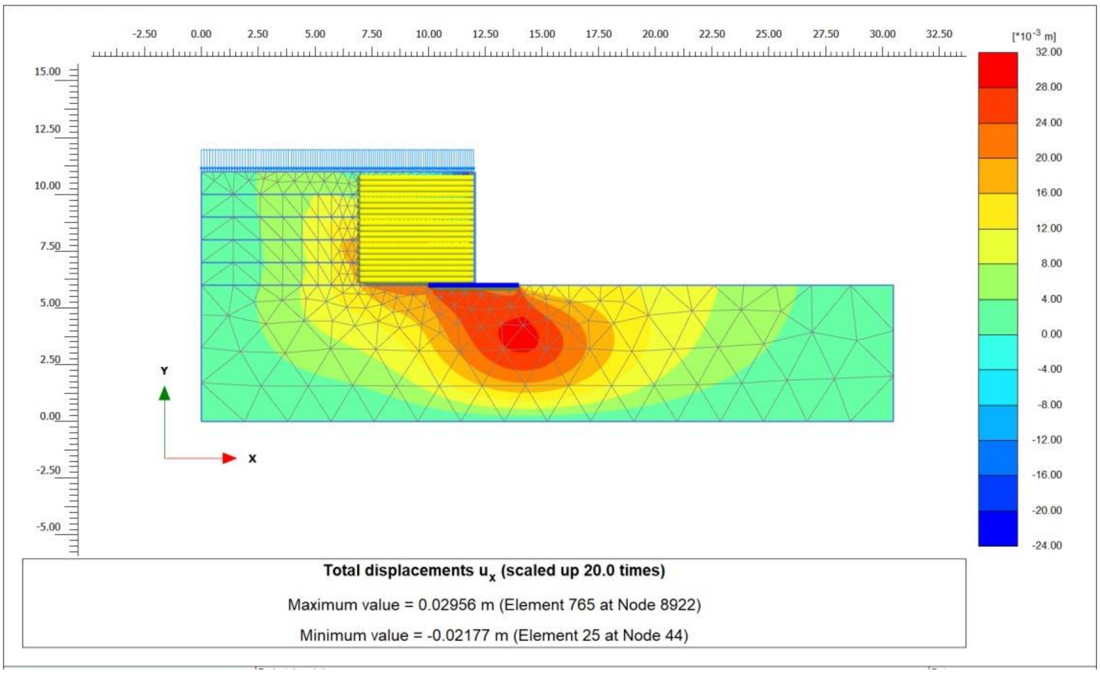

Figure 4.47 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.25m

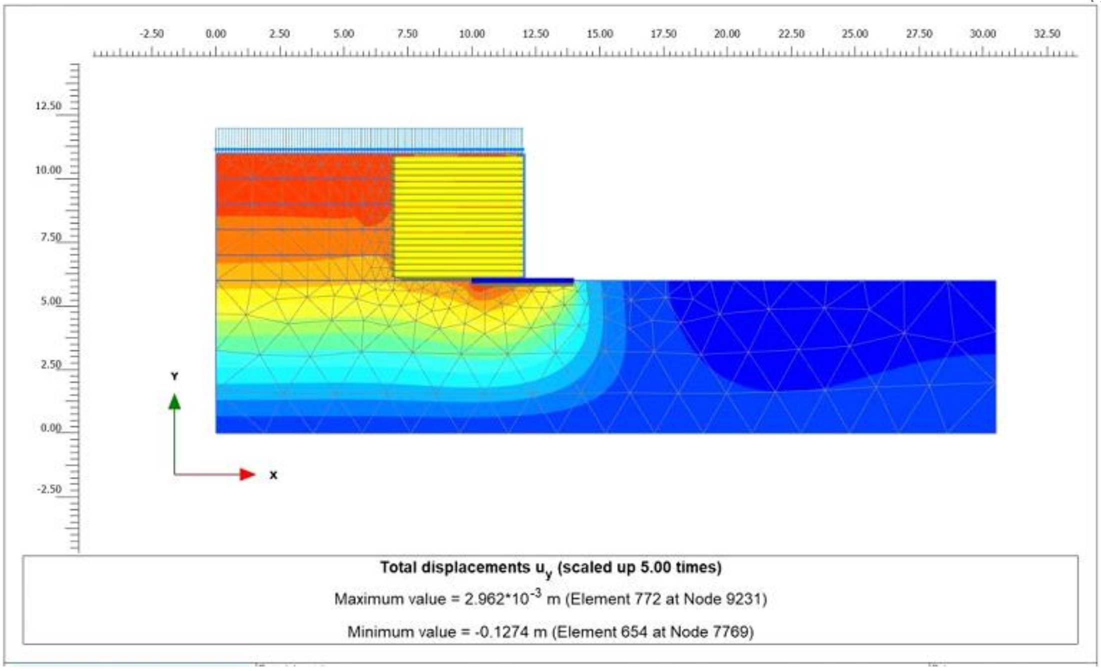

Figure 4.48 vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness9000 (kN/m)) with vertical spacing 0.25m

