Tunnel Analysis of Dhaka Subway using PLAXIS 2D Considering Building Loads of Pile Foundation

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THESIS APPROVAL

The thesis titled "Tunnel analysis of Dhaka Subway using PLAXIS 2D Considering Building Loads of Pile Foundation" submitted by Mohammad Hasin Ishraq, Md. Towsif Obaid, Muhaimin Uddin, St. No 180051229, 180051108 and 180051116 has been found satisfactory and accepted as partial fulfillment of the requirement for the Degree Bachelor of Science in Civil Engineering.

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work presented in this thesis was conducted under the supervision of Professor Dr. Hossain Md. Shahin, and that it has not been sent elsewhere for any reason other than publication.

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DEDICATION

Our combined thesis work is dedicated to our respective parents, family, and friends who have been a constant source of support and encouragement. We also express our gratitude to our respected supervisor Professor Dr. Hossain Md Shahin. We are forever in debt to all who supported and encouraged us throughout not only this thesis but also our undergraduate journey.

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"In the name of Allah, the most merciful and most gracious."

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ABSTRACT

Keywords: *Dhaka Subway, Tunnel, Surface settlement, Settlement trough, Ground behavior, Finite Element Analysis, Plaxis 2D, Lining stresses*

To ease the increasing traffic in the city, an underground Dhaka metro system is being planned. Ground movement and surface settlement must get special consideration during the planning of the subway due to the city's high level of congestion. For the long-term design of the tunnel, it is also necessary to take into account the increase in building density as the city expands. Utilizing Plaxis 2D, a 2D finite element analysis was performed for this project. Different soil profiles representing various parts of the Central Dhaka city were taken into consideration, and the surface settlement brought on by tunnel excavation was looked at. It was discovered that as tunnel excavation depth grows, surface settlement diminishes and the settlement trough widens. Additionally, the axial forces and grouting pressure needed for a particular surface settlement after the tunnel was built were analyzed, and it was shown that both of these requirements rise with tunnel depth. Additionally, an analysis of the tunnel lining stresses under various groundwater conditions was done. It was discovered that the axial forces the tunnel lining experiences increase with tunnel depth. Additionally, the future rise in ground water level will primarily cause an increase in the axial forces, bending moments, and shear forces.

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CHAPTER 1. INTRODUCTION

1.1. General

Throughout the course of human civilization, man-made tunnels have existed, paralleling our extensive history. The rationale behind their existence is quite clear—they serve as integral components of efficient sewage and irrigation systems. In the bustling urban landscape of Dhaka and its surrounding municipalities, where the population exceeds 22 million and continues to grow at an annual rate of 3.25%, the utilization of Tunnel Boring Machine (TBM)-based mechanized tunneling is widespread, particularly when excavating beneath densely populated areas of the city.

The current transportation system in the city proves inadequate in meeting the ever-increasing demands. As a result, tunnels have become indispensable in providing a rapid and dependable urban commute. By utilizing the underground realm for transportation, not only does it significantly reduce travel time, but it also introduces a novel mode of transportation that enhances the overall quality of life for the city's inhabitants.

It's worth noting that the construction of underground structures is a highly intricate process due to the substantial impact of ground deformation on various surfaces and sub-surface structures. Consequently, the utmost care and precision are required when undertaking underground construction works.

The tunnel analysis of Dhaka Subway takes into consideration the building loads of pile foundations. Pile foundations are commonly used in urban areas to support structures. In this analysis, the focus is on assessing the impact of these building loads on the stability and performance of the subway tunnel. By considering the loads from nearby buildings with pile foundations, engineers can accurately evaluate the potential stresses and deformations that the tunnel may experience. This analysis helps ensure that the design and construction of the subway tunnel in Dhaka can effectively withstand the influence of nearby buildings and their foundation loads, ensuring the long-term safety and functionality of the transportation system.

1.2. Background

1.2.1.Background

The construction of tunnels in Dhaka City holds significant importance due to its densely populated urban environment and strained transportation system. Tunnels provide a vital solution by improving the city's infrastructure, reducing congestion, and enhancing the quality of life for its residents. This progress brings positive outcomes, including improved connections, economic growth, job creation, and urban revitalization. However, careful risk assessment is crucial, considering factors such as geological conditions, impact on existing infrastructure, and environmental considerations. Prioritizing risk management ensures worker safety, long-term tunnel stability, and successful project implementation.

1.2.2. Project Details

The four initial routes that will be constructed are:

Route 1 is 30.51 kilometres long and connects Gabtoli with Bholabo.

Route 2: the intersection at Jhilmil and Tongi (29.35 km)

Route 3 runs 47.5 kilometres between Jahngirnagar University and Narayanganj.

Route 4 travels 19.5 kilometres between Keraniganj and Sonapur.

Six locations along Route 4 have been set aside for our specific investigation. One of them was beneath the Buriganga River. People living close to the project won't be affected by the soil digging by the usage of a tunnel boring machine (TBM). It is thought that the project is environmentally favorable. This will be the most cost-effective method of transportation, and it will ease traffic congestion. GoB will struggle with the expense of O&M and maintaining continuous power for this project.

1.2.3. Objectives of the study

- Evaluating the impact of existing nearby structures during tunnel construction
- Stress development in tunnel lining
- Surface settling caused by the existing structure and by the excavation of tunnel
- Stress development and water pressure due to the excavation of tunnel
- Tunnel depth and grouting pressure connections
- Stress development in the tunnel's lining including axial stress, bending moment, and shear force.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

In many cities across the world, subways are a common form of mass transit. In addition to being used for subways, tunnels are also used for road tunnels, railway tunnels, and underwater expressways. With a few tunnel project now under progress, Bangladesh is still in the early phases of using tunneling technology. There aren't many research on tunnels that concentrate exclusively on Bangladesh as a result. By locating pertinent research on tunneling and presenting their results, this review of the literature seeks to close this gap. By doing this, it hopes to advance knowledge and understanding of tunneling techniques in the context of Bangladesh.

2.2. Tunnel Construction

Different tunnel excavation techniques are used based on the kind, length, depth, soil conditions, and other variables. Given factors like geotechnical features and project needs, technique selection is essential for effective and safe construction. To guarantee effective tunnel excavation, engineers carefully assess these aspects before selecting the best approach.

There are typically two main kinds of excavations. As follows:

• The Cut and Cover technique entails digging open trenches and then pavering over them. This technique is frequently employed for short tunnels when there are no buildings above and simply open surfaces. It supports reasonably straightforward construction and is well-suited for some tunneling projects that fit these particular requirements.

• Without any surface excavations, the tunnel is excavated underground using a Tunnel Boring Machine (TBM). This method is best suited for highly populated cities when buildings are located above the tunnel path. It is often used all around the world and is known as shield tunneling. The standard tunnel cross-section is round or horseshoe-shaped, allowing for accurate and effective excavation with the least amount of damage to the surrounding landscape and structures.

2.3. Existing research on Tunnel excavation

 Shahin et al. (2016) Conventional and numerical analyses were conducted on a braced cut sheet pile type retaining system for a tunnel using the cut and cover method. The purpose of the study was to perform numerical analysis to simulate the tunneling system using the New Austrian Tunnelling Method (NATM). The results obtained from both the conventional and numerical analyses were compared to assess their effectiveness. By comparing these results, a comprehensive evaluation of the braced cut sheet pile retaining system's performance could be obtained, aiding in the optimization of tunnel construction methodologies.

- **Shahin et al. (2019)** The study found that, especially when the rate of stress release is taken into consideration, 2D finite element modelling is capable of properly forecasting ground deformation and settlement. However, the 2D analysis could provide absurd findings when it comes to strains on the tunnel lining. In these situations, 3D analysis is required since it necessitates taking the precise building process into account. Additionally, a sophisticated constitutive model that accurately captures the mechanical characteristics of the soils must be used in order to perform finite element analysis correctly. These components can be included to produce a more thorough and accurate analysis, enabling well-informed decision-making in tunnel building projects.

- **KUMAR (2020)** The study aimed to observe the impact of tunnel-induced settlement on existing pile structures by altering the position of the tunnel relative to the piles using Finite Element Method (FEM). Through this analysis, the researchers examined how different tunnel positions affected the settlement experienced by the nearby pile foundation. By varying the tunnel's location, valuable insights were gained into the interaction between the tunneling process and existing piles, enabling a better understanding of the potential risks and effects on the structural integrity of the piles. The application of FEM provided a reliable numerical tool to simulate and assess the behavior of the pile foundation under different tunneling scenarios, contributing to informed decision-making and design considerations in similar geotechnical projects.

- **Raja et al. (2015)** The study includes estimating the displacement of the earth as a result of digging and examining how this soil movement affects surrounding piles. Calculating the ensuing pile reactions brought on by the induced soil motions was the main goal. The purpose of this investigation was to help the researchers comprehend how pile behavior is impacted by ground movements brought on by digging. The study entailed calculating the size and scope of earth movements and analyzing how these changes impact the effectiveness of the piles. This work helped in the evaluation and design of pile foundations under comparable geotechnical situations by illuminating the relationship between tunneling-induced ground motions and pile behavior.

- **Maisha et al. (2021)** The analysis carefully considered the implications of groundwater withdrawal and slip factors along the diaphragm wall, focusing on the role of building foundations on the braced excavation of the Dhaka Subway. The effects of building foundations near the excavation site on the stability and effectiveness of the braced excavation was examined by the researchers. The impacts of groundwater withdrawal, which can drastically alter soil behavior and cause ground movement, were given special attention. The study also looked at the function of slip components along the diaphragm wall in minimizing possible problems caused by lateral displacements. The goal of the research was to examine these variables in order to offer useful insights into the design and construction parameters required for braced excavations to be effective in the context of the Dhaka Subway.

- **Irtiza et al. (2022)** The results of the study show that groundwater migration and surface settlement are important factors in tunnel construction. According to the study, surface settlement tends to decline while the settlement trough expands as tunnel excavation depth increases. This shows that a more dispersed settlement pattern results from deeper excavations. The research also showed that the tunnel's structural behavior is significantly impacted by the presence of groundwater. Axial forces, bending moments, and shear forces have all been found to increase when the level of groundwater rises. This implies that in order to preserve the structural integrity of the tunnel, future groundwater levels need be carefully taken into account during the design and building stages. These findings emphasize the significance of thorough planning and analysis to control surface settling and groundwater impacts during tunnel construction.

CHAPTER 3. METHODOLOGY

3.1.Introduction

During and after tunnel excavation, the surface settlement, ground response, lining stresses, etc. can be calculated using techniques like empirical analysis, numerical analysis, or finite element analysis. By far the earliest and most popular technique for determining these forces, which were discovered through the use of recorded data or laboratory experiments, is empirical analysis. And even so, the surroundings there. Numerical analysis is a technique that uses algorithms to find the best solution feasible while yet leaving a margin of error. While it is simple to construct a numerical model for less complex scenarios, as the complexity and variables of the problems rise, it becomes increasingly challenging to manually develop a numerical model. Nevertheless, it can yield results with the desired precision. . Finite element modeling, then, is a technique for numerical analysis in which a challenging issue is broken down into smaller portions.

To analyze the data for this investigation, we used finite element modeling (FEM), which would accurately capture the various particular effects of the soil profilesare simpler to use, they might not offer correct data due to unanticipated.

3.2. Finite Element Method (FEM)

A numerical technique called the Finite Element Method, or FEM, is used to carry out finite element analysis on any model or structure. By creating a mesh of the item, a complex model is broken into much smaller and simpler sections using this technique. Finite elements are the name for these tiny components. As a result, calculating a complex structure becomes considerably simpler and more precise. It can also forecast local effects on the model. A more complex system of equations that reflects the entire problem is created by combining the simpler equations that represent the finite elements.

The study made use of Plaxis 2D. Plane strain and axial symmetry geometric types are supported by the software. Plaxis is a geotechnical engineering software program that performs finite element analyses. Two-dimensional finite element analyses, such as those for deformation, stability,water flow, etc., are performed in Plaxis 2D.

3.3. Tunnel Boring Machine (TBM)

The Tunnel Boring Machine (TBM) is a device used to dig tunnels and lay circular cross-sectional lining. It may simultaneously bore through different types of soil. With little disruption to the land around it, the machine drills into soil. The diameter of the excavated area can be rather big. One meter to around 17.6 meters is the range for tunnel diameters. Due to the minimal ground disturbance caused by the TBM, smooth tunnel walls can be produced as opposed to drilling, blasting, or cut and cover techniques. It is also much better to use it in urban settings for this reason. It is more effective than the traditional method since the boring machine simultaneously excavates the ground and installs the liner. The machines' costlier initial outlay is one of their drawbacks. They are expensive to assemble and challenging to carry. However, because TBMs are more effective than other methods, if the required tunnel excavation is long enough, it is relatively less expensive than other approaches.

3.4. Soil Models

- Linear Elastic Model (LE)
- Mohr-Coulomb Model (MC)
- Hardening Soil Model (HS)
- Hardening Soil Model with small stress-strain stiffness (HS small)
- Soft Soil Model (SS)
- Soft Soil Creep Model (SSC)
- Concrete Model (Concrete)
- Jointed Rock Model (JR)

Mohr-Coulomb, HS small, or Soft Soil Models were used to model soil for this study.

The easiest and most straightforward model is the Mohr-Coulomb Model. This model makes use of variables like cohesiveness, angle of friction, dilatancy, soil yield strength, etc. These factors are frequently tested. This makes using this soil model preferable.

For clays close to usually cemented clays, the Soft Soil model is utilized. When modeling the soil, additional factors like the Compression Index (Cc) and Swelling Index (Cs) were given in order to obtain an accurate representation.

Small HS models are intended to mimic common soil behaviors as densification, stiffness stress dependence, plastic yielding, and dilatancy, among others.

3.5. Method of Analysis

- Analysis done with Plaxis 2D software
- Used Plane Strain model for 2D ground model
- Soil models used - Mohr-Coulomb Model, HS small and Soft Soil Model
- Microsoft Excel for generating tables and graphs

3.6. Calculation Phases

Phases were established for the tunneling process so that it could accurately imitate the conditions on the ground. The phases are not interchangeable, and these were also in the sequence of the actual construction techniques.

Phase 1: The ground's initial condition. This stage reflects the soil profile prior to the start of excavation. The initial stress condition stage or K0 stage are other names for it. At the conclusion of this phase, the deformation is automatically set to zero.

Phase 2: During this phase, the tunnel boring machine drills holes through the dirt to dig it. Due to the Boring Machine's modest conic shape, the earth immediately surrounding the excavated area collapses and contracts once it leaves the region. Due to TBM conicity, this phase also simulates the ground's decompression behind the tunnel face and the excavation's contraction.To obtain only the displacements brought on by tunneling and excavation, the displacement has been reset to zero.

Phase 3: In this phase, the grouting pressure is assigned. The space between the earth and the liner is filled with grouting.

Phase 4: As the machine excavates, the tunnel liner is built concurrently. A smooth tunnel wall is made by installing pieces of lined after they have been cast in concrete.

Phase 5: The last phase replicates an increase in ground water levels to assess long-term effects

3.7. Mesh Generation

The software creates a finite element mesh for FEM analysis. The mesh can be created with finer or smaller pieces. The software will subdivide the model into a greater number of subdivisions when fine mesh is generated.

The investigation conducted in this study uses Plaxis 2D's medium mesh generation.

3.8. Grouting Pressure

An essential factor is grouting pressure. The stability of the ground around the tunnel depends on this criterion. The amount of grouting can affect how much top soil is displaced. We required an appropriate technique to compare the results in order to draw a conclusion. Thus, the grouting pressure required for displacements of 10 mm was calculated. Given how crowded Dhaka is, a surface settlement of 10 mm was selected because a settlement higher than this could have a negative impact on structures there.

3.9. Volume Loss

The soil tends to soften and cave in when tunneling is completed. As a result, the real section is less than the original piece that was excavated. Volume Loss is the measure of the difference between these areas and the first one. Its percentage serves as a representation of the volume loss.

The finite element approach is used to build a large number of nodes in the simulation software. We may obtain the coordinates of each node as well as the distances by which they have deformed from the software. The plate elements that make up the tunnel lining were previously established. We may determine the volume loss by measuring the variation in the distance between the nodes that form the tunnel face.

3.10. Results Collection

The following requirements were discovered and noted for analysis.

•At Phase 2, surface settlement measurements were taken because they reflect the surface settlement brought on by tunnel excavation.

•During phases 4 and 5, which correspond to, respectively, the finished tunnel during the initial groundwater level and the finished tunnel after the groundwater level has risen, axial forces, shear forces, and bending moments were gathered.

•In phase 4, the grouting pressure necessary to achieve a 10mm surface settlement was also noted.

•In order to determine the volume loss of the completed tunnel, the volume loss of the tunnel in phase 4 was also measured.

CHAPTER 4. CONSIDERATIONS

4.1. Introduction

These elements were considered when simulating the soil profiles.

•Tunnel Finite Element Analysis

•Deconfinement = 85%, Contraction, cr=0.5%

•The TBM shell and tunnel lining were classified as Plate Elements.

•Taking into account that other water sources for the city are replacing pumping wells. It was made sure that there was at least a 2D gap between the tunnel invert and the terminal border of the last soil layer so that the groundwater table would rise to a comparable elevation level as the Buriganga river. (D=Excavation Diameter).

•Tectonic movement of groundwater flow was not taken into account.

4.2. Soil Parameters of the Study Area

From the Bangladesh Bridge Authority, the geological characteristics of each and every type of soil were gathered. Key soil factors are essential for the modeling of the geological profiles to be correct.

Table 1: Soil Parameters

Properties		Artificial fills	Holocene soft	Holocene dense	Madhupur clay	Dupi Tila coarse	Dupi Tila fine
General Description		Heterogeneous soils	Fine Soils	Sands SM	CL, CH clays	Sands SM	Fine Soils CL, ML, CH
Density	γ_{ap}	19.1	18.6	20.2	18.6	19	19
	γ_{sat}	19.8	18.7	20.5	19.1	20	19.2
Permeability (hydraulic conductivity)	K (m/s)	1.0E-04	5.0E-07	1.0E-05	1.0E-08	1.0E-06	5.0E-08
Stress-strain relationship (FEM models)	Constitutive model	Mohr-Coulomb	Soft Soil	HS-Small	Soft Soil	HS-Small	HS-Small
	Parameters (moduli in Mpa)	E = 20 n = 0.3	Cc = 0.26 Cs = 0.03 OCR = 1.2	E_{50ref} = 15.7 E_{urref}=47 G_{0ref}=104.3 m = 0.28 $g_{0.7}$ = 1.0E-4	Cc = 0.21 Cs = 0.02 OCR = 2.0	E_{50ref} = 26.4 E_{urref}= 79.3 G_{0ref}= 158.7 m = 0.25 $g_{0.7}$ = 1.0E-4	E_{50ref} = 19.5 E_{urref}= 58.4 G_{0ref}= 146.1 m = 0.30 $g_{0.7}$ = 1.4E-4
Strength parameters	Cohesion c' (kPa)	1	20	5	25	5	20
	Friction (ϕ)	28	23	32	23	35	24
	Dilatancy	0	0	2	0	5	0
	Tensile Strength (kPa)	0	5	0	10	0	5
Interfaces	Rinter	0.65	0.65	0.65	0.7	0.75	0.7
Overconsolidation ratio	OCR	1	1.2	1.1	2	1.5	1.5
Initial stresses	K_0	0.53	0.7	0.5	1	0.52	0.76

4.3. Tunnel Geometry

The tunnel is shaped like a circle. Since the TBM face is likewise round, it creates a tunnel that is unique to itself. The tunnel's dimensions are comparable to those of the TBM.

