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Excavation Support Systems and Safety in Excavation

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Abstract

Excavations of soil and rock are one of the most important elements in laying the subsurface structures. These excavations usually require excavation support systems that have fundamental influence on the safety, profitability, speed and quality of construction projects.

The purpose of this project is to review of excavation support systems available worldwide and locally, including available types, reasons for failure, and methods of design and construction of excavation support systems.

Also, in this project safety in excavation will be addressed. due to poor planning and lack of experience. These issues include landslides or earthflows, unstable ground surfaces from excessive loading from excavation equipment such as backhoes and bulldozers, potential cave-ins where soil walls collapse under high pressure from excavators pushing forward with their blades raised above their shoulders at various angles as they try to clear blocked paths through mud-filled trenches filled with loose rocks).

1 CHAPTER ONE

Introduction

1.1 General Background

One of the most crucial parts of building underground installations or foundations is excavating in rock or soil. These excavations require a sufficient support and stabilization system to assure both the site's and the surrounding areas' safety, as well as a sufficient support and stabilization system that won't raise the project's cost, time to completion, or construction quality. Despite the significance of this procedure, the majority of engineers, engineers, supervisors, and contractors have little knowledge of how it is designed and carried out and instead rely heavily on past experience, particularly that of those who perform drilling operations, the majority of whom are not engineers or experts in the carrying out of excavation support and stabilization operations. Additionally, because to cost reductions, the owner and supervising engineer frequently shovels the site intended for construction without conducting an engineering study or planning ahead for operations related to excavation support and stability. Numerous instances of excavation operations and careless road construction in the context of excavation support have resulted in significant and multiple issues on site and in the neighborhood, as well as numerous threats to the public's safety and the safety of nearby buildings and their occupants, as well as workers and those present in the excavation area. As a result, the neighborhood and construction area have frequently been evacuated.

Without an engineering study and a functioning support system, these excavations frequently cause breakdowns and endanger public safety, particularly the safety of workers and engineers on the job site, as well as the safety of nearby installations such as buildings, roads, water and sewage lines, etc., and their users from residents and other parties. As a result, the cost of the project rises, the project is delayed, and the quality of the building is decreased. Due to cost-saving measures, the owner and supervising engineer frequently shovel the area designated for the establishment level without doing any engineering studies on the drilling process, such as proposing an excavation support system or drilling with an appropriate inclination. If the owner puts off starting the project, the situation will worsen and become more problematic. Without any intervention, the land continues to be washed away over time. Its surrounding ground is also under danger of collapsing and sliding. This has occurred numerous times.

1.2 Objectives

This report provides an overview of the global and local excavation support and stabilization systems, as well as the factors that contribute to local and global breakdowns. In addition, it suggests the application of contemporary and novel techniques to assist local excavations, as well as the conclusions and suggestions required to develop local excavation support and stabilization to ensure on-site public safety. Also, it seeks to understand local support systems, general support systems, and the benefits and drawbacks of each approach and understand the causes of the failure of some local support systems that endangered public safety and the lessons learned from these cases. It also provides a summary of a few international codes-compliant public safety practices. In order to accomplish public safety, this report makes recommendations for local public safety measures that can be used during drilling operations. These precautions can ensure the site, workers, and neighboring installations and people are all kept safe.

Chapter Two introduces the up-to-date review of excavation support systems, which includes soil nailing, sheet piles, deep mixing, soil freezing. Also, this chapter summarizes the local exaction support systems, such as, retaining walls, big boulders, open cut, and cantilever retaining walls.

Collapses in excavations have taken place in chapter 3 as well, which talks about the cases and the causes of failures and collapses in different types of soils.

Safety precautions have been introduced in chapter 4 which includes some safety standards codes such as OSHA and HSE standards. It also mentions that procedure of being safe while performing excavation works for workers and even the machines used in excavation.

2 CHAPTER TWO

The Global and Local Excavation Support Systems

The world's most significant excavation support techniques are summarized in this section, along with local methods for supporting local excavation, reasons why they collapse, and techniques for designing local supporting excavation systems.

2.1 Techniques for General Supporting Excavation Systems

There are several ways to support excavation; the method chosen depends on the size of the drilling area, the type of soil, the depth of the groundwater, the amount of vertical and horizontal movement permitted for facilities adjacent to the drilling area, the availability of the method, the expertise and mechanisms for that method, the cost, the pace of the project, and other factors. The most renowned excavation can be supported in a wide variety of methods.