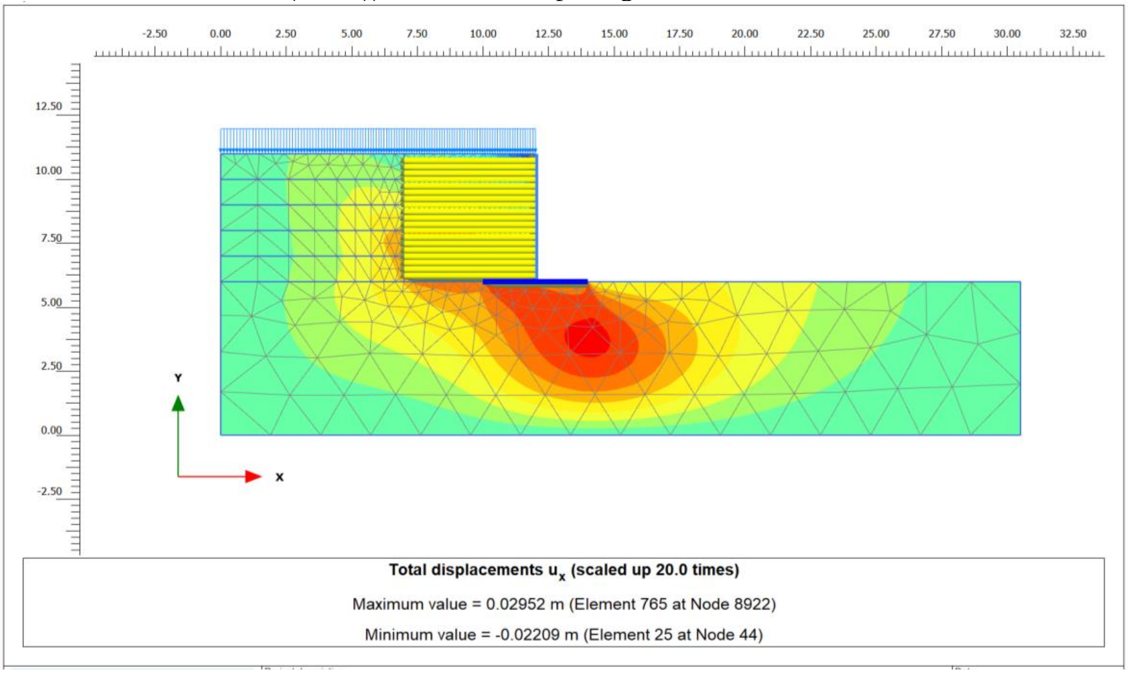

Figure 4.49 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 0.25m

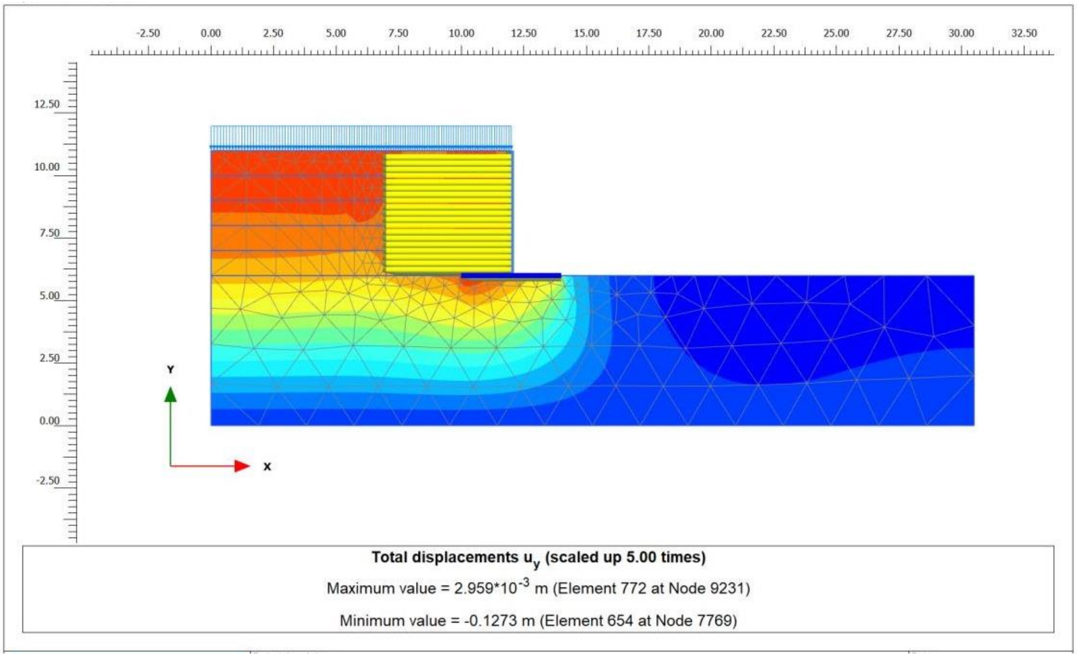

Figure 4.50 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness12000 (kN/m)) with vertical spacing 0.25m