We have examined tunnels at various depths to determine the effects of excavation depth on the soil profile. As a result, the tunnel's depth ranged from 25 to 75 meters. The tunnel had a 10-meter diameter.

4.3.1. TBM parameters

The boring machine had the following specifications:

TBM Shell Thickness = 0.08m

Weight = 32.16 kN/m

Young's modulus of Steel, E = 210E6 kN/m^2

Moment of inertia, I $= \frac{bh^3}{12} = \frac{1 \times 0.08^3}{12}$ = 4.26E-5 m^4

TBM Axial Modulus, EA = 16.8E6 kN/m

TBM Bending Modulus, EI = 8960 kNm^2

4.3.2. Lining Parameters

The lining was made from precast concrete segments and had the following parameters:

Lining Thickness = 0.4 meter

Weight = 9.6 kN/m

Concrete Strength = 40MPa

Concrete unit weight = 24 kN/m

Poisson’s Ratio = 0.15

Modulus of Elasticity of Concrete, E = $4700\sqrt{40}$ = 29725.41 N/m^2 =29.725E6 kN/m^2

Moment of inertia, I = $\frac{bh^3}{12}$ = $\frac{1\times0.4^3}{12}$ = 5.33E-3 m^4

Lining Axial Modulus, EA = 11.89E6 kN/m

Lining Bending Modulus, EI = 158.5E3 kNm

4.4. Soil Profile

Soil profile was consideredrepresenting central Dhaka area.

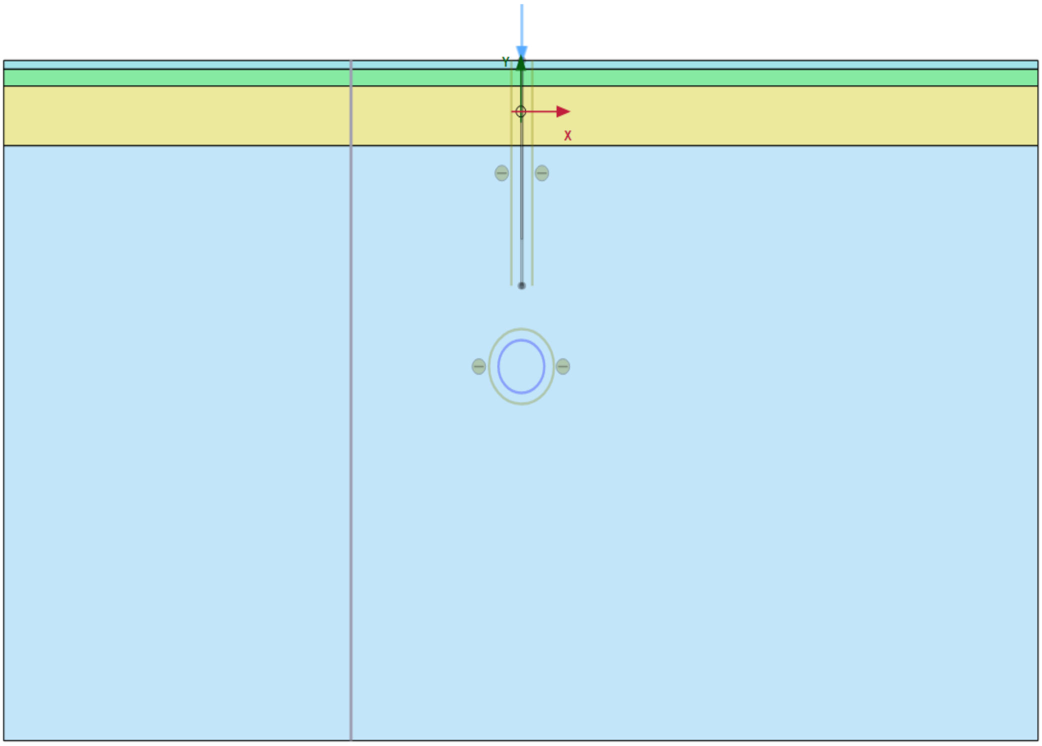


Figure 1. Soil Profile

CHAPTER 5. RESULTS & DISCUSSION

5.1. Introduction

Here are the outcomes from several Plaxis simulation scenarios that were discovered. The effects of the tunnel excavation include displacement, forces such as axial and shear forces, bending moments on the tunnel lining, effective primary stress, and lastly, the change in forces on the lining after the water level has returned to its original level. This part also includes the volume loss and needed grouting pressure for a 10mm settlement.

The grouting pressures necessary to achieve a 10 mm settlement were tabulated and recorded. This settlement should not be confused with the excavation-induced settlement that was previously stated because they were obtained at separate phases of the tunneling operation.

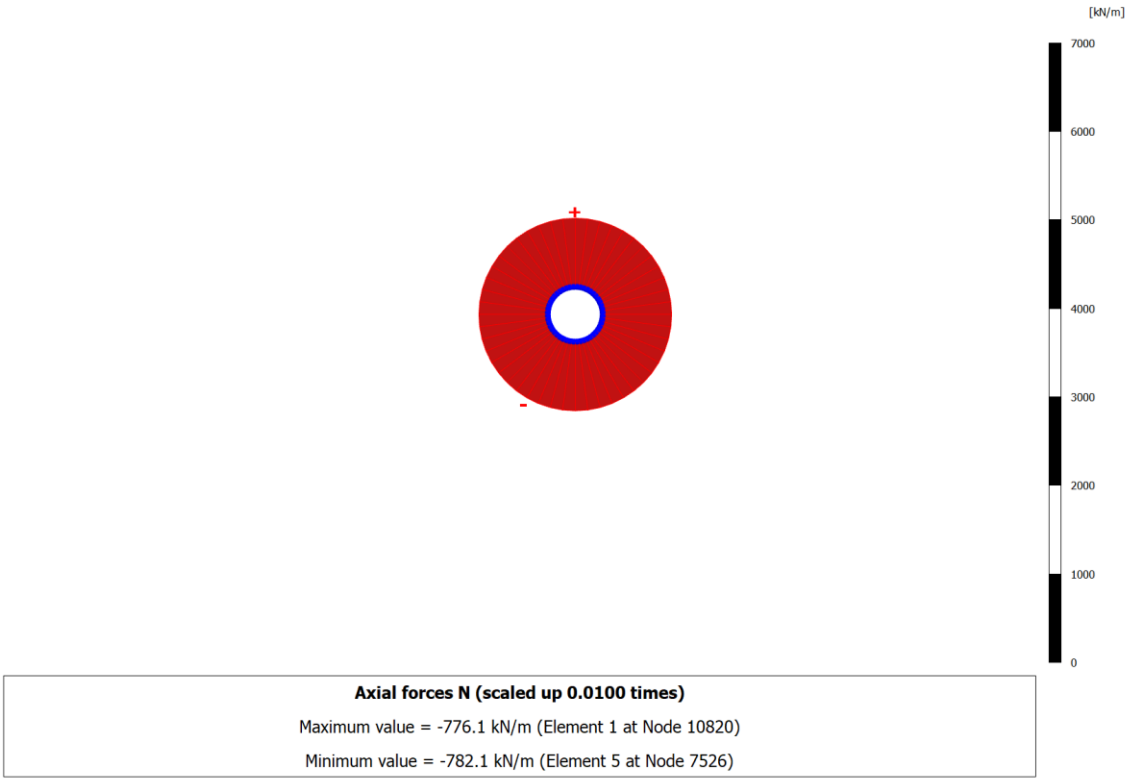
It is important to note that when the lining has been put, the stability and settling of the top soil are related to the grouting pressure. It is evident that greater grout pressure is needed for stability in deeper excavations. The grout pressure ranged in our study from 100 kPa to 700 kPa. The range for soil profiles beneath water bodies was 500kPa to 800kPa.

5.2. Results from Plaxis

Plaxis 2D software provides us with values as well as photos of the distorted mesh and a visualization of the displacement.

5.2.1. Profile #A, Tunnel depth 30m, Pile depth 10m

Results for settlement values, axial forces and bending moments with respect to 10m of pile depth is given below:



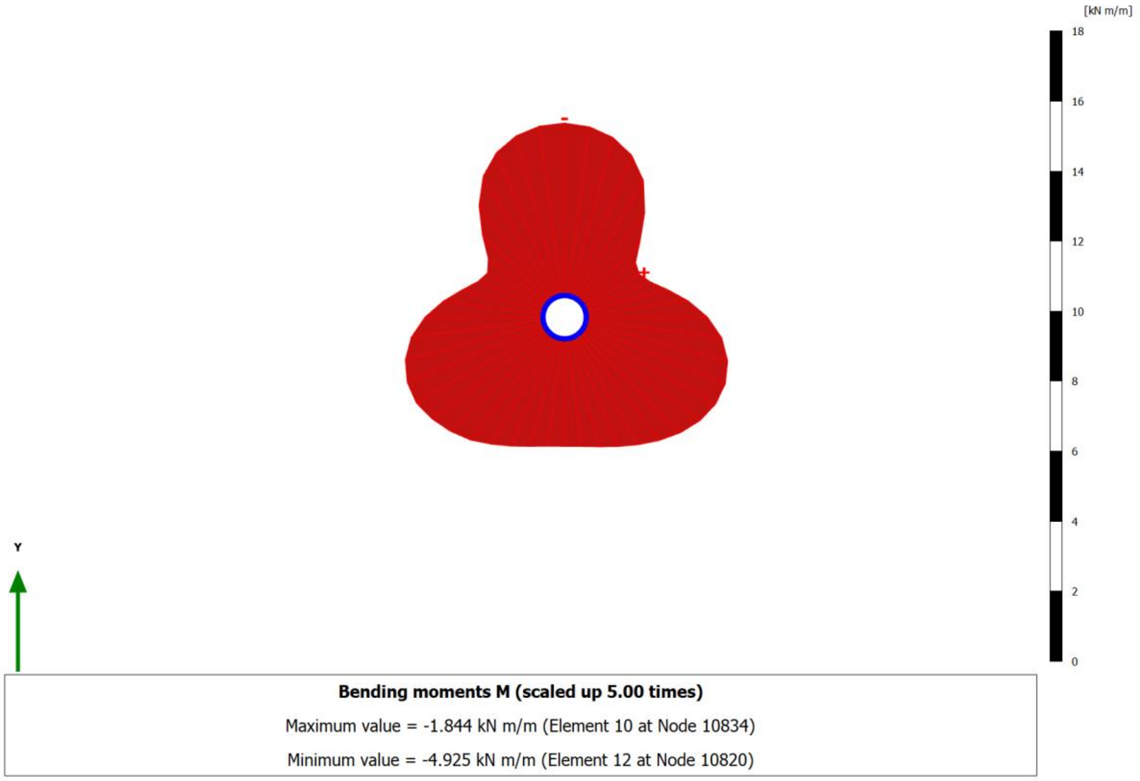
Axial forces N (scaled up 0.0100 times)

Maximum value = -776.1 kN/m (Element 1 at Node 10820)

Minimum value = -782.1 kN/m (Element 5 at Node 7526)

Figure 2. Axial Forces for depth 10m

We can found the maximum and minimum bending moment from result:



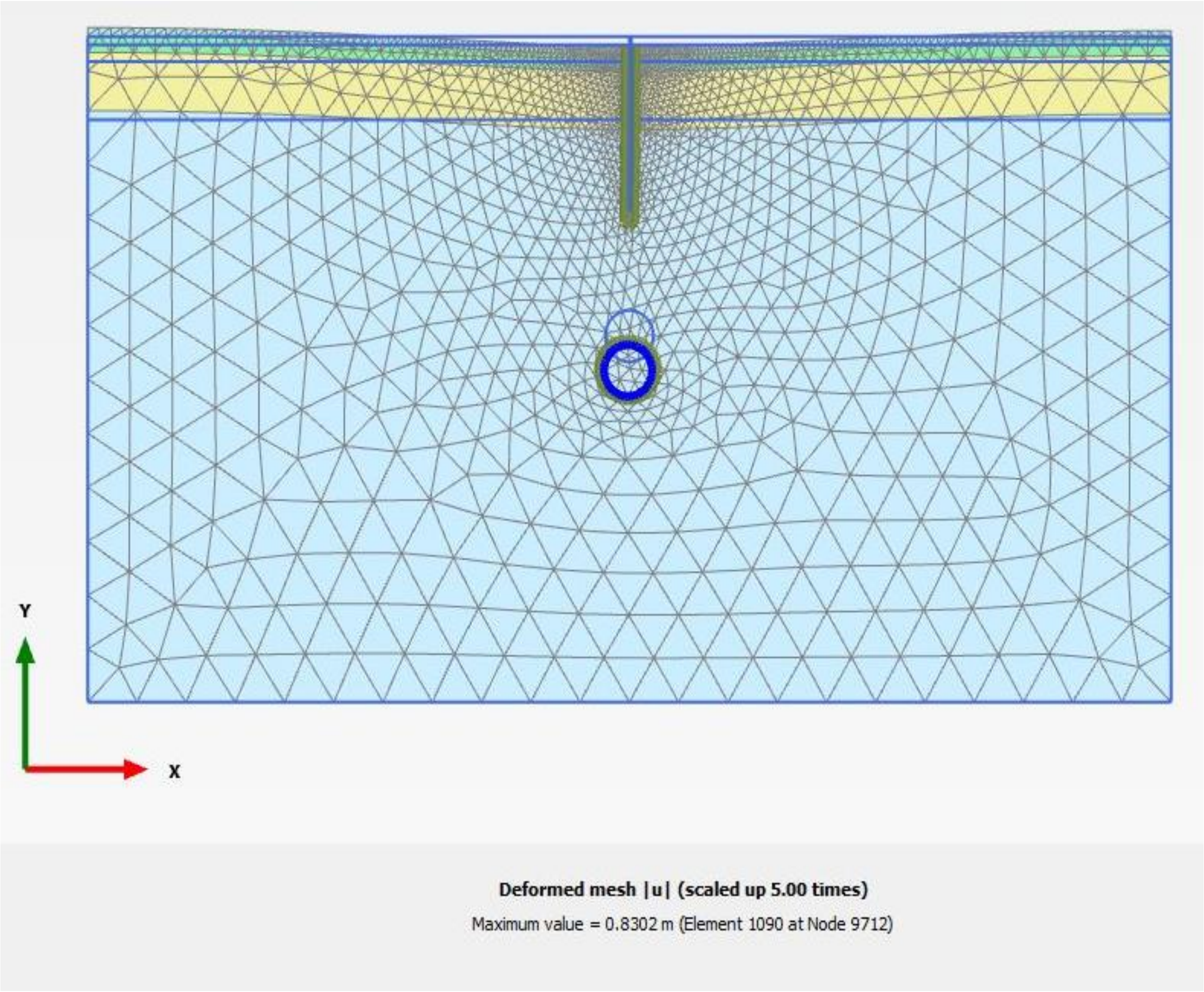
Bending moments M (scaled up 5.00 times)

Maximum value = -1.844 kN m/m (Element 10 at Node 10834)

Minimum value = -4.925 kN m/m (Element 12 at Node 10820)

Figure 3. Bending Moments for depth 10m

We can found the maximum value of deformed mesh from this result:

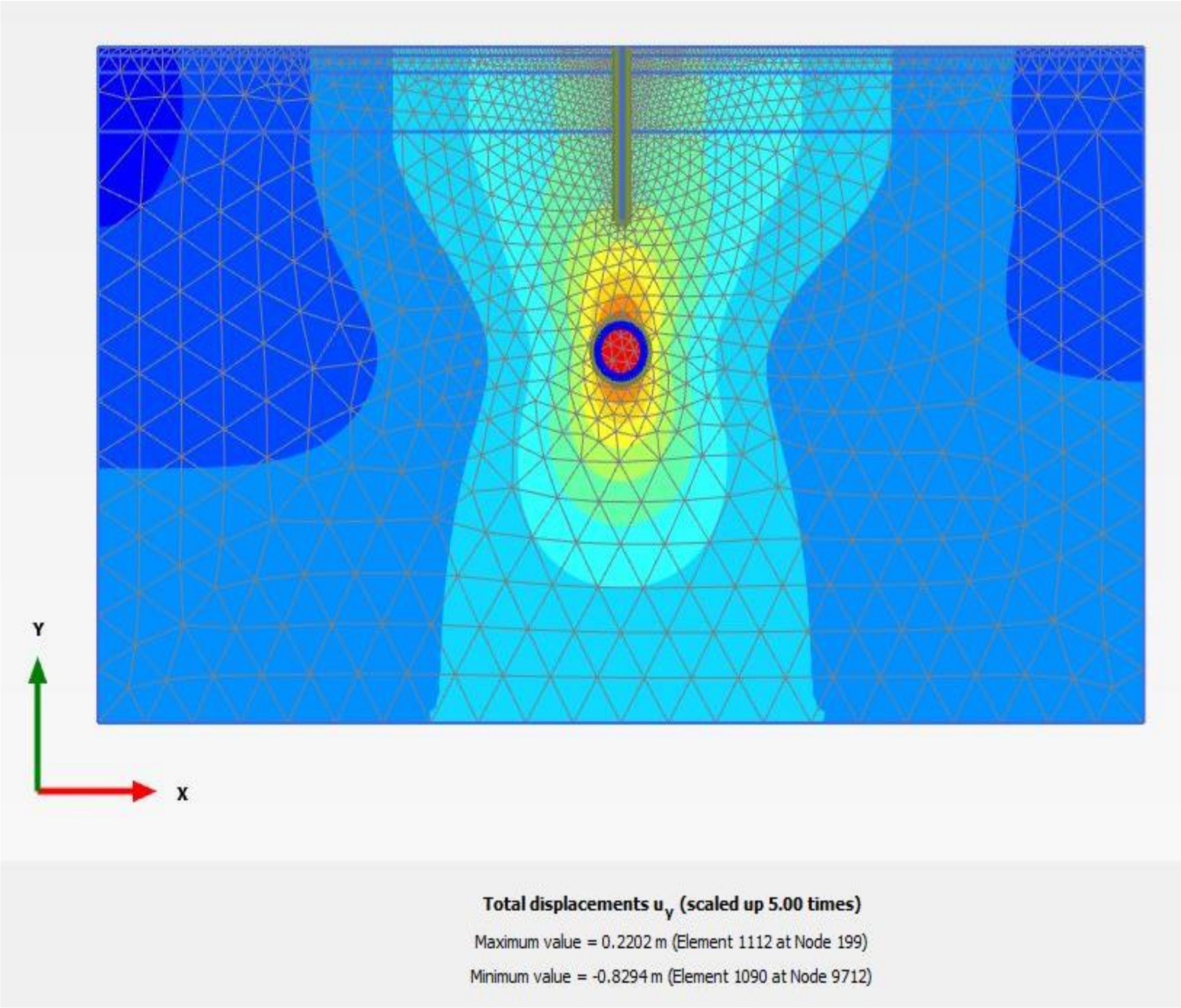


Deformed mesh |u| (scaled up 5.00 times)