- Typical Retaining Walls
- Soldier Beam with lagging without or with rakes
- Sheet Pile Walls
- Bored cast in-situ reinforced concrete sheet pile walls, secant or tangent or contiguous
- Slurry Walls
- Cofferdams
- Caissons
- Soil Nailing
- Grouting or Injection
- Soil Freezing
- Deep Mixing
- Top-down construction method

In this report, the group members have decided to briefly discuss 6 types of the general excavation supporting systems. Each type among them will be discussed separately and in a sufficient way such that it gives the overall outcome about these systems.

2.1.1 Soil Nailing

Construction near steep slopes presents several challenges that should be thought through beforehand and handled properly. Depending on the situation, a variety of slope stabilization techniques can be used. Soil nailing is one of the most advanced techniques in the last ten years. It is affordable and versatile for different types of soil.

A technique called "soil nailing" involves inserting tendons to stabilize the slope on either naturally occurring or excavated slopes. The nails, which deal with the overall slope stability, are linked to a facing system, which offers surface stability.

Figure 2.1 shows a wall that has been supported by soil nails.

Figure 2.1: Shows Supporting a Wall by Soil Nails

It is a technique for strengthening the soil on site, especially for containing excavations and stabilizing slopes. The basic concept of soil nailing consists in strengthening the soil, with negative inclusions, to increase the overall resistance of the soil on the site and that the friction between the soil and the anchors limits the displacement of the soil before and after construction. This technology originated as an extension of the “new automatic tunneling method, which combines reinforced shotcrete and anchor placement, to provide a flexible support system for the construction of underground excavations. The tensile force packed into the anchors increases the apparent natural stresses along the surface of the potential failure, increasing the strength of the Shear for Soil Stabilizers placed across a potential fault surface can capture the shearing and bending moment by developing the passive resistance.

- **<u>The history about the nailing soil:</u>**

Since the early 1960s, the stabilization of rock slopes has also used this technique of mixing passive steel reinforcement with concrete. Figure 2.2 below shows the shotcrete of the wall.

In 1972, soil nailing was used for the first time in a railroad construction project close to Versailles, France.

Following that, soil nailing was first employed in the United States in 1976 to support a 13.7-meter-deep foundation excavation in silt-rich, thick sands.

Figure 2.2: Shows the Application of Shotcrete

The Good Samaritan Hospital's expansion in Portland, Oregon, used soil nailing. This retaining system was made in roughly half the time and cost around 85% less than standard retaining systems.

- **<u>There is an advantages of nailing soil, some of these:</u>**

  - It uses fewer building materials than other alternatives.
  - It is less expensive than alternative procedures.
  - In terms of seismic load, it is more stable than other techniques.
  - In soil, it is simple to change the angle, size, and placement of nails.
  - Less room is required for installation

❖ **Restriction of Soil Nailing:**

- Use of the soil nailing technique is not possible everywhere.
- Using the soil nailing technique requires skilled labor.
- It is incompatible in locations with a lot of water.
- Sand and gravel might not work with this technique.
- The metal nail eventually becomes rotten.
- The use of a soil nail may not be ideal for long-term adjusting.

2.1.2 Sheet Piles

To support excavations and retain earth, sheet piles—sections of sheet material with interlocking edges—are driven into the ground. Steel is the most popular material for sheet piles, but they can also be composed of reinforced concrete or wood. Along the alignment of the seawall or excavation perimeter, they are erected in a certain order according to design depth. With less groundwater inflow, the interlocking sheet piles create a wall for permanent or temporary lateral earth support. If necessary, anchors can be added to offer further lateral support

Sheet piles are frequently employed for retaining walls, land reclamation, underground buildings including parking garages and basements, riverbank protection in coastal environments, seawalls, cofferdams, and other constructions. Permanent steel sheet piles are made to last a very long time in service. Sheet piles are often installed using vibratory hammers. An impact hammer can be used to complete the installation if the soils are too dense or hard. There are two primary methods for creating sheet piles: hot rolling and cold forming. Hot rolled heaps are created at high temperatures, and the interlocks seem to be stronger and more robust.

❖ **Advantages of sheet pile:**

- can be applied to both permanent and temporary constructions.
- Reusable and recyclable
- Available a wide range of lengths, size and steel options.
- Can be installed using silent and vibration-free methods.
- The pile's length and pattern are simply customizable.
- faster installation than contiguous or secant walls.
- Cofferdams can be built nearly any way you like, and they offer a tight-fitting junction that creates a reliable water seal.
- Lightweight makes handling and lifting easy.
- Some maintenance is required both above and underwater.
- Joints are made to endure the intense pressure required to install them.