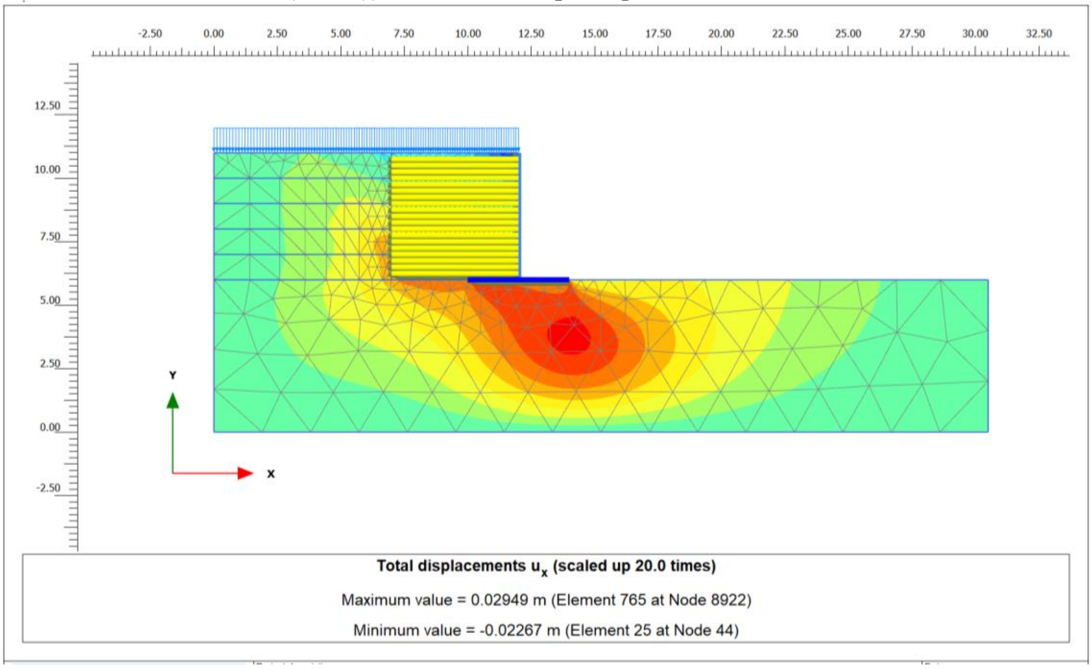

Figure 4.51 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.25m

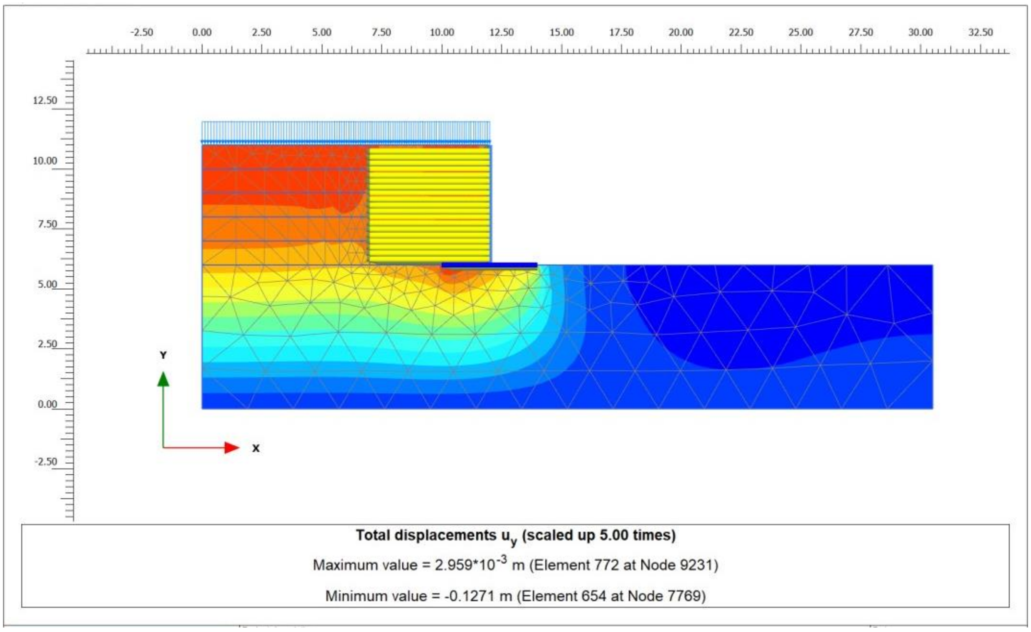

Figure 4.52 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness24000 (kN/m)) with vertical spacing 0.25m