Maximum value = 0.8302 m (Element 1090 at Node 9712)

Figure 4. Deformed Mesh [u] for depth 10m

We can found the total settlements value from this result:



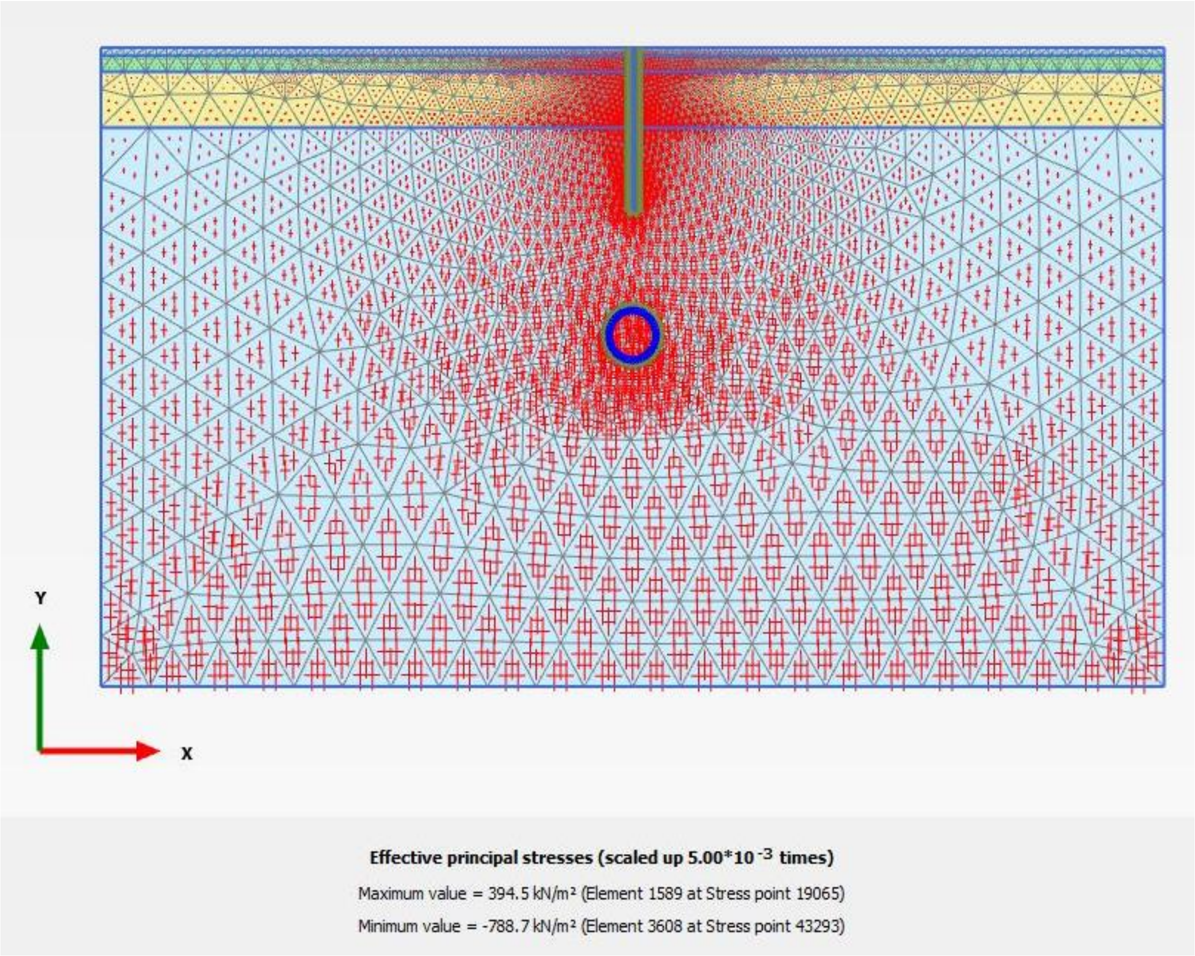
Total displacements u_y (scaled up 5.00 times)

Maximum value = 0.2202 m (Element 1112 at Node 199)

Minimum value = -0.8294 m (Element 1090 at Node 9712)

Figure 5. Total Displacements for depth 10m

We can found the effective principal stresses from result:



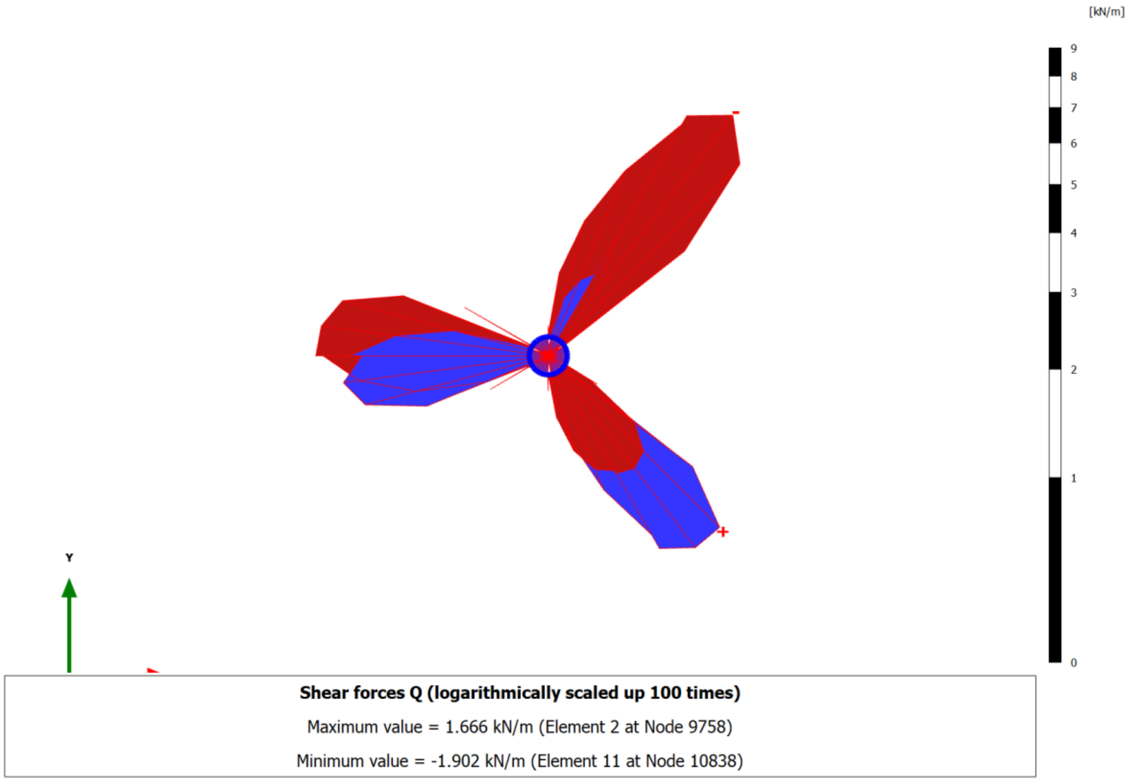
Effective principal stresses (scaled up $5.00*10^{-3}$ times)

Maximum value = 394.5 kN/m^2 (Element 1589 at Stress point 19065)

Minimum value = -788.7 kN/m^2 (Element 3608 at Stress point 43293)

Figure 6. Effective Principal Stresses for depth 10m

We can found the maximum and minimum shear forces from result:



Shear forces Q (logarithmically scaled up 100 times)

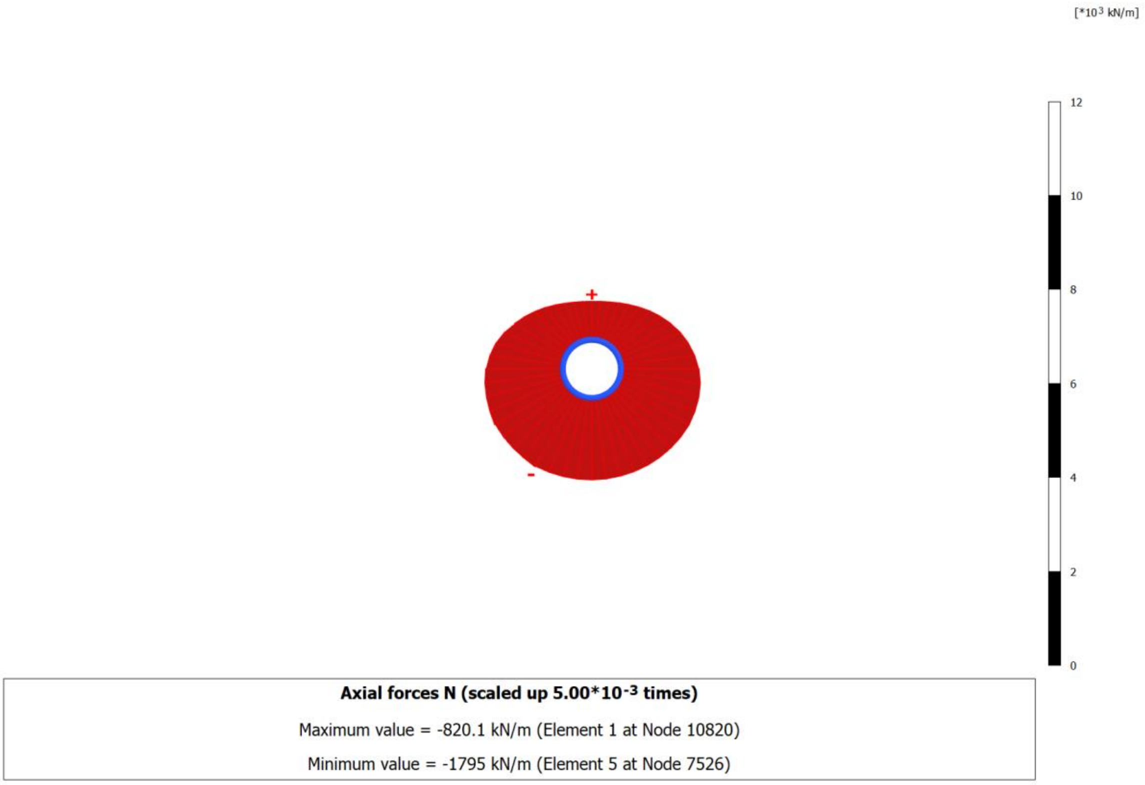
Maximum value = 1.666 kN/m (Element 2 at Node 9758)

Minimum value = -1.902 kN/m (Element 11 at Node 10838)

Figure 7. Shear forces for depth 10m

5.2.2. Profile #B, Tunnel depth 30m, Pile depth 15m

Results for settlement values, axial forces and bending moments with respect to 15m of pile depth is given below:



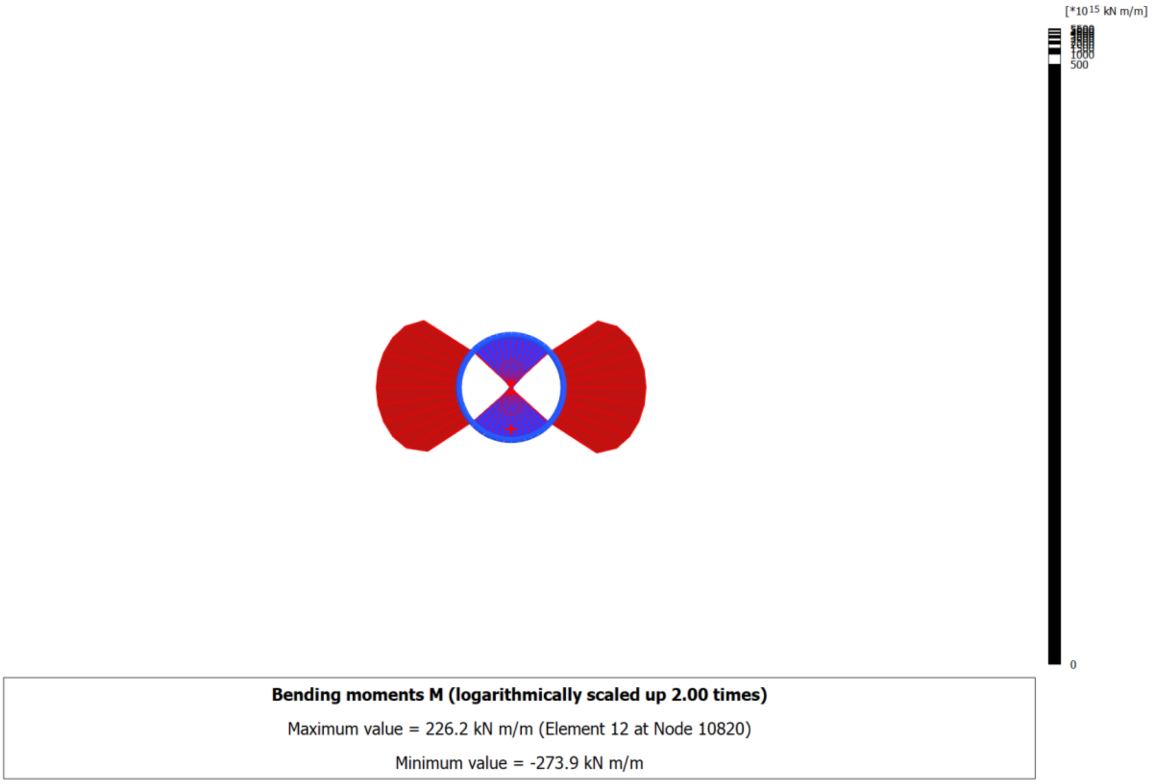
Axial forces N (scaled up $5.00*10^{-3}$ times)

Maximum value = -820.1 kN/m (Element 1 at Node 10820)

Minimum value = -1795 kN/m (Element 5 at Node 7526)

Figure 8. Axial Forces for depth 15m

We can found the maximum and minimum bending moment from result:



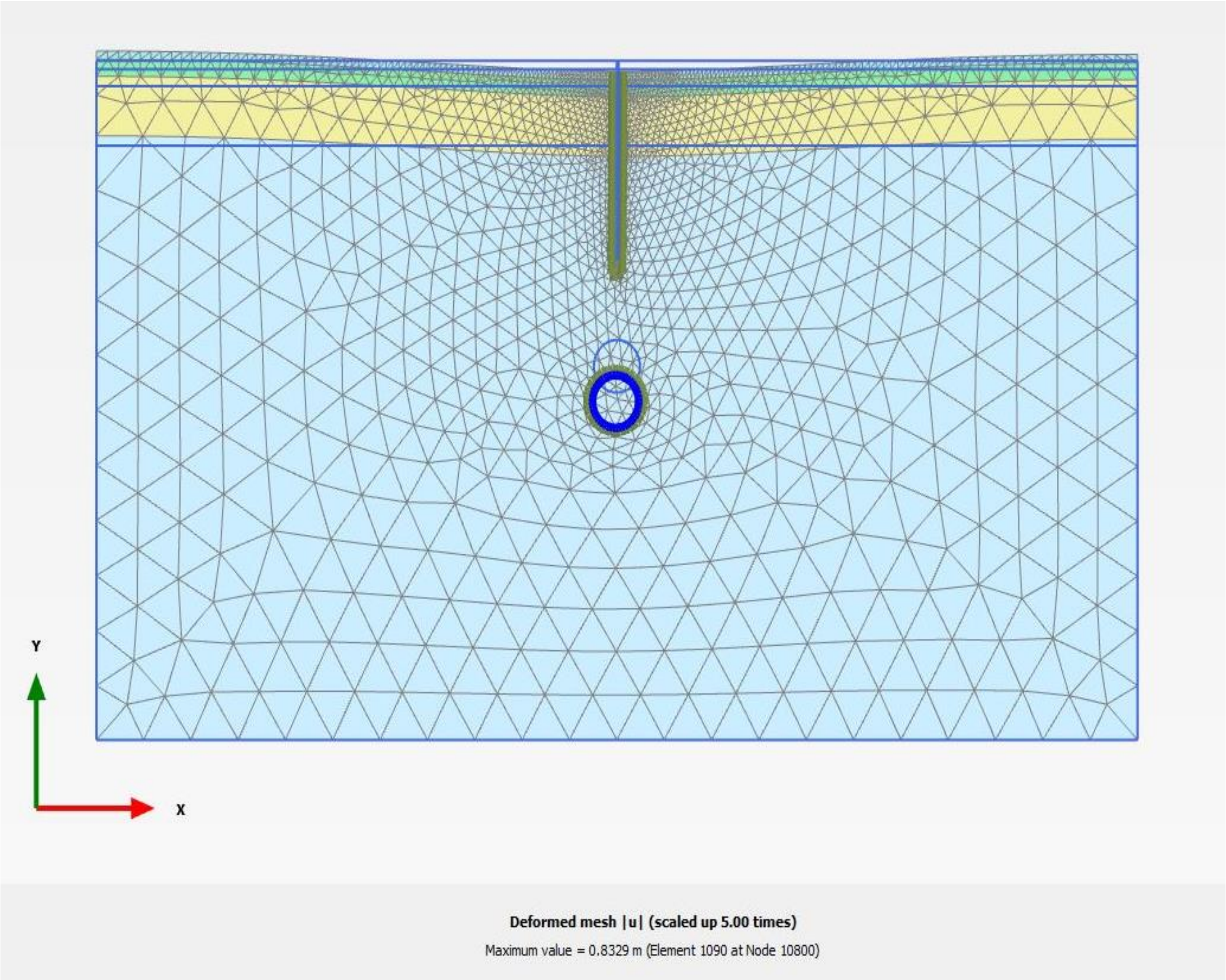
Bending moments M (logarithmically scaled up 2.00 times)

Maximum value = 226.2 kN m/m (Element 12 at Node 10820)

Minimum value = -273.9 kN m/m

Figure 9. Bending Moments for depth 15m

We can found the maximum value of deformed mesh from result:

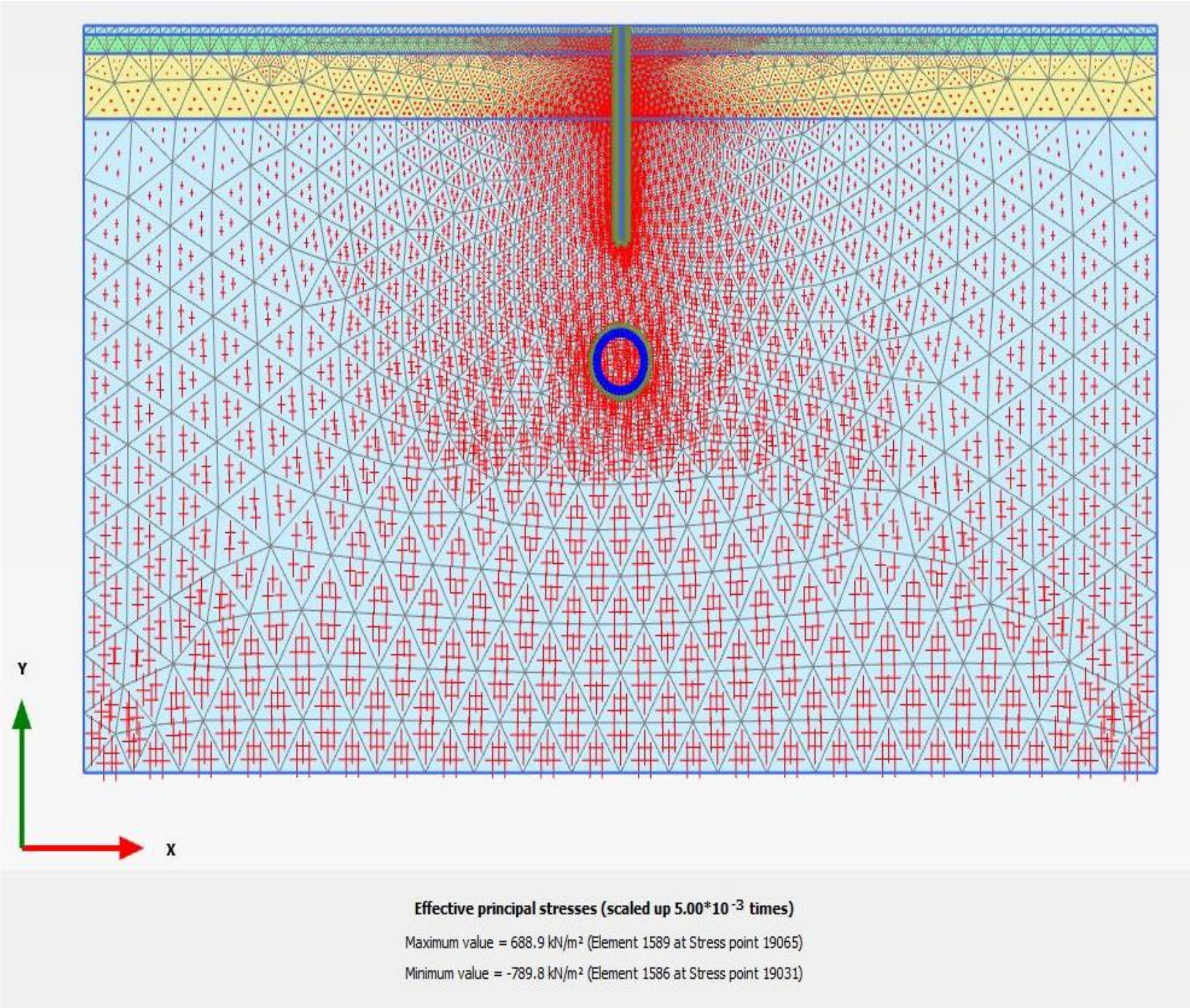


Deformed mesh |u| (scaled up 5.00 times)

Maximum value = 0.8329 m (Element 1090 at Node 10800)

Figure 10. Deformed Mesh [u] for depth 15m

We can found the effective principal stresses from result:



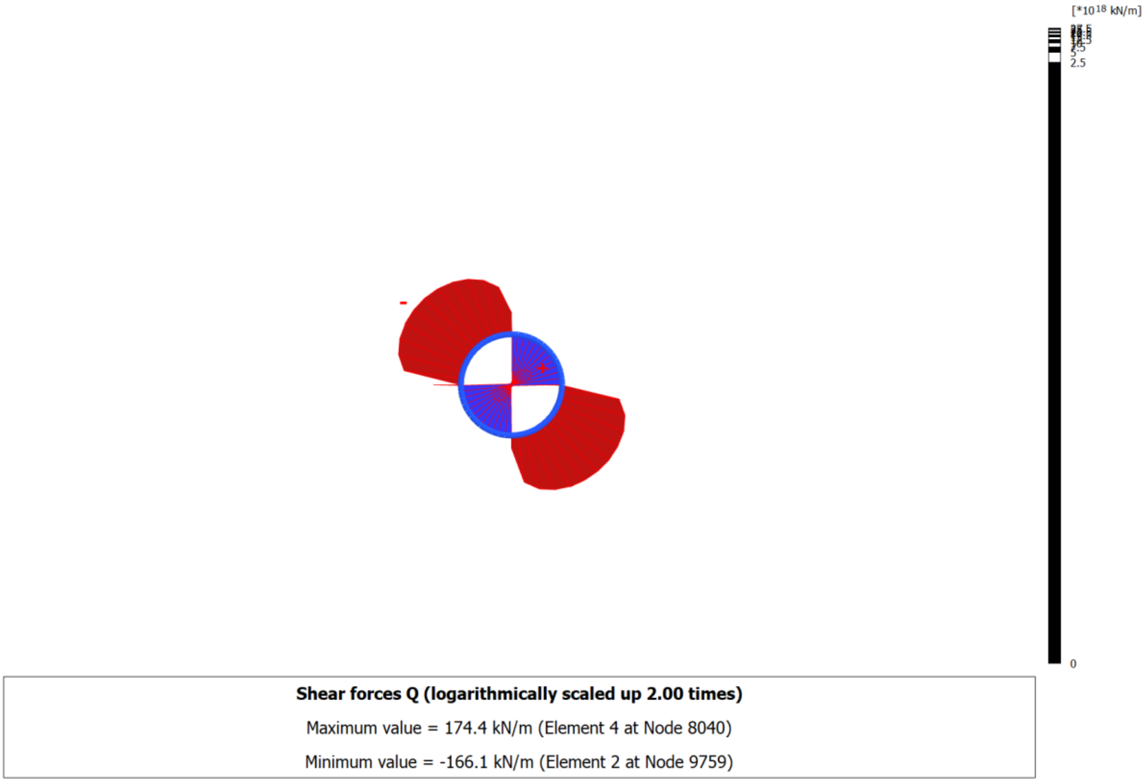
Effective principal stresses (scaled up 5.00*10 $^{-3}$ times)

Maximum value = 688.9 kN/m² (Element 1589 at Stress point 19065)

Minimum value = -789.8 kN/m² (Element 1586 at Stress point 19031)

Figure 11. Effective Principal Stresses for depth 15m

We can found the maximum and minimum shear forces from result:



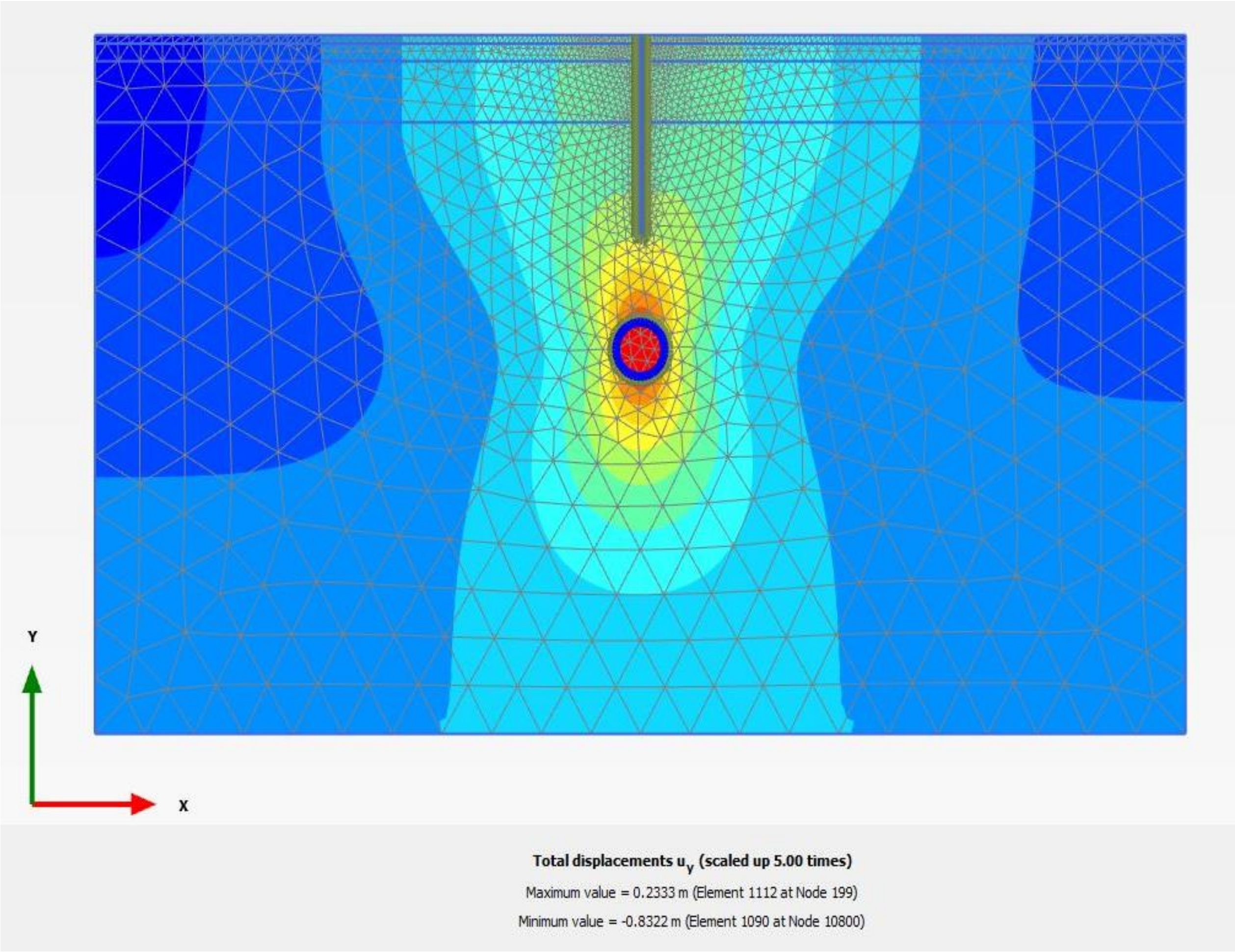
Shear forces Q (logarithmically scaled up 2.00 times)

Maximum value = 174.4 kN/m (Element 4 at Node 8040)

Minimum value = -166.1 kN/m (Element 2 at Node 9759)

Figure 12. Shear forces for depth 15m

We can found the total settlements value from result:



Total displacements u_y (scaled up 5.00 times)

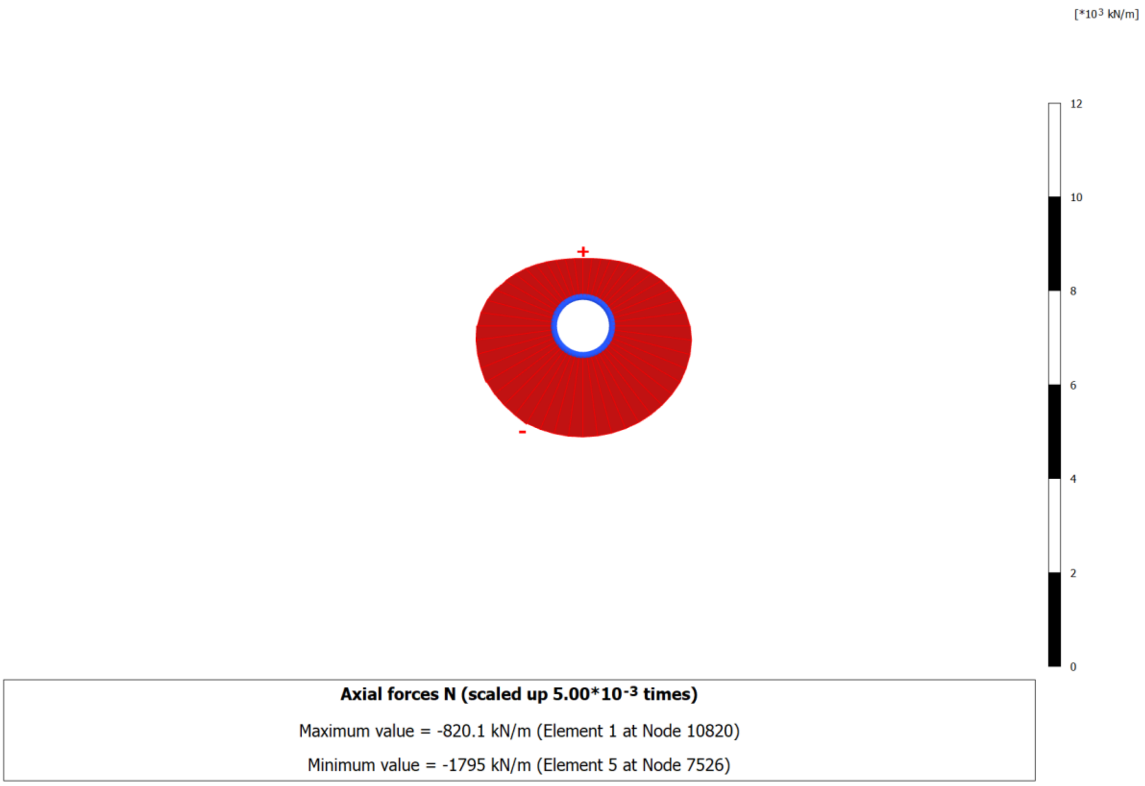
Maximum value = 0.2333 m (Element 1112 at Node 199)

Minimum value = -0.8322 m (Element 1090 at Node 10800)

Figure 13. Total displacements for depth 15m

5.2.3. Profile #C, Tunnel depth 30m, Pile depth17m

Results for settlement values, axial forces and bending moments with respect to 17m of pile depth is given below:



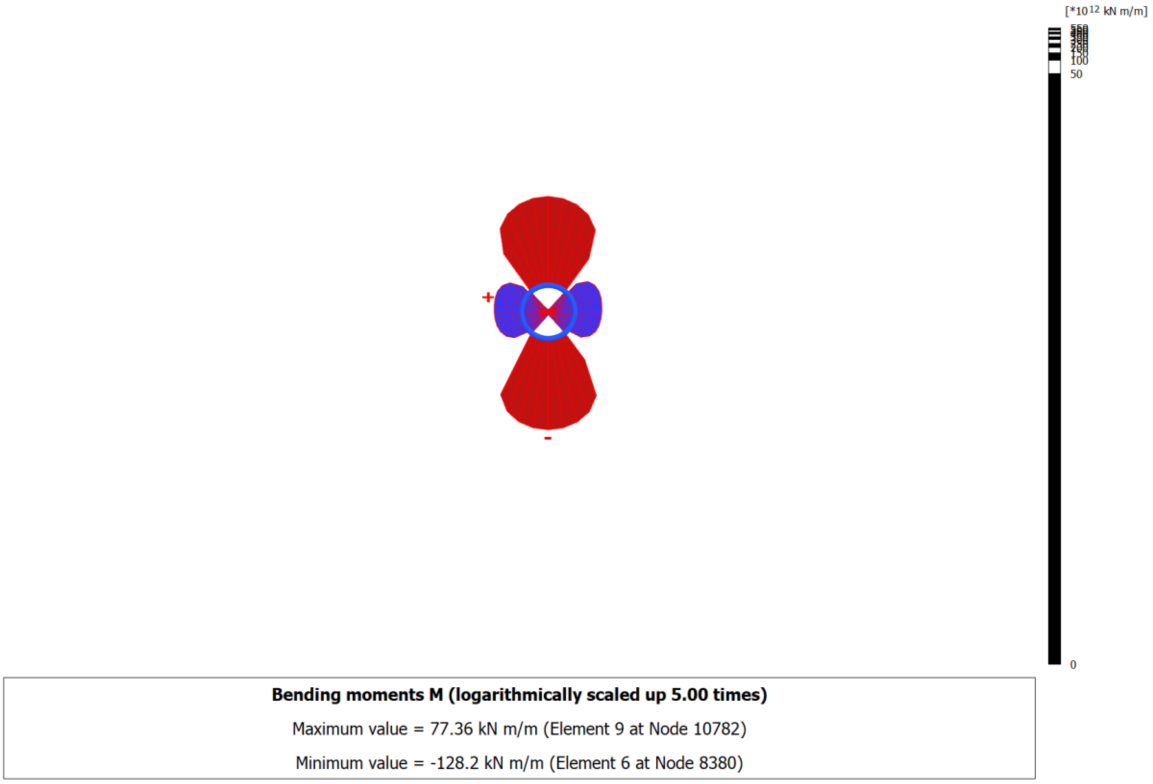
Axial forces N (scaled up $5.00*10^{-3}$ times)

Maximum value = -820.1 kN/m (Element 1 at Node 10820)

Minimum value = -1795 kN/m (Element 5 at Node 7526)

Figure 14. Axial forces for depth 17m

We can found the maximum and minimum bending moments from result:



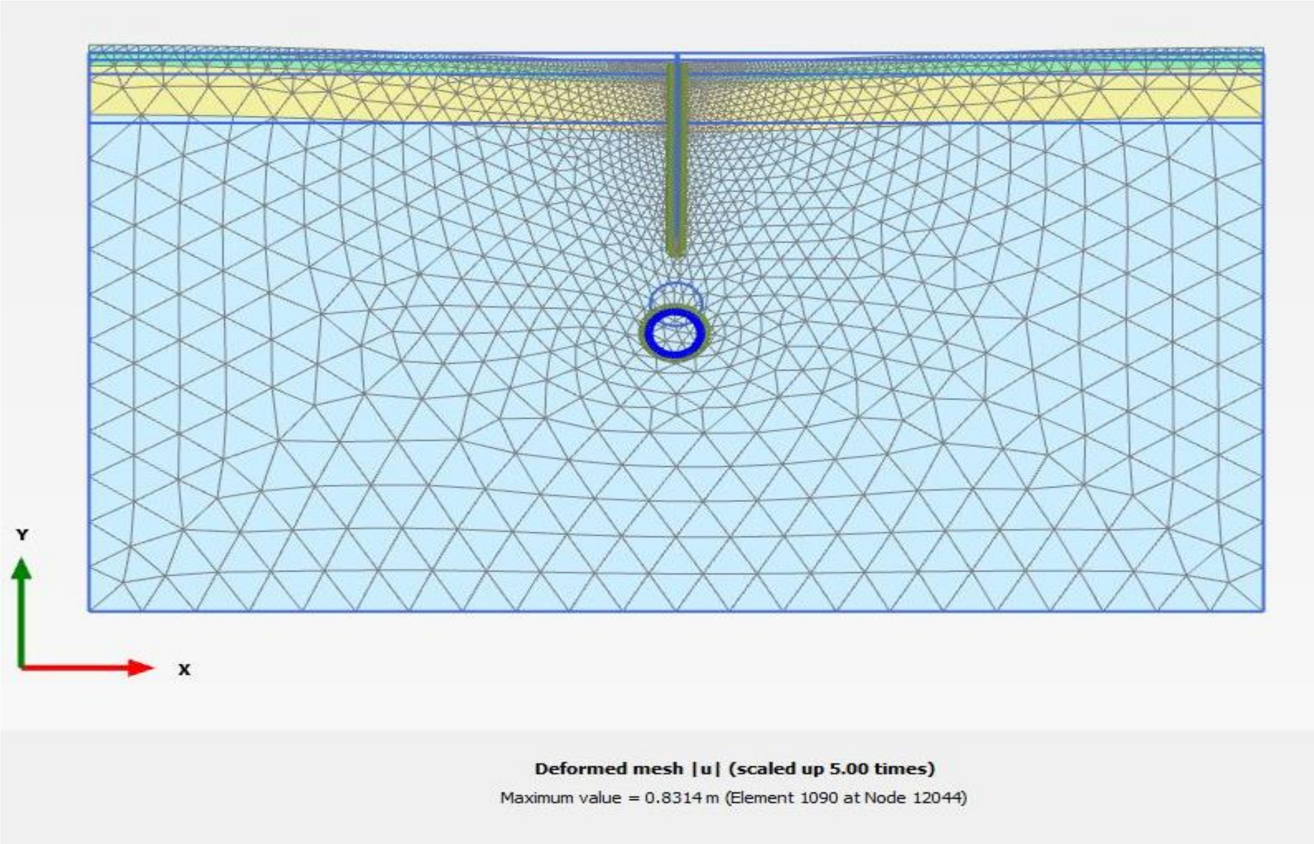
Bending moments M (logarithmically scaled up 5.00 times)