4.5 CASE 5: VERTICAL SPACING BETWEEN TWO GEOGRIDS ARE 1M WITH TIE ANCHOR

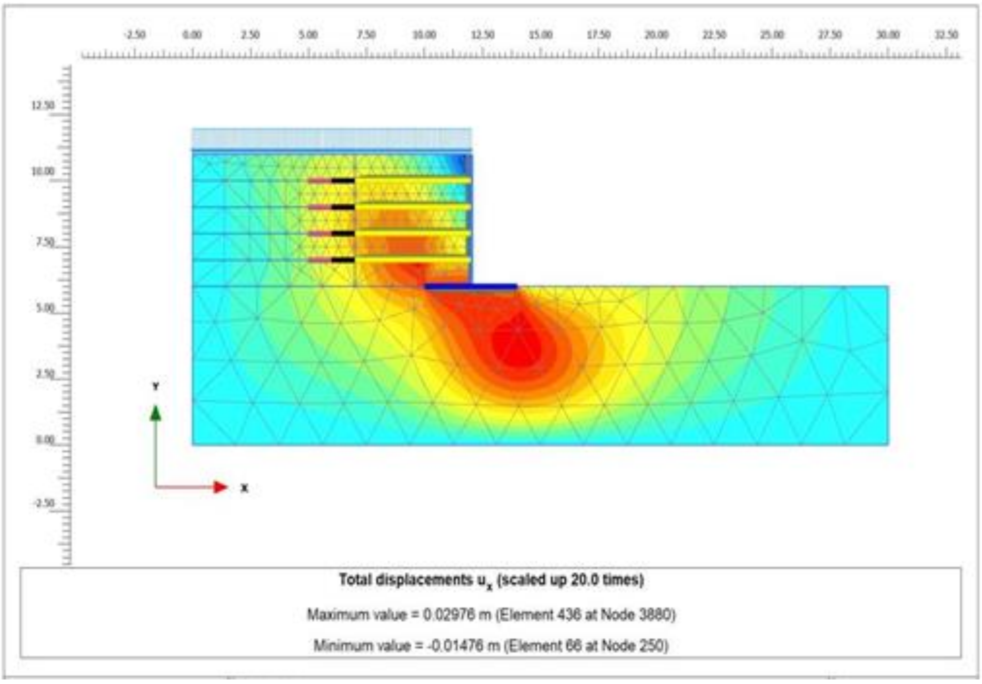

Fig. 4.53 Lateral deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) and tie anchor