Maximum value = 77.36 kN m/m (Element 9 at Node 10782)

Minimum value = -128.2 kN m/m (Element 6 at Node 8380)

Figure 15. Bending moments for depth 17m

We can found the value of deformed mesh from result:

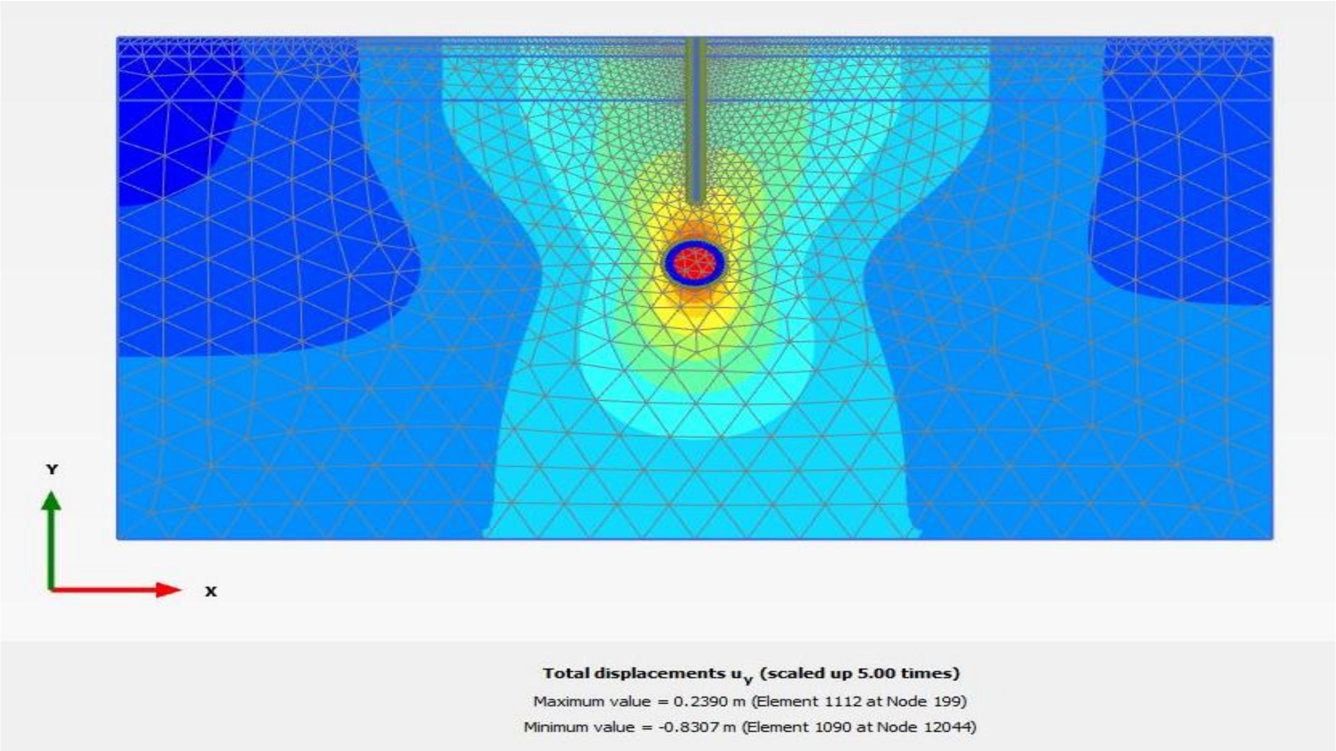


Deformed mesh |u| (scaled up 5.00 times)

Maximum value = 0.8314 m (Element 1090 at Node 12044)

Figure 16. Deformed mesh [u] for depth 17m

We can found the total settlements value from result:



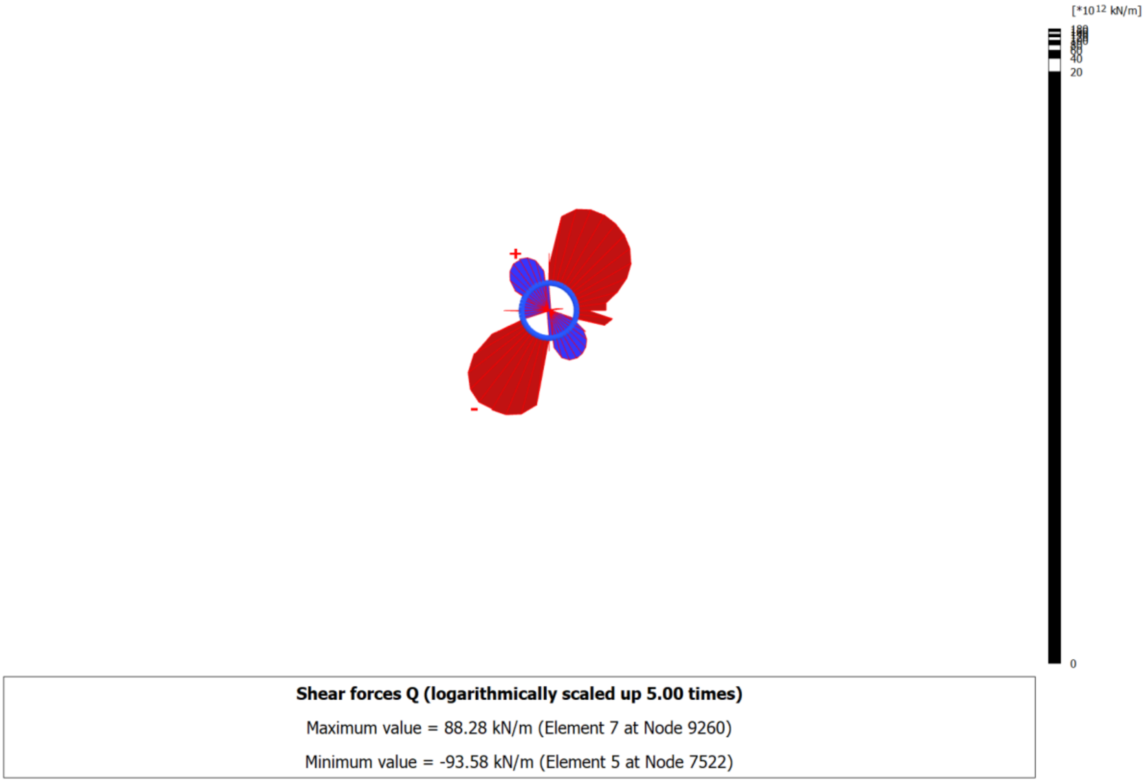
Total displacements u_y (scaled up 5.00 times)

Maximum value = 0.2390 m (Element 1112 at Node 199)

Minimum value = -0.8307 m (Element 1090 at Node 12044)

Figure 17. Total displacements for depth 17m

We can found the maximum and minimum shear forces from result:



Shear forces Q (logarithmically scaled up 5.00 times)

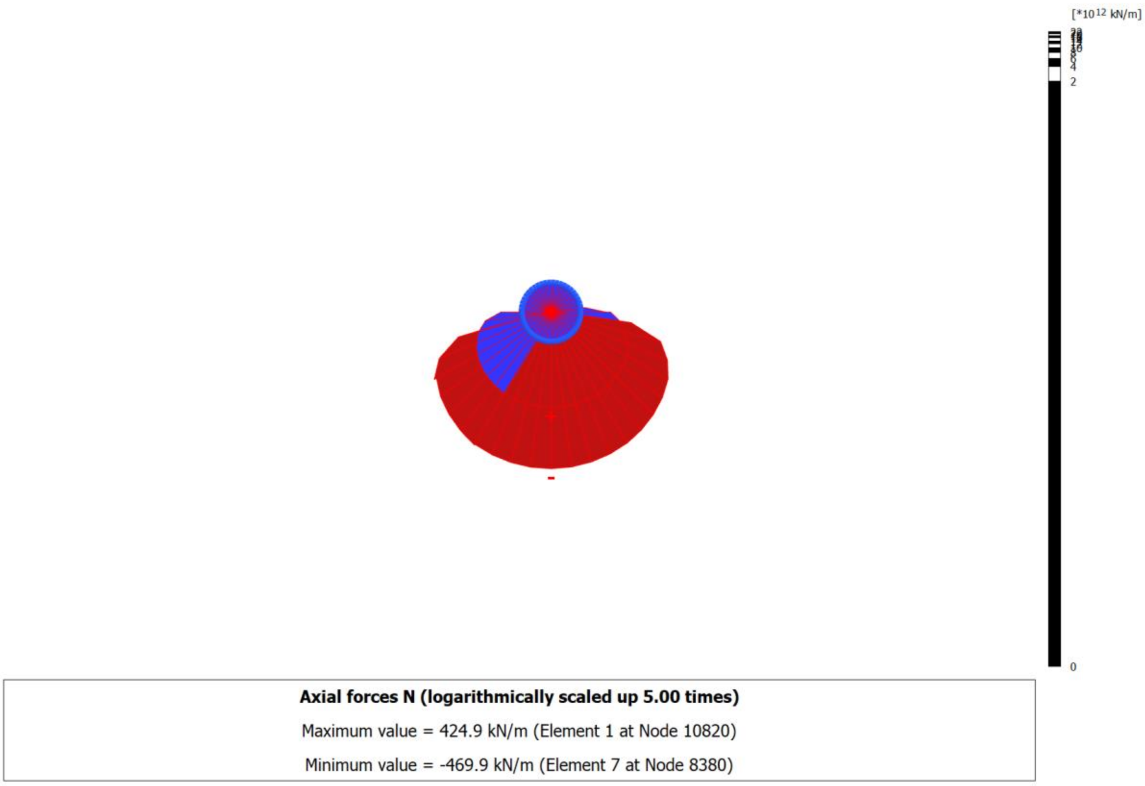
Maximum value = 88.28 kN/m (Element 7 at Node 9260)

Minimum value = -93.58 kN/m (Element 5 at Node 7522)

Figure 18. Shear forces for depth 17

5.2.4. Profile #D, Tunnel depth 30m, Pile depth 19m

Results for settlement values, axial forces and bending moments with respect to 19m of pile depth is given below:



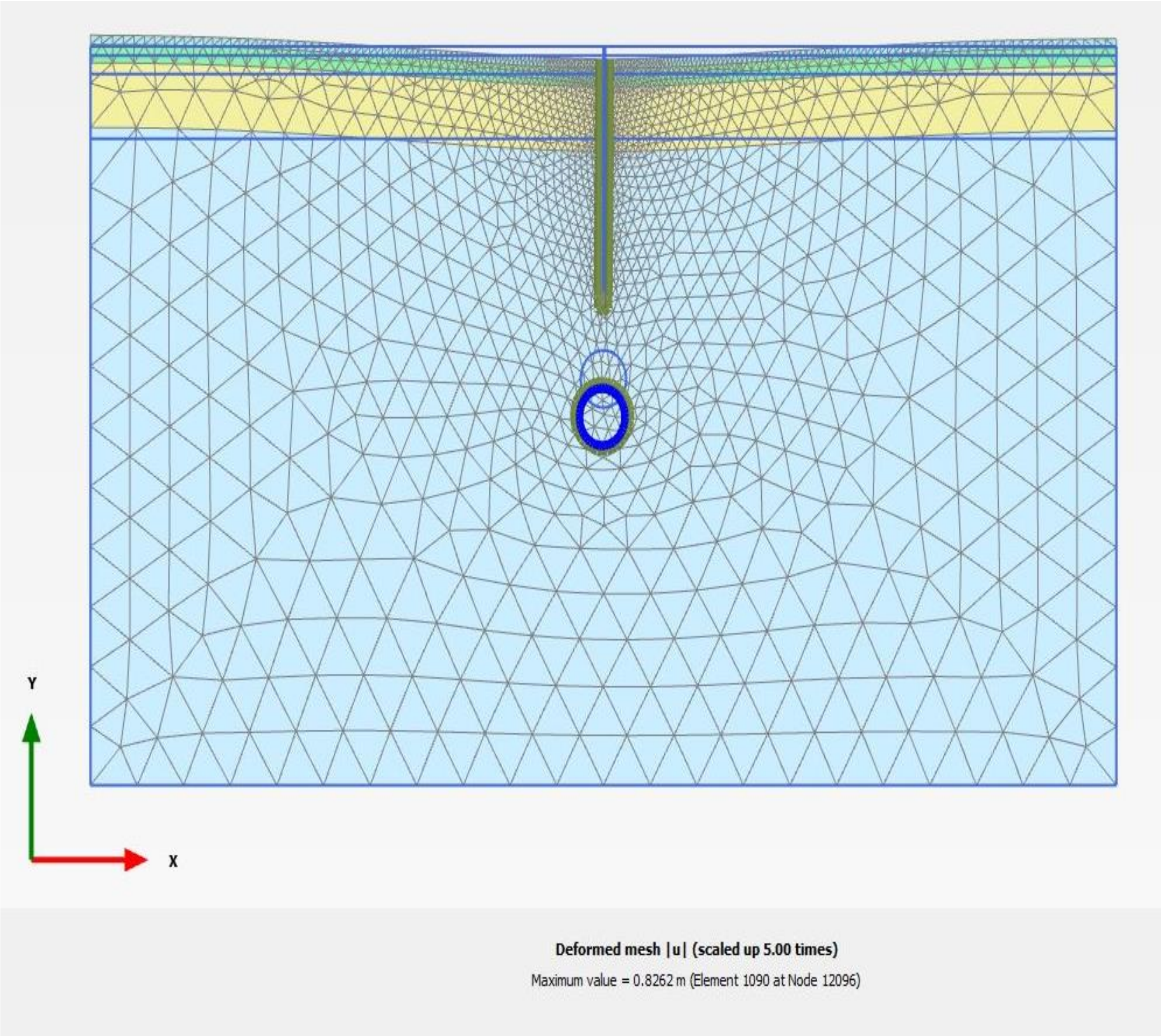
Axial forces N (logarithmically scaled up 5.00 times)

Maximum value = 424.9 kN/m (Element 1 at Node 10820)

Minimum value = -469.9 kN/m (Element 7 at Node 8380)

Figure 19. Axial forces for depth 19m

We can found the value for deformed mesh from result:

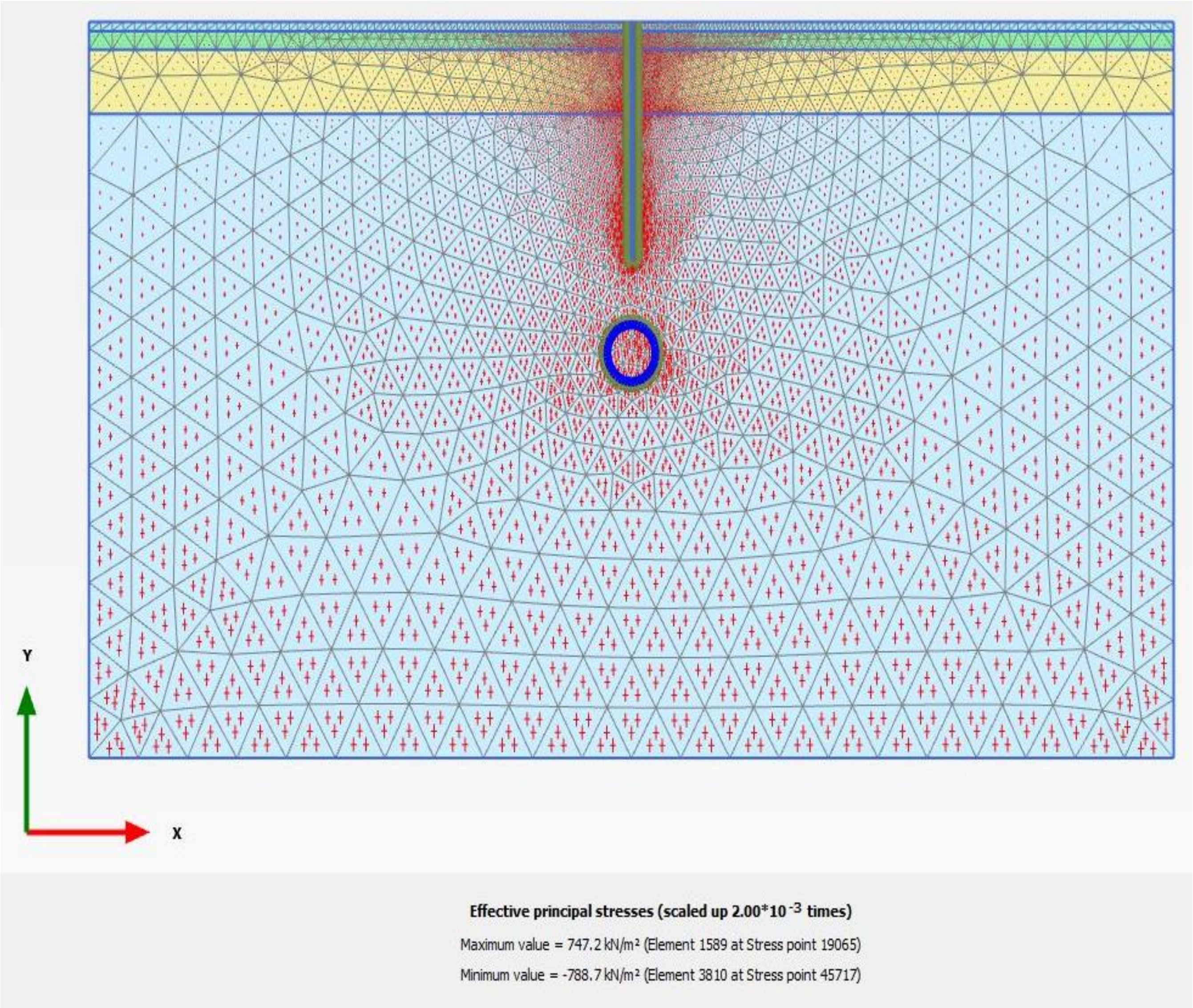


Deformed mesh |u| (scaled up 5.00 times)