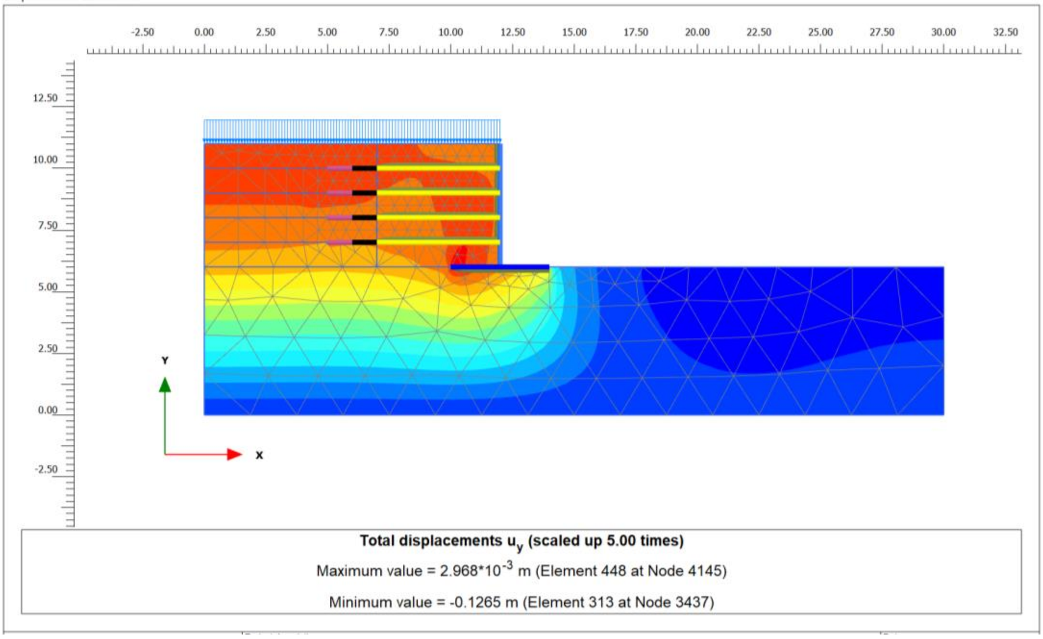

Fig. 4.54 Vertical deflection of 5m high retaining wall reinforced with geogrid (stiffness7000 (kN/m)) and tie anchor

Table 4.1 Horizontal deflection, vertical deflection and factor of safety of 4m and 5m high retaining wall when vertical spacing between geogrid is 1m and length of geogrid is 6m

Wall ht.	Geogrid Dis. (m)	Geogrid stiffness (kN/m)	Horizontal deflection (m)	Vertical deflection (m)	Factor of safety
4m	1	7000	0.02485	0.002487	1.869
4m		9000	0.02469	0.002486	1.871
4m		12000	0.02466	0.002485	1.871
4m		24000	0.02461	0.002483	1.871
4m		30000	0.02459	0.002482	1.872
5m		7000	0.02983	0.002971	1.699
5m		9000	0.02981	0.002972	1.701
5m		12000	0.02980	0.002972	1.7
5m		24000	0.02977	0.002972	1.702
5m		30000	0.02976	0.002972	1.7

Table 4.2 Horizontal deflection, vertical deflection and factor of safety of 4m and 5 m high retaining wall, when vertical spacing between geogrid is 0.5m and length of geogrid is 6m

Wall ht.	Distance between two geogrid	Geogrid stiffness (kN/m)	Horizontal Deflection (m)	Vertical deflection (m)	Factor of safety
4m	0.5m	7000	0.02449	0.002474	1.969
		9000	0.02446	0.002473	1.969
		12000	0.02444	0.002472	1.969
		24000	0.02437	0.002470	1.969
		30000	0.02436	0.002470	1.969
5m	0.5 m	7000	0.02978	0.002960	1.774
		9000	0.02976	0.002960	1.771
		12000	0.02972	0.002960	1.769
		24000	0.02971	0.002960	1.771
		30000	0.02970	0.002960	1.769

Table 4.3 Horizontal deflection, vertical deflection and factor of safety of 4m and 5 m high retaining wall, when vertical spacing between geogrid is 0.25m and length of geogrid is 6m

Wall ht.	Distance between two geogrids	Geogrid stiffness (kN/m)	Horizontal Deflection (m)	Vertical deflection (m)	Factor of Safety
4m	0.25m	7000	0.02440	0.002470	2.008
		9000	0.02436	0.002468	2.009
		12000	0.02433	0.002468	2.009
		24000	0.02427	0.002466	2.009
		30000	0.02427	0.002465	2.009
5m	0.25m	7000	0.02954	0.002960	1.805
		9000	0.02956	0.002962	1.806
		12000	0.02956	0.002962	1.806
		24000	0.02949	0.002959	1.805

As Geogrids support soil masses and hold it properly and spread loads over wide area, the deflections are improved as well as factor of safety.

When comparing different parameters we have seen following things-

4.6 EFFECT OF REINFORCEMENT STIFFNESS

In three different height of wall, the difference in horizontal and vertical deflections are made with changing stiffness of geogrid reinforcement. It has been seen that at 7,000 kN/m to 30,000 kN/m lateral deflection is reduced gradually with the increase in stiffness. When the height of wall was 4 m lateral deflection changed from 0.02485 m to 0.02459m according to the increased stiffness of geogrid.

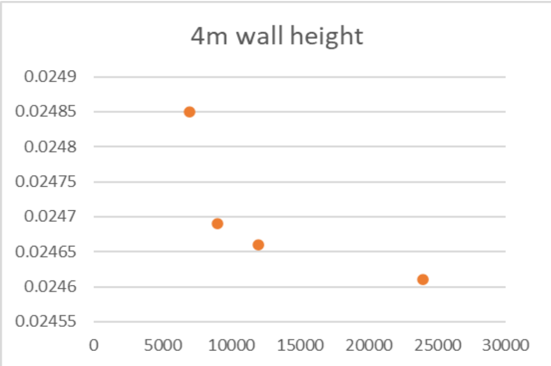

Fig.4.55 Horizontal deflection with different geogrid stiffness and wall height 4m

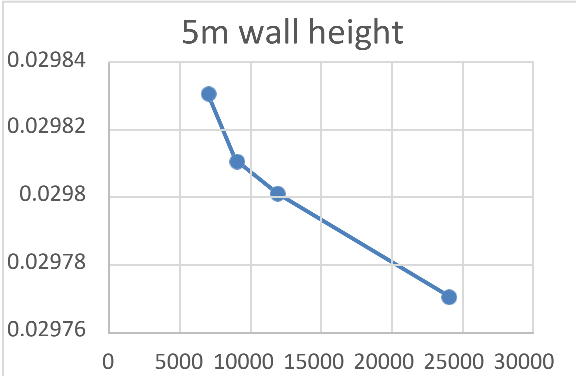

Fig.4.56 Horizontal deflection with different geogrid stiffness and wall height 5m

In case of 5 m wall height change is from 0.02983 m to 0.02977 m. So, it is shown that the deflections are reducing in very little amount according to increase of the stiffness of geogrid.

4.7 EFFECT OF SPACING OF GEOGRID

The vertical spacing between each two geogrids has been taken as a varying parameter too. The changes in spacing are 1 m, 0.5 m and 0.25 m. With reduction of spacing between geogridsthe lateral deflection as well as vertical deflection has been shown to be reduced. Again a significant increase in factor of safety can be seen can be seen too here.

The plots are shown here when geogrid stiffness is 7000 kN/m.

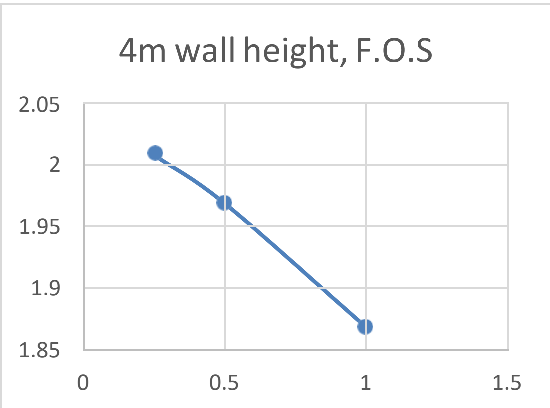

Fig.4.57 Factor of safety variation with different spacing between geogrids and wall height 4m

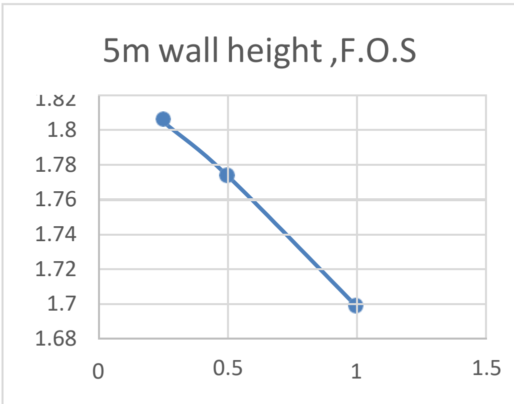

Fig 4.58 Factor of safety variation with different spacing between geogrids and wall height 5m