Maximum value = 0.8262 m (Element 1090 at Node 12096)

Figure 20. Deformed mesh for depth 19m

We can found the effective principal stresses from result:



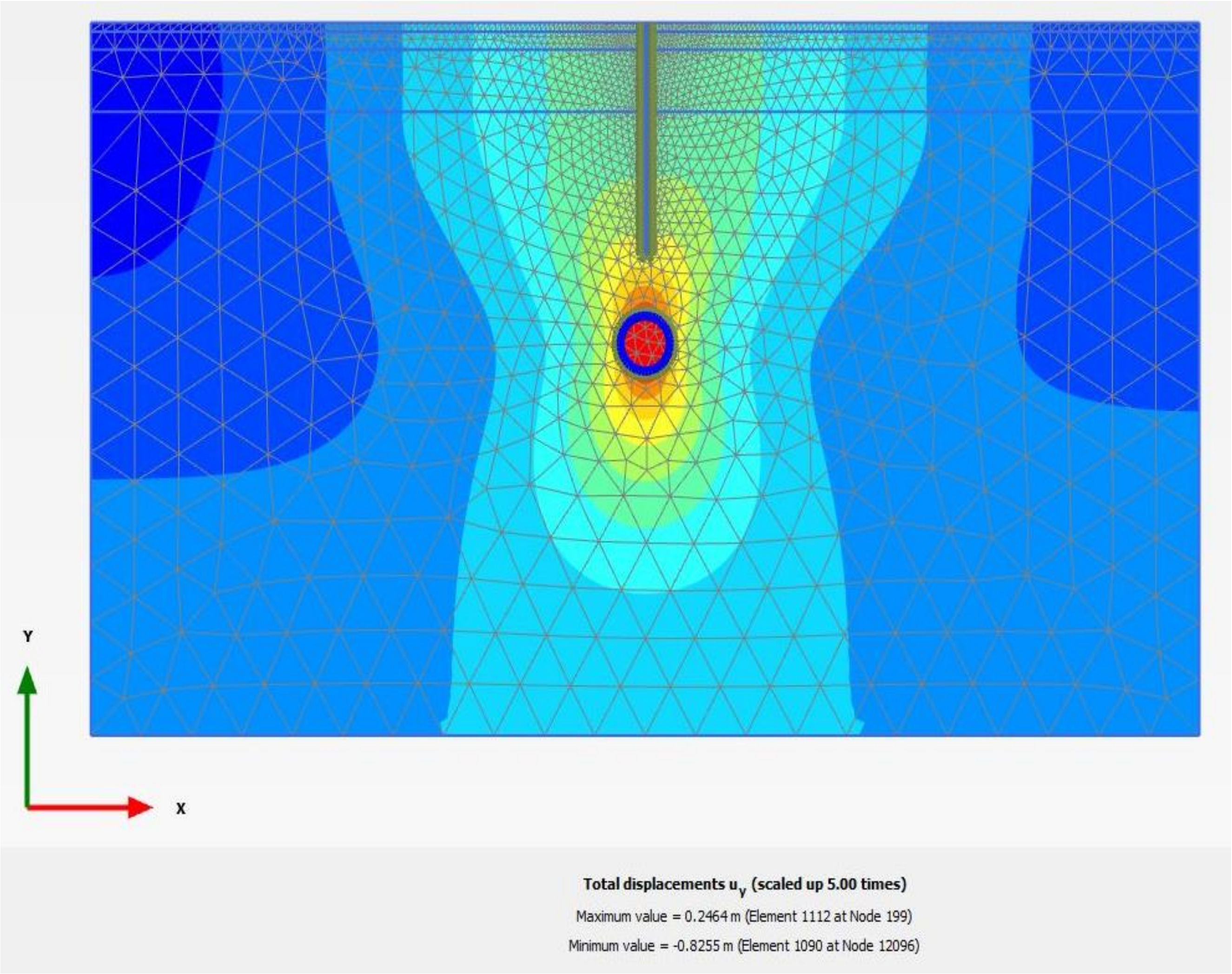
Effective principal stresses (scaled up 2.00*10 $^{-3}$ times)

Maximum value = 747.2 kN/m² (Element 1589 at Stress point 19065)

Minimum value = -788.7 kN/m² (Element 3810 at Stress point 45717)

Figure 21. Effective principal stresses for depth 19m

We can found the total settlements value from result:



Total displacements u_y (scaled up 5.00 times)

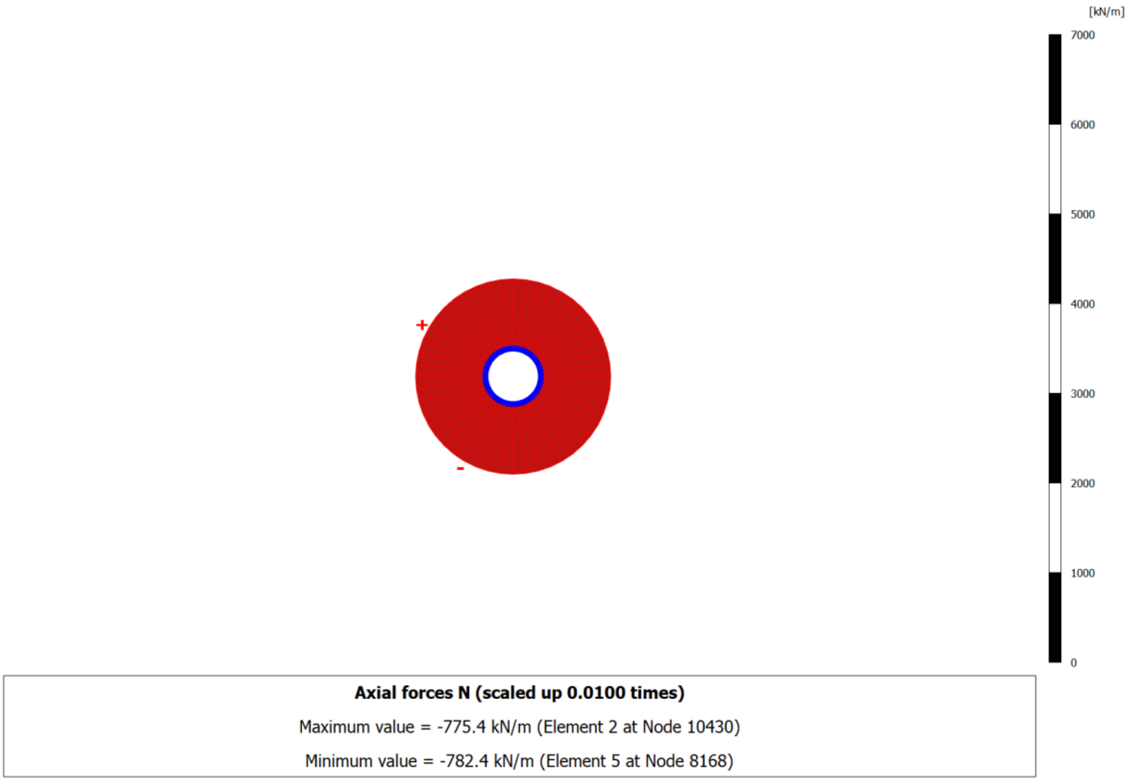
Maximum value = 0.2464 m (Element 1112 at Node 199)

Minimum value = -0.8255 m (Element 1090 at Node 12096)

Figure 22. Total displacements for depth 19m

5.2.5. Profile #E, Tunnel depth 30m, Pile depth 20m

Results for settlement values, axial forces and bending moments with respect to 20m of pile depth is given below:



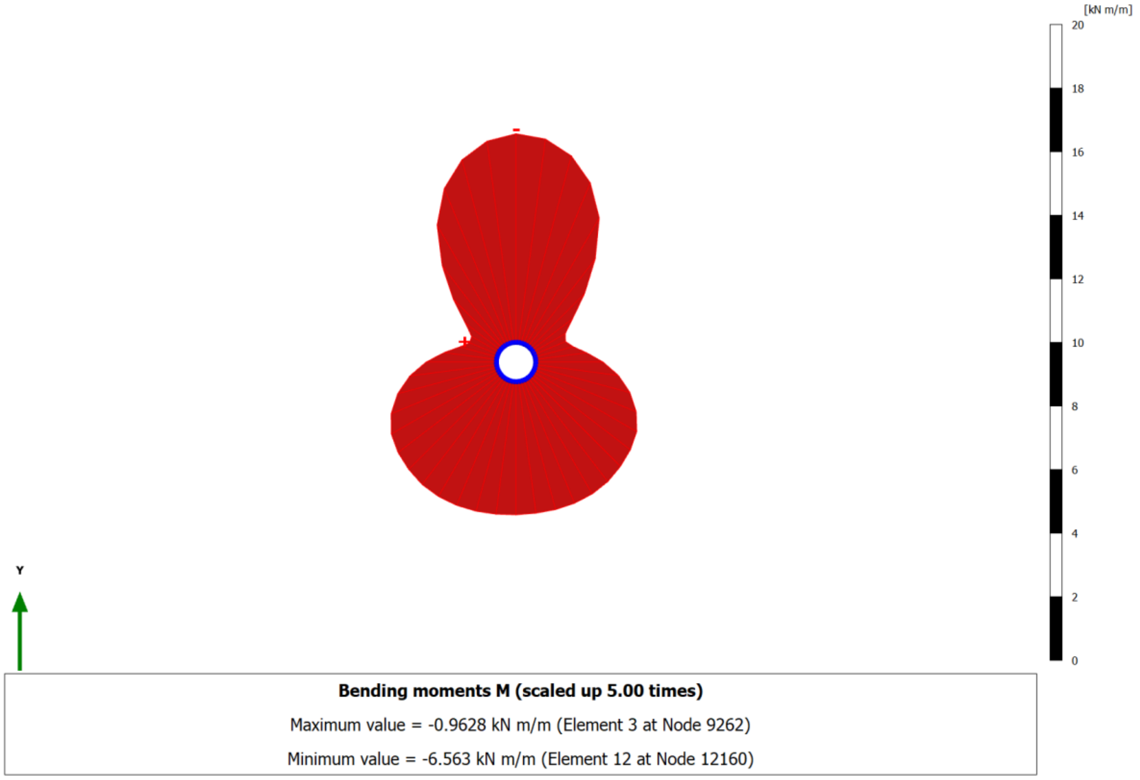
Axial forces N (scaled up 0.0100 times)

Maximum value = -775.4 kN/m (Element 2 at Node 10430)

Minimum value = -782.4 kN/m (Element 5 at Node 8168)

Figure 23. Axial forces for depth 20m

We can found the maximum and minimum bending moments from result:



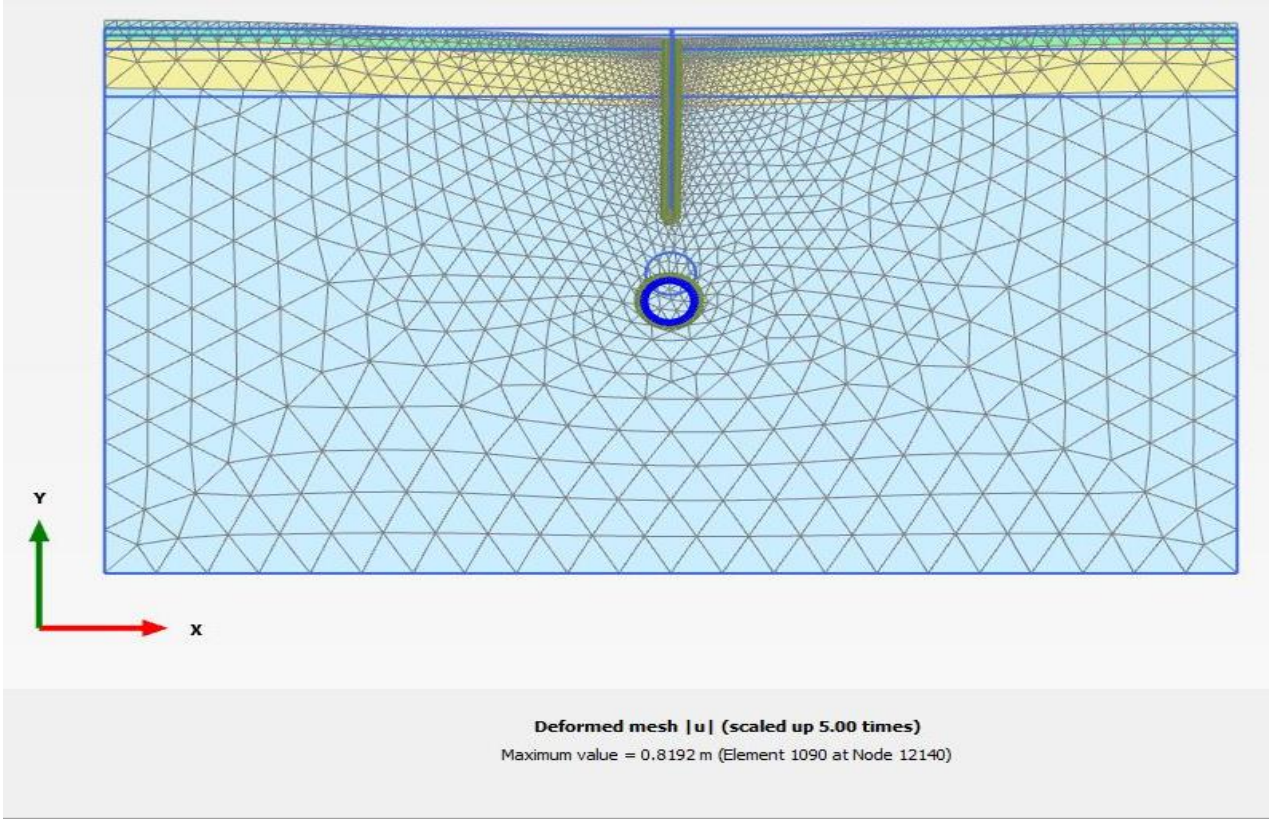
Bending moments M (scaled up 5.00 times)

Maximum value = -0.9628 kN m/m (Element 3 at Node 9262)

Minimum value = -6.563 kN m/m (Element 12 at Node 12160)

Figure 24. Bending moments for depth 20m

We can find the value for deformed mesh from this result:

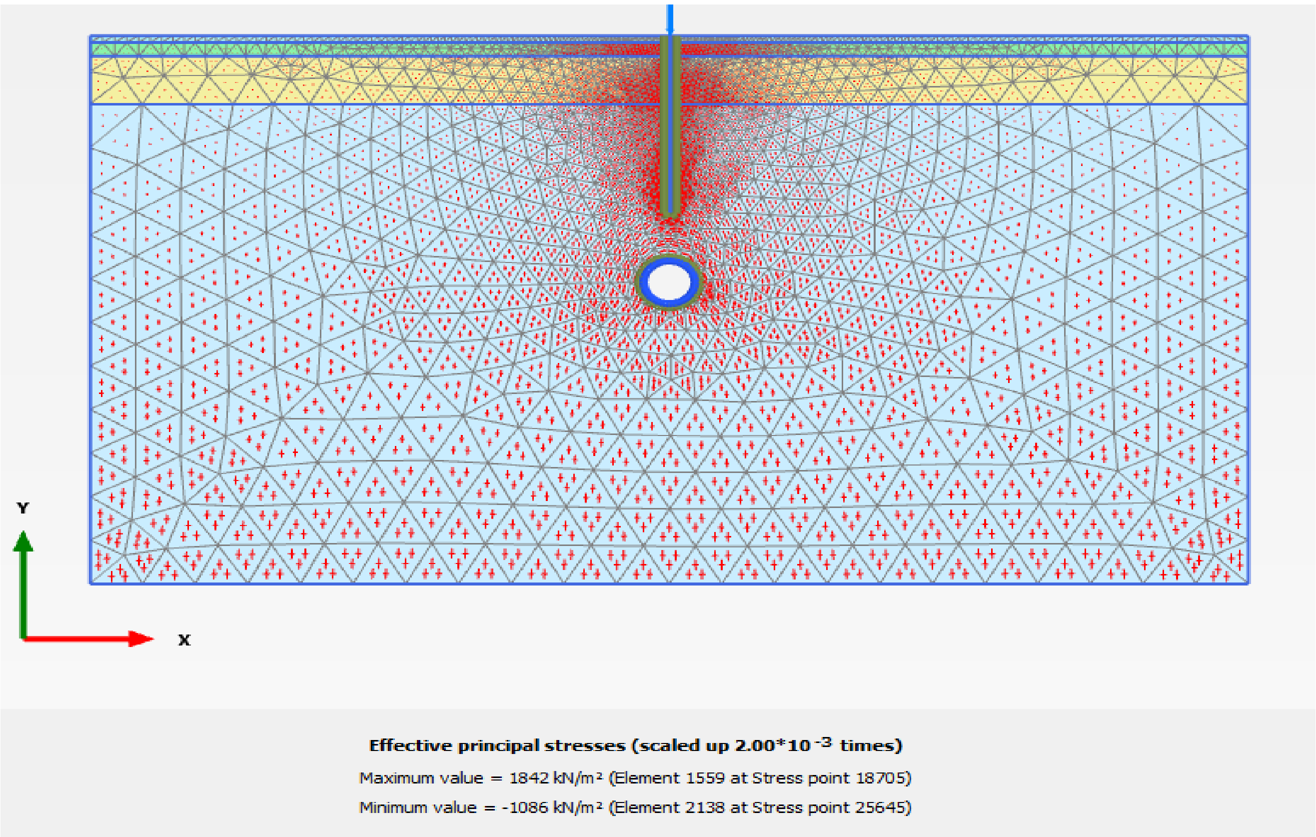


Deformed mesh |u| (scaled up 5.00 times)

Maximum value = 0.8192 m (Element 1090 at Node 12140)

Figure 25. Deformed mesh for depth 20m

We can find effective principal stresses from this result:



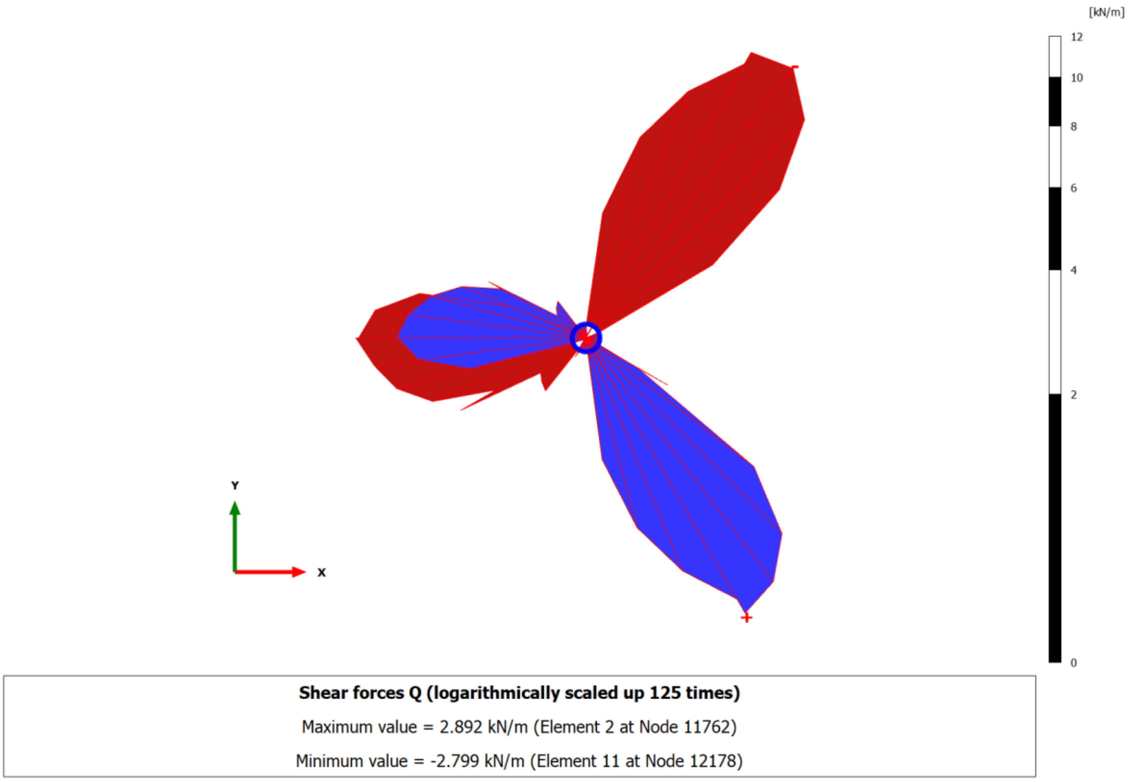
Effective principal stresses (scaled up $2.00*10^{-3}$ times)

Maximum value = 1842 kN/m² (Element 1559 at Stress point 18705)

Minimum value = -1086 kN/m² (Element 2138 at Stress point 25645)

Figure 26. Effective principal stresses for depth 20m

We can found the maximum and minimum shear forces from result:



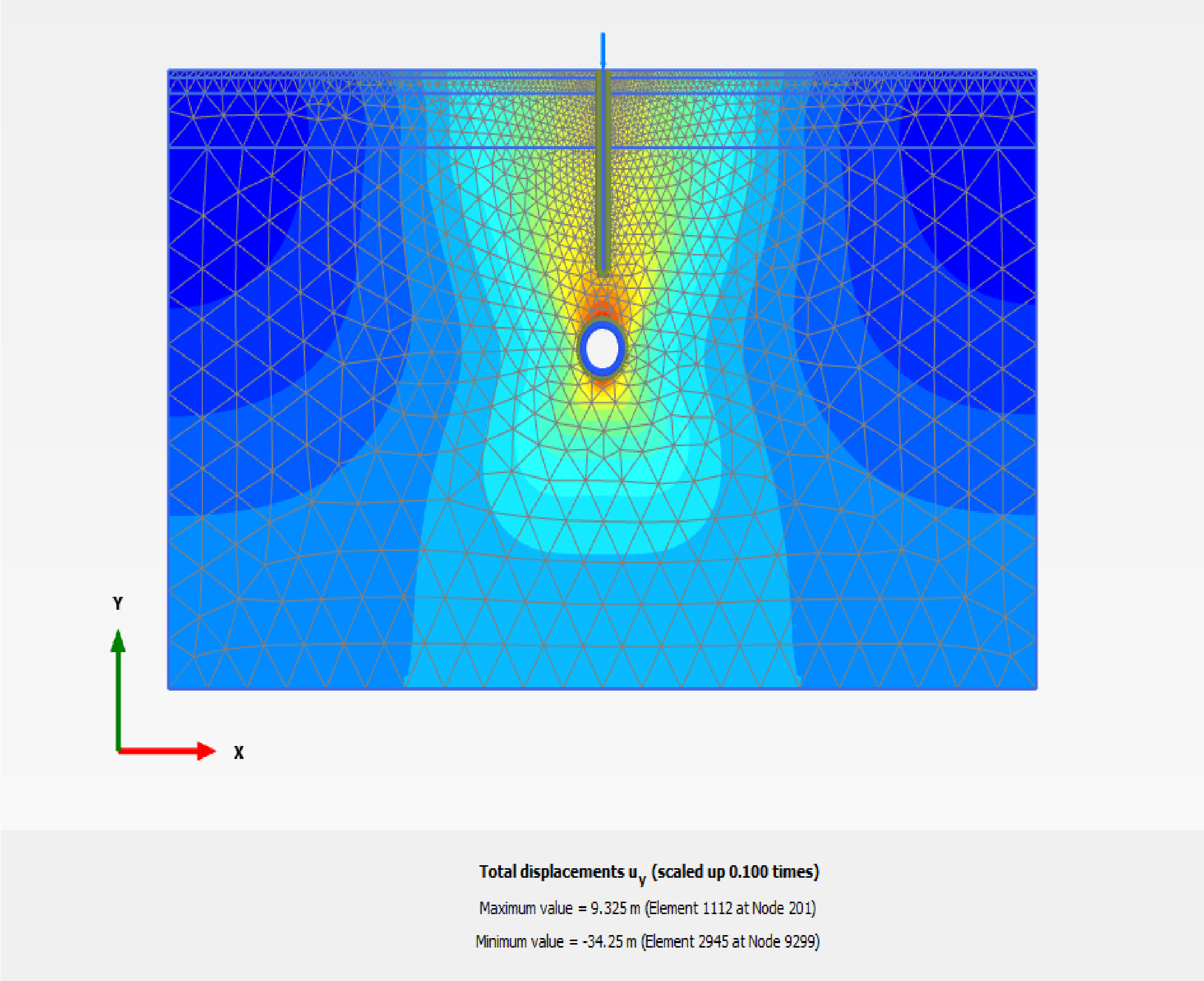
Shear forces Q (logarithmically scaled up 125 times)

Maximum value = 2.892 kN/m (Element 2 at Node 11762)

Minimum value = -2.799 kN/m (Element 11 at Node 12178)

Figure 27. Shear forces for depth 20m

We can find the total settlements value from this result:



Total displacements u_y (scaled up 0.100 times)

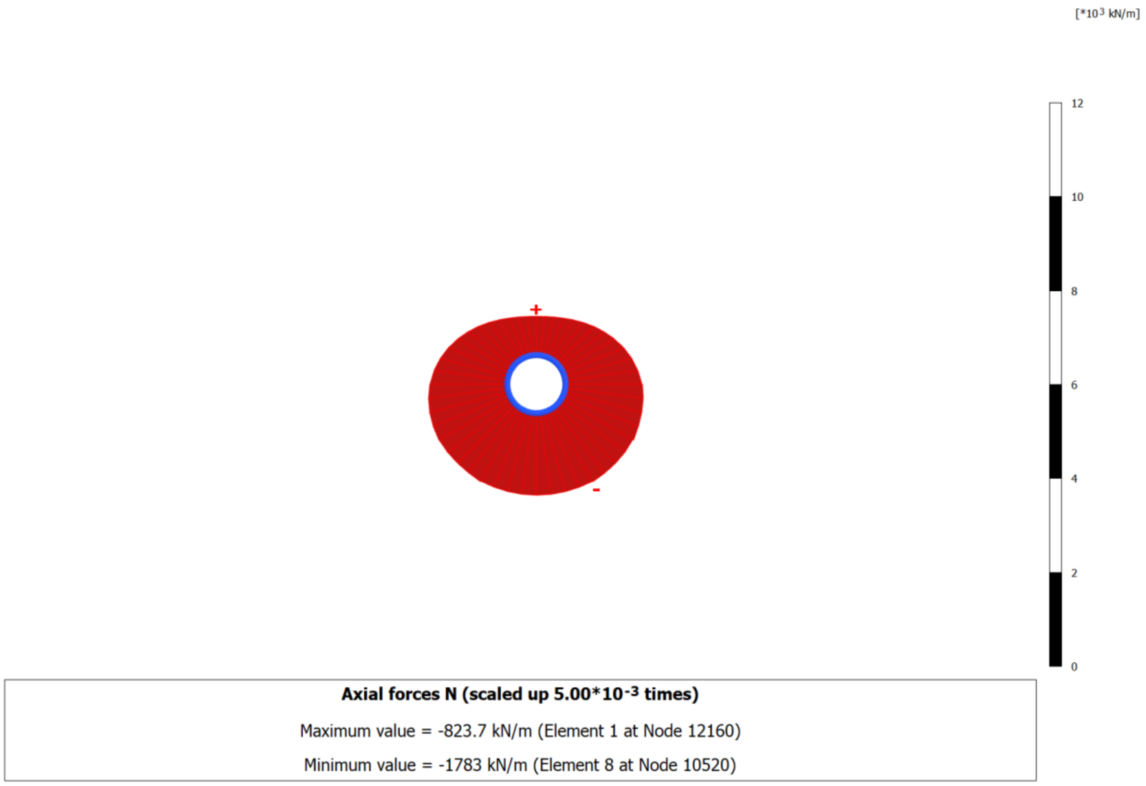
Maximum value = 9.325 m (Element 1112 at Node 201)

Minimum value = -34.25 m (Element 2945 at Node 9299)

Figure 28. Total displacements for depth 20m

5.2.6. Profile #F, Tunnel depth 30m, Pile depth 25m

Results for settlement values, axial forces and bending moments with respect to 25m of pile depth is given below:



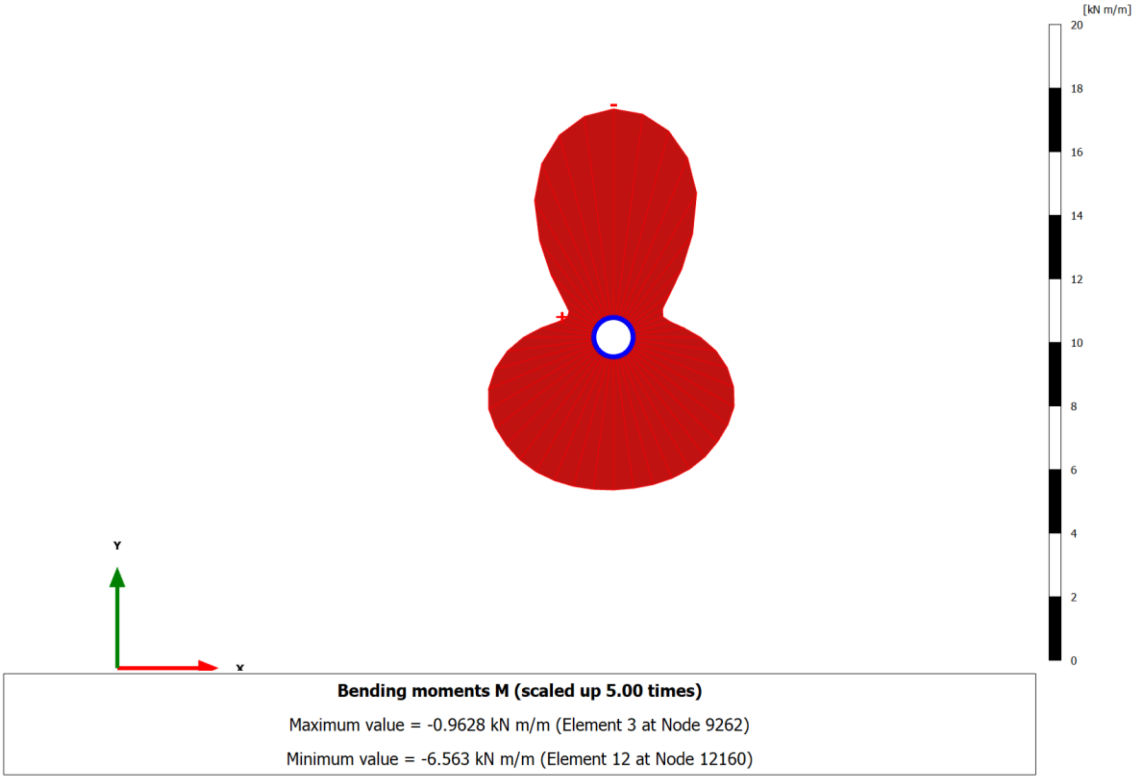
Axial forces N (scaled up $5.00*10^{-3}$ times)

Maximum value = -823.7 kN/m (Element 1 at Node 12160)

Minimum value = -1783 kN/m (Element 8 at Node 10520)

Figure 29. Axial forces for depth 25m

We can find the maximum and minimum bending moments value from this result:



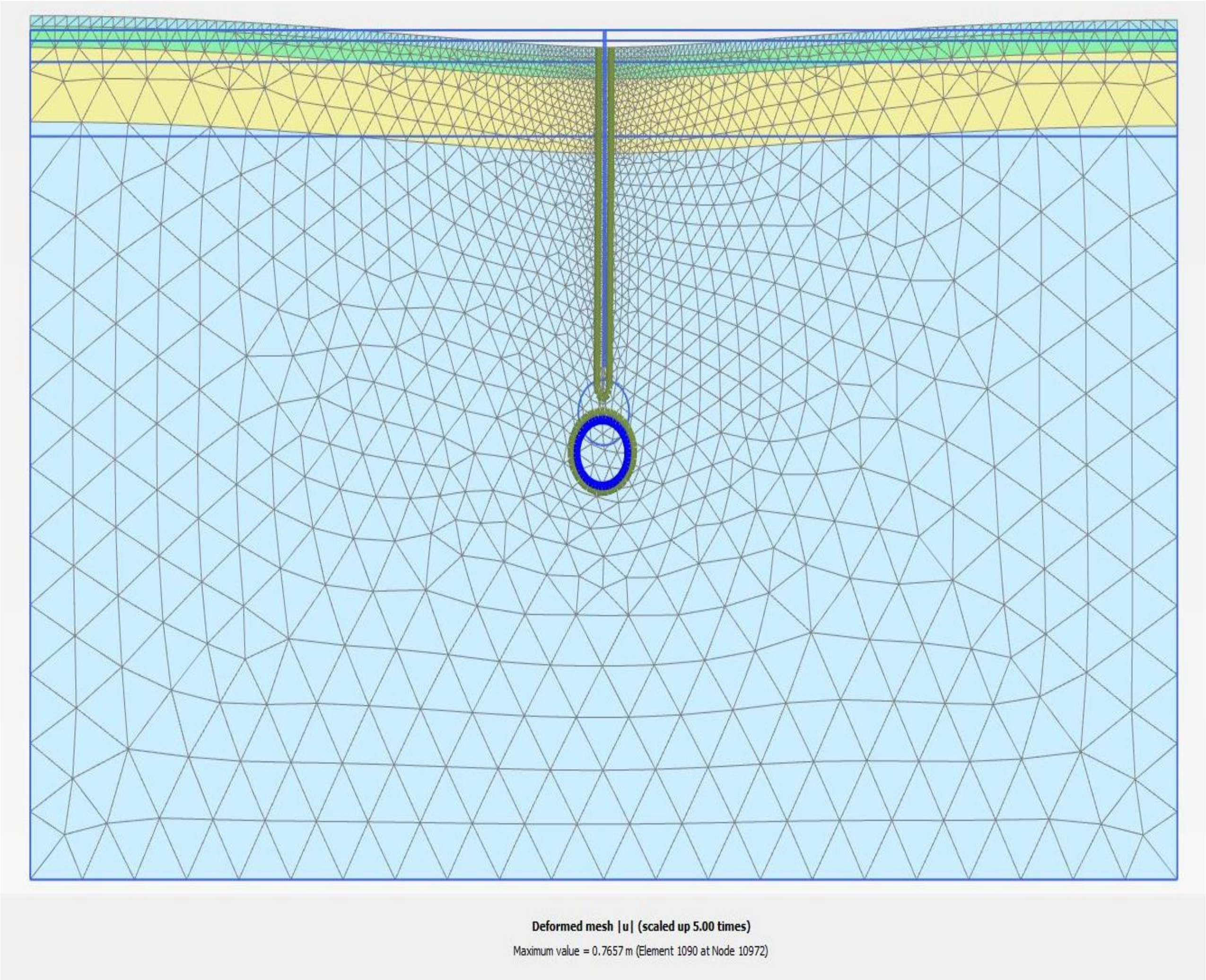
Bending moments M (scaled up 5.00 times)

Maximum value = -0.9628 kN m/m (Element 3 at Node 9262)

Minimum value = -6.563 kN m/m (Element 12 at Node 12160)

Figure 30. Bending moments for depth 25m

We can find the value for deformed mesh from this result:

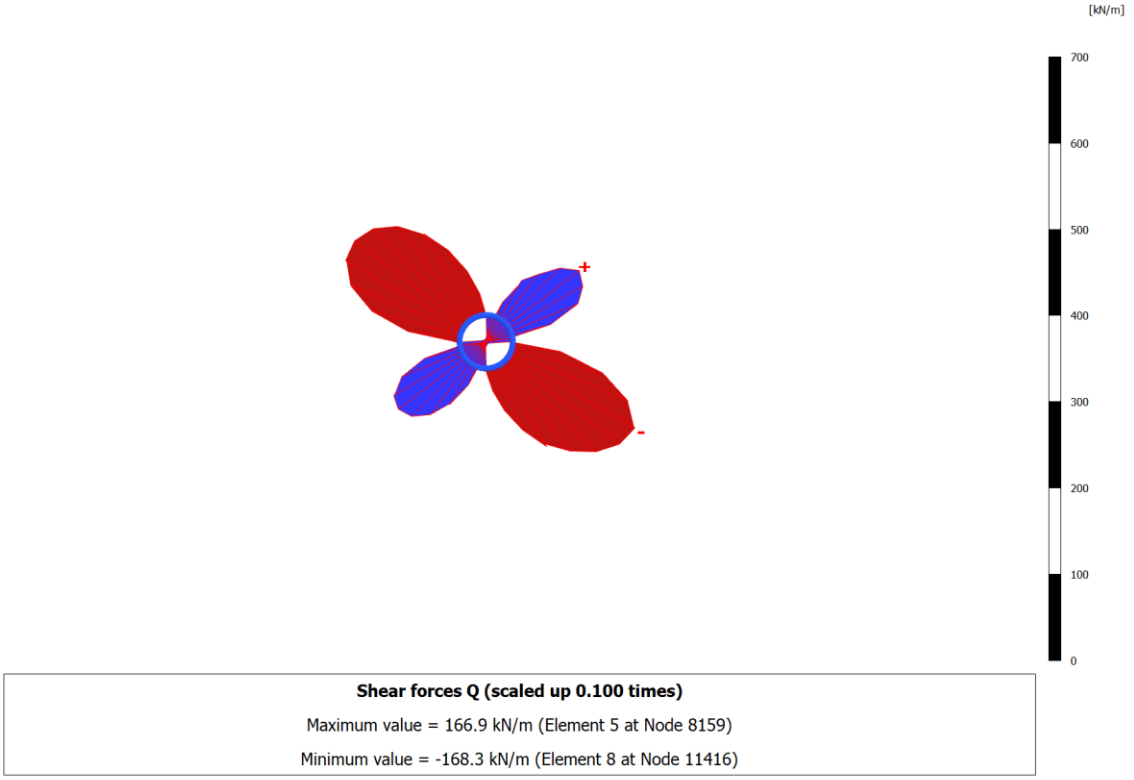


Deformed mesh |u| (scaled up 5.00 times)