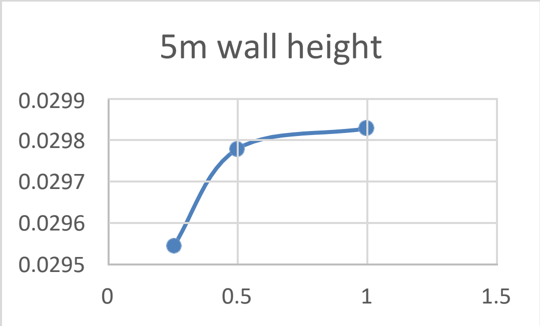

Fig 4.59 Horizontal deflection for wall height 5m

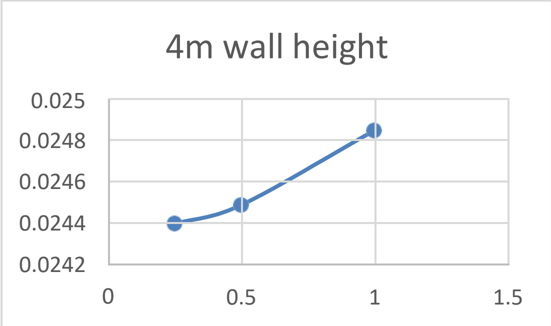

Fig 4.60 Horizontal deflection for wall height 4m

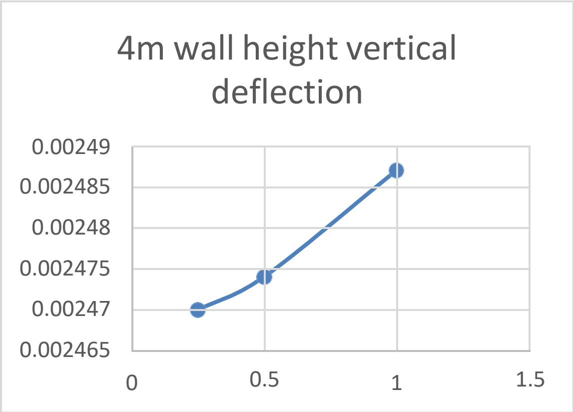

Fig 4.61 Vertical deflection for wall height 4m

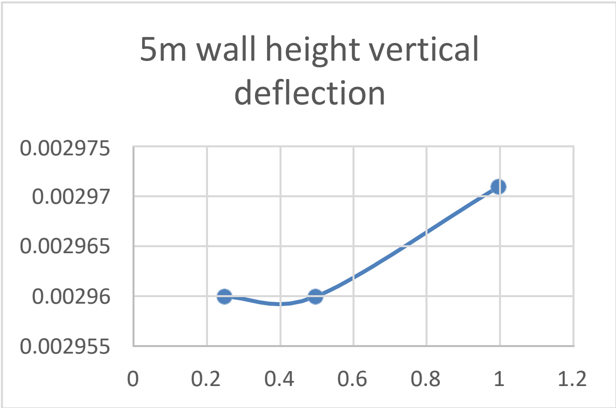

Fig 4.62. Vertical deflection for wall height 5m

Similarly when stiffness of geogrid is 9000 kN/m

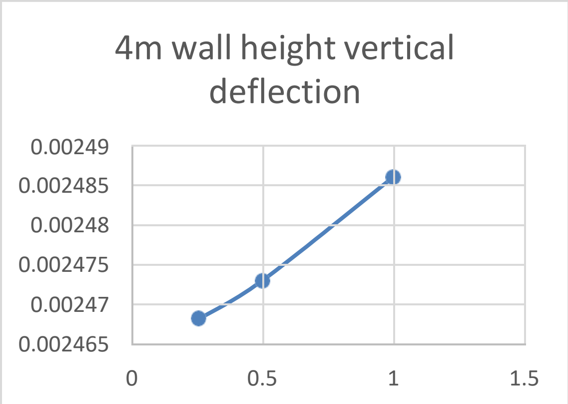

Fig 4.63 Vertical deflection for wall height 4m

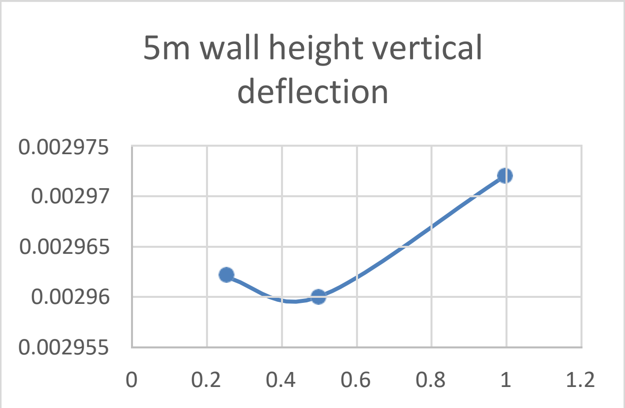

Fig 4.64 Vertical deflection for wall height 5m

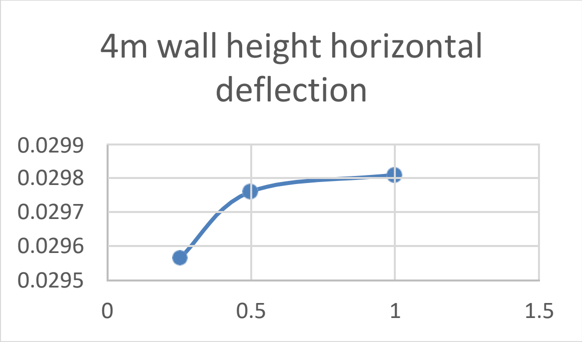

Fig 4.65 Horizontal deflection for wall height 4m

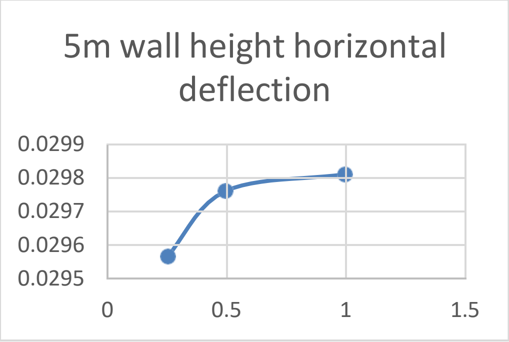

Fig 4.66 Horizontal deflection for wall height 5m

4.8 EFFECT OF TIE ANCHOR

In the wall height of 5m tie anchor is attached along with geogrid with varying stiffness. Here it is shown that the horizontal deflection as well as vertical deflection has been improved. Factor of safety has been also increased but it is not varying. It is constant. Also, Lawson et. al. (2010) applied the combined action of geogrid and tie anchor successfully in their case study.

Table.4.4 Horizontal deflection, vertical deflection and factor of safety of 5 m high retaining wall with tie anchor, when vertical spacing between geogrid is 1m and length of geogrid is 6m

Wall Ht. (m)	Geogrid stiffness (kN/m)	Anchor	Horizontal Deflection (m)	Vertical deflection (m)	Factor of safety
5	7000	Yes	0.02979	0.002969	1.737
5	9000	Yes	0.02976	0.002968	1.736
5	12000	Yes	0.02973	0.002968	1.737
5	24000	Yes	0.02966	0.002965	1.737

Therefore, it can be observed that-

- without reinforcement in the retaining structure, both horizontal and vertical deflections are high when loading is applied.
- soil is weak in tension. With engagement of geogrid reinforcement in the soil slope, it has given better result, as geogrid reinforcement cut the failure surface of the soil slope and absorb the maximum tensile stress.
- tie anchor is also a well-known product used for reduction of deflections. When it is used along with geogrid, it has shown more better result than before because, now the tensile

stress is carried by both geogrid and tie anchor which ultimately pass the tensile stress to the deep soil.