Maximum value = 0.7657 m (Element 1090 at Node 10972)

Figure 31. Deformed mesh for depth 25m

We can found the maximum and minimum shear forces from result:



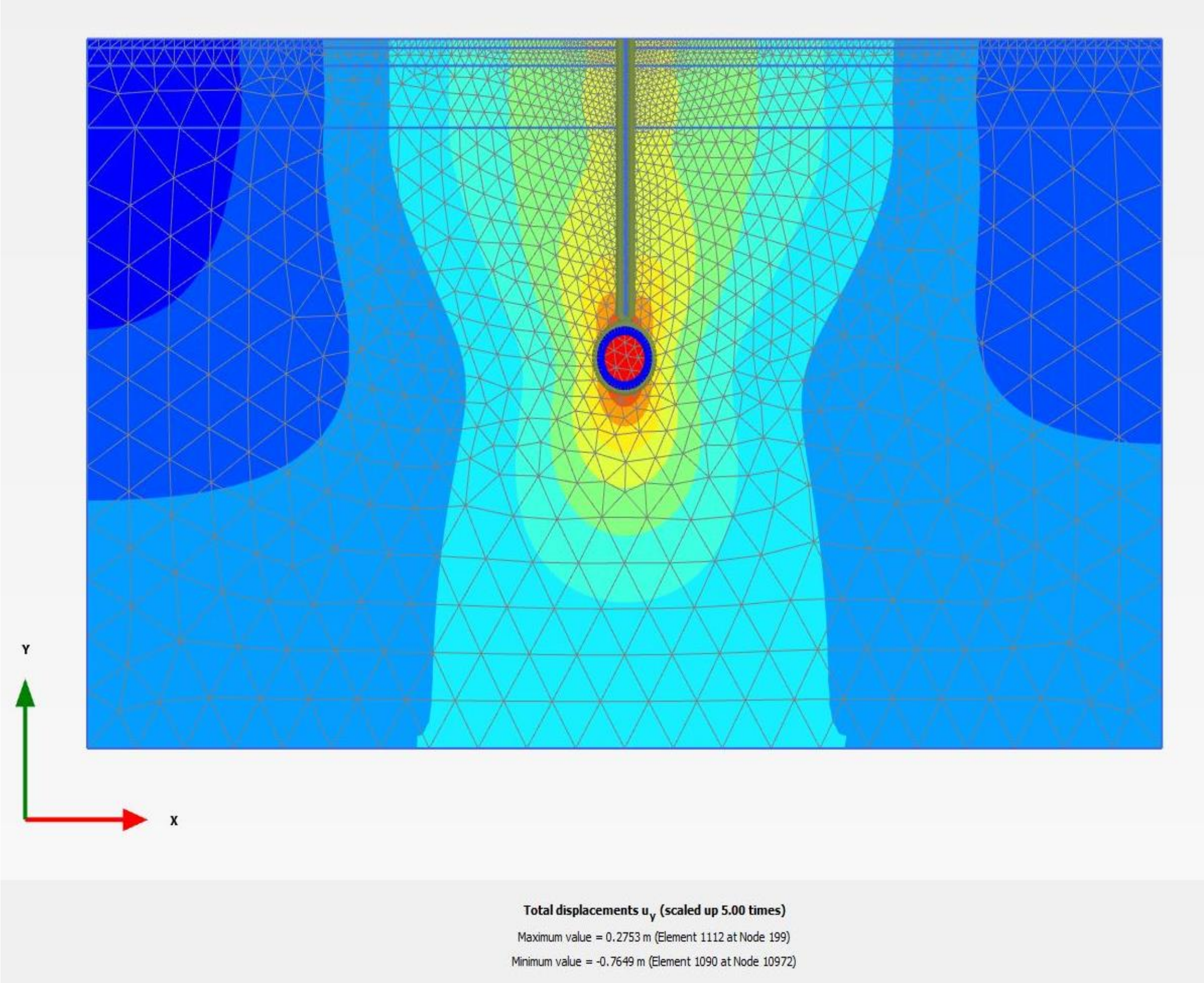
Shear forces Q (scaled up 0.100 times)

Maximum value = 166.9 kN/m (Element 5 at Node 8159)

Minimum value = -168.3 kN/m (Element 8 at Node 11416)

Figure 32. Shear forces for depth 25m

We can find the total settlement value from our result:



Total displacements u_y (scaled up 5.00 times)

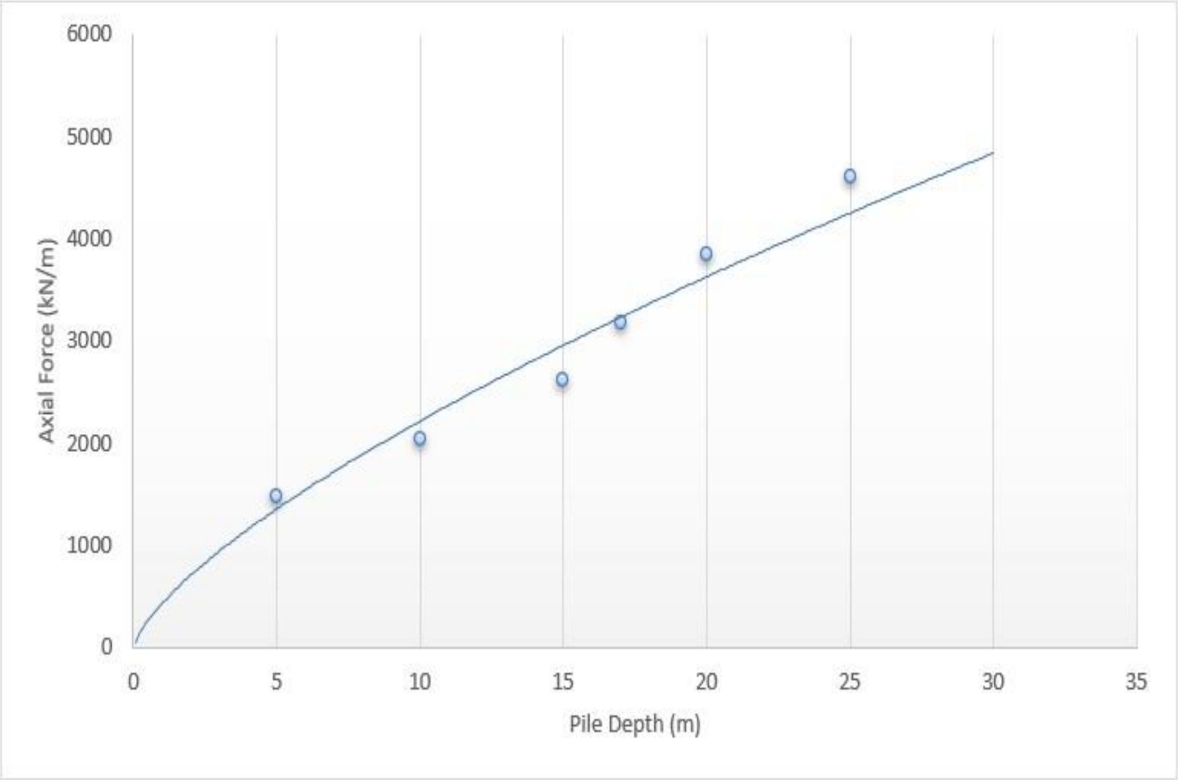
Maximum value = 0.2753 m (Element 1112 at Node 199)

Minimum value = -0.7649 m (Element 1090 at Node 10972)

Figure 33. Total displacements for depth 25m

5.2.7. Comparison Graph for Axial forces

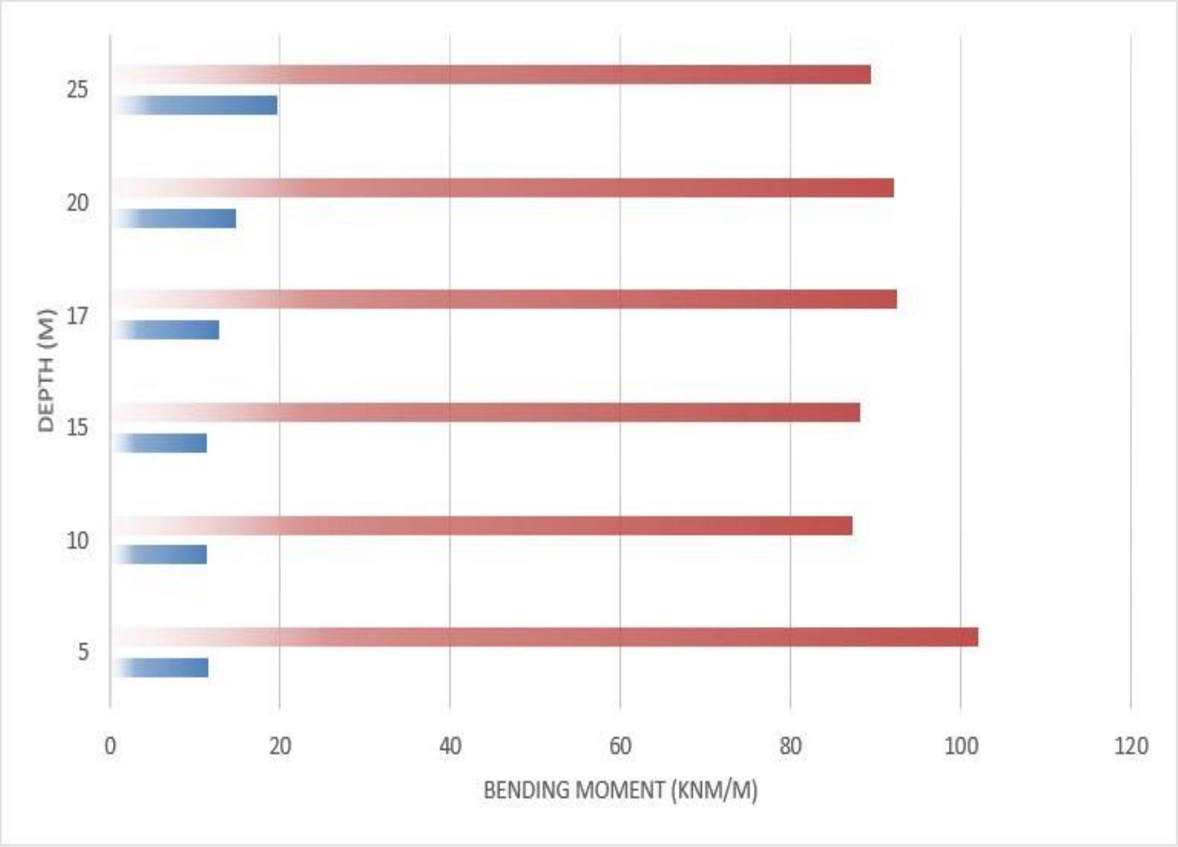
All of the data found in the research have similar results and followed a trend line. The graph generated for the profiles based on axial forces is shown below:



Graph 1. Axial Force vs Pile Depth

5.2.8. Comparison Graph for Bending Moment

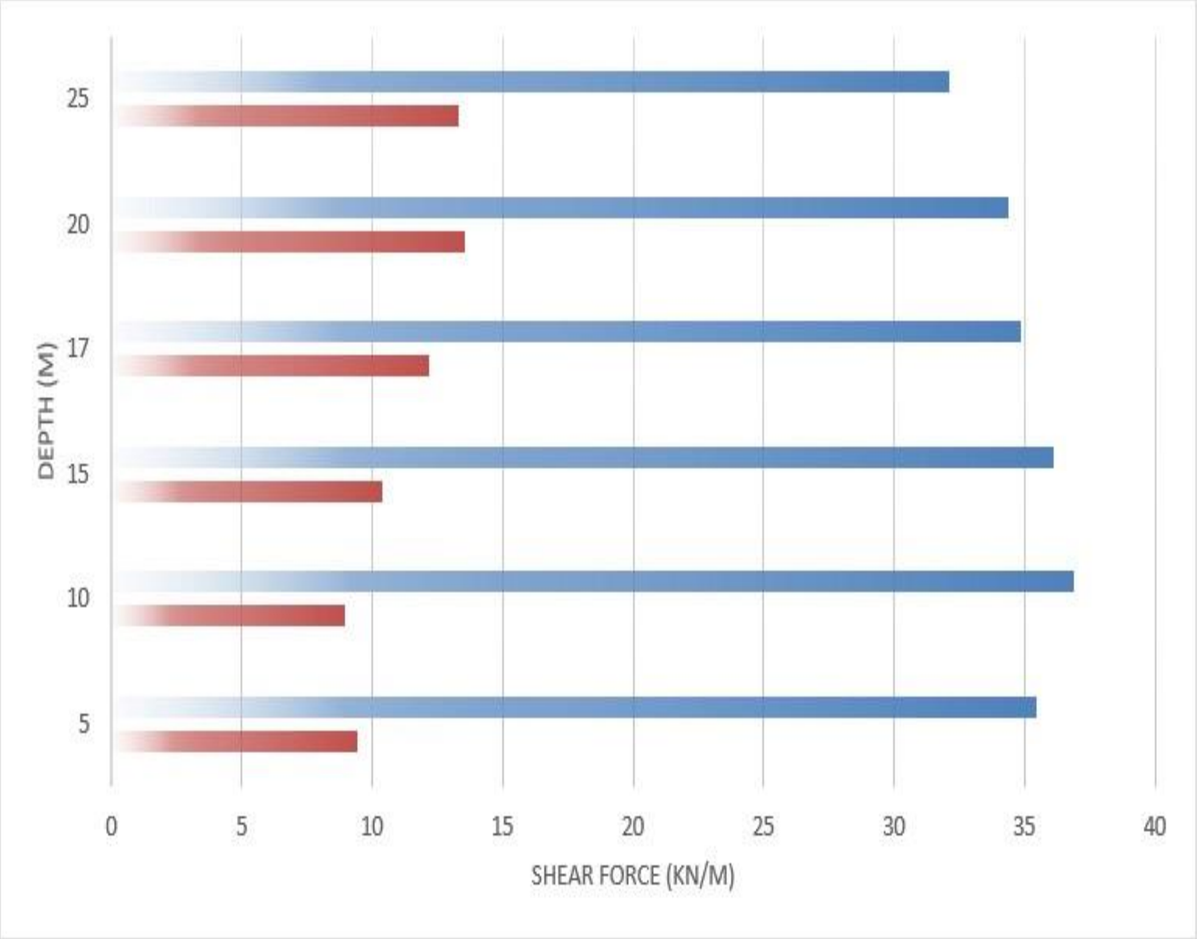
All of the data found in the research have similar results and followed a trend line. The graph generated for the profiles based on bending moment is shown below:



Graph 2. Bending Moment vs Depth

5.2.9. Comparison Graph for Shear Force

All of the data found in the research have similar results and followed a trend line. The graph generated for the profiles based on shear force is shown below:



Graph 3. Shear Force vs Depth

5.3. Discussion

The findings show that surface settlement caused by excavation diminishes as the depth of the pile from the surface rises. Additionally, it has been shown that as tunnel excavation depth grows, the settling trough widens. These results are in agreement with those of Shahin et al. (2004).

Figures present the calculated and measured bending moment profiles along the piles. In terms of the recorded values, the pile exhibits no appreciable changes in bending moment up to 10m owing to the subsequent construction of the tunnel, however the pile depth at 25m (which is closer to the tunnel) exhibits considerable rebound bending toward the tunnel, particularly around the tunnel crown. Additionally, axial force profiles for the pile are presented. It demonstrates a fair degree of consistency between the analysis and the measurements. It is noted that the additional axial stress on the piles caused by the following tunnel excavation increases along with the highest recorded values. It can also be seen thatto maintain a surface settlement of 10mm, the required grouting increases as the depth of the tunnel increases.

CHAPTER 6. CONCLUSIONS& RECOMMENDATIONS

6.1. Conclusions

Our investigation has led us to the following conclusions:

1) Surface settling caused by excavation reduces as tunnel depth rises.

2) As tunnel depth grows, tunnel axial force also rises.

3) As the tunnel's depth rises, volume loss gets worse.

4) The tunnel has to be higher than groundwater. The axial forces, bending moment, and shear forces in the tunnel lining increases as the groundwater level above the tunnel rises. Otherwise, the only forces that increase when the groundwater level rises are shear and bending moments.

5) To manage surface settling brought on by excavation, shallow tunnels must be specially taken into account during tunnel design.

6.2. Further Study

1) The study might take into account building loads from stacked and shallow foundations.

2) Clay-type soils can be utilized to compare drained drainage conditions.

3) 3D finite element analysis may be used to calculate lining forces and soil behavior in three dimensions with more accuracy.

4) It is also possible to take into account the ground response to various excavation techniques, such as the NATM or Cut and Cover approach.

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APPENDIX

Appendix: Tabulated Data of max Axial Force, Shear Force and Bending Moment

Profile #A, Pile Depth= 10m						
Tunnel depth(m)	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**
30	1470	11.4	13.84	1481	49.01	127.1
27	2033	12.15	13.45	2035	64.59	173.6
25	2605	13.99	14.63	2605	81.44	223.1

Profile #B, Pile Depth= 15m				Depth 15m		
Tunnel depth(m)	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**
30	1557	9.405	11.54	1556	34.2	100.1
27	2310	8.952	11.34	2724	36.45	85.33
25	3068	10.38	11.42	3622	36.16	90.41

Profile #C, Pile Depth 17m				Depth 17m		
Tunnel depth(m)	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**
30	1848	4.34	11.58	1989	44.77	119.1
27	2373	37.67	23.2	2385	74.26	195.5
25	2894	13.66	14.51	2894	86.51	247.3

Profile #D, Pile Depth 19m				Depth 19m		
Tunnel depth(m)	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**
30	1996	6.011	11.73	1996	23.08	51.47
27	2680	32.81	21.24	2680	32.81	38.17
25	3388	10.08	12.91	3388	36.99	93.51

Profile #E, Pile Depth 20m				Depth 20m		
Tunnel depth(m)	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**
30	1504	14.16	16.88	1569	51.94	139.6
27	2899	14.67	15.06	2914	101.6	268.6
25	4628	15.39	18.76	4628	131.1	338.6

Profile #F, Pile Depth 25m				Depth 25m		
Tunnel depth(m)	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**	**Max Axial Force(kN/m)**	**Max Shear Forces(kN/m)**	**Max Bending moment(kNm/m)**
30	1583	12.56	15.04	1583	40.16	107.7
29	3452	10.79	11.94	3452	39.09	94.49
28	5374	13.48	14.44	5374	34.46	85.08