Table 4.5 Horizontal deflection, vertical deflection and factor of safety of 4m high retaining wall with tie anchor, when vertical spacing between geogrid is 1m and length of geogrid is 6m

Wall Ht. (m)	Geogrid stiffness (kN/m)	Anchor	Horizontal Deflection (m)	Vertical deflection (m)	Factor of safety
4	7000	Yes	0.02481	0.002489	1.902
4	9000	Yes	0.02478	0.002488	1.902
4	12000	Yes	0.02475	0.002487	1.903
4	24000	Yes	0.02468	0.002484	1.904

4.9 COMPARISON OF HORIZONTAL DEFLECTION WITH AND WITHOUT APPLICATION OF GEOGRID

Table 4.6 Horizontal deflection at 4 m height

Stiffness of geogrid (kN/m)	Horizontal deflection without geogrid (m)	Horizontal deflection with geogrid (m)	Percentage decrease in deflection (%)
7000	0.02498	0.02485	0.52
9000	0.02498	0.02469	1.16
12000	0.02498	0.02466	1.28
24000	0.02498	0.02461	1.48

From this table, it can be seen that with the application of geogrid, horizontal deflection is reduced and factor of safety is increased.

Table 4.7 Horizontal deflection at 5 m height

Stiffness of geogrid (kN/m)	Horizontal deflection without geogrid (m)	Horizontal deflection with geogrid (m)	Percentage decrease in deflection (%)
7000	0.04991	0.02983	40.23
9000	0.04991	0.02981	40.27
12000	0.04991	0.02980	40.29
24000	0.04991	0.02977	40.35

With increment of stiffness of geogrid ,percentage decrease in deflection is improved.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE OF STUDY

5.1 CONCLUSIONS

After investigating the problem following conclusions can be drawn –

- Use of geogrids is excellent techniques for the purpose of improvement of stability of retaining structure.
- Factor of safety of retaining wall increases if the vertical spacing between geogrids are reduced.
- Vertical deflection along with horizontal deflection reduces when stiffness of geogrid is increased.
- With increase in stiffness of geogrid, factor of safety also increases thus increasing the stability of the retaining wall.
- Tie anchor along with geogrid improves the lateral deflection than, when geogrid is only used. Factor of safety also increases but not that much variation is present there when stiffness of geogrid is increasing.

5.2 FUTURE SCOPE

- Further research is needed for combined action of geogrid and tie anchor for different backfill.
- In case of higher height of wall how geogrids are working should be checked.

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