❖ **Different Types of Sheet Piles**

1. **Steel Sheet Piles**

Offers protection from installation stresses. The sheets must be pushed into the ground, although they are quite resilient to being pushed down with force.

- Because of its incredibly low weight, it is simpler to handle and lift.
- Reusable and recyclable steel sheeting
- It has a long lifespan both above and below the water. It simply needs minimal protection to be kept in good condition.
- It's simple to modify the pile length and make it functional by welding or bolting.
- They can endure the force of being forced into place because their joints are stronger.

- Figure 2.3 below shows a layout of steel sheet piles inserted in water

Figure 2.3: Shows the Layout View of the Steel Sheet Piles

2. Vinyl Sheet Piles

A good alternative to steel sheet piling for bulkheads, cutoff walls and seawalls. They also outperform substitutes like concrete and wood in terms of quality. Vinyl sheet piles' better corrosion resistance in seawater, where oxidation doesn't happen, it is their key benefit. The following figure, Figure 2.4 below shows Vinyl sheet pile.

Figure 2.4: Shows the Vinyl Sheet Piles

3. Wooden Sheet Piles

These are employed in temporary structures and braced sheeting in excavation works. It must get some sort of preservative treatment if it is going to be used in permanent structures above the water table. Timber sheet piles have a limited lifespan, even with preservation treatments. Tongue and groove connectors are used to attach timber sheet piles. wood piles are inappropriate in the strata consisting of gravel and boulders. An example of the wooden sheet piles, Figure 2.5 below shows this.

Figure 2.5: Shows a Picture of Wooden Sheet Piles

4. **Concrete Sheet Piles**

These are usually connected by tongue and groove joints. they are usually applied in permanent river embankments, canals, and other marine projects, The heads are finished off by casting a capping beam, while the toes of the piles are usually cut with an oblique face to permit easy driving and interlocking. Figure 2.6 shows establishing the concrete sheet piles.

Figure 2.6: Shows the construction Process of the Concrete Sheet Piles

They are relatively heavy and bulky and displace large volumes of soil during driving. The driving resistance rises as a result of the considerable volume displacement.

The piles must be handled and driven carefully, and the necessary reinforcement must be offered.

2.1.3 Deep Mixing

- ***The Beginnings of This Method***

The founder, Mr. Shuntaro Shiga, created and received a patent for an electric motor-driven top drive auger in 1956. This technique was created in the 1950s and introduced to Japan in the 1970s. Since then, this technology has been used and enhanced to create the leading driving technologies of today. popularity growth in Europe, North America, and Asia, DSM was extensively promoted to local building in 1997 as a temporary earth retaining technique (both reinforced and non-reinforced), To far, more than 80 projects have been successfully completed, some of which involve the HDB, the LTA, and private development.

- ***Methodology and Procedure of This Method***

The deep mixing method (DMM), also known as deep soil mixing or cement deep soil mixing (DSM/CDSM), stabilizes soft soil in place with a binder without compaction. In order to improve soft clays and organic soils for a variety of goals, including stability, settlement reduction, excavation support, and seepage management, deep mixing method (DMM) is typically used. Figure 2.7 below shows the deep soil mixing method.

Figure 2.7: Shows Deep Soil Mixing

It's a novel kind of bridge abutment made out of a thin reinforced concrete (RC) parapet structure (i.e., a parapet) supporting a bridge girder and a backfill made of geogrid-reinforced, cement-mixed gravely soil. Geogrid layers incorporated into the cement-mixed backfill secure the parapet and backfill to one another firmly. In contrast to the conventional-type bridge abutment, which consists of a relatively large RC structure supporting the backfill of uncemented soil, this structure supports the RC parapet laterally rather than applying static and dynamic earth pressure to the back face of the parapet. It has been demonstrated how cost-effective the new style of bridge abutment is.

Wet mixing and dry mixing DMMs are both used in the United States. Binders are injected into the soil during wet mixing in a slurry (wet) form. In order to produce isolated elements, continuous walls or blocks for large-scale foundation improvement, earth retaining systems, hydraulic barriers, and contaminant/fixation systems, cement-based slurries are often mixed using single-auger, multi-auger, or cutter-based mixing methods. Dry mixing involves the use of binders that are powdered (dry) and interact with the soil's preexisting water.

Cement is the perfect material to use for deep mixing applications in a range of soils due to its binding and moisture absorption qualities. Due to its accessibility and ease of purchase, cement is a popular choice among contractors. Figure 2.8 below shows the machines mixing the cement deeply inside the soil to stabilize it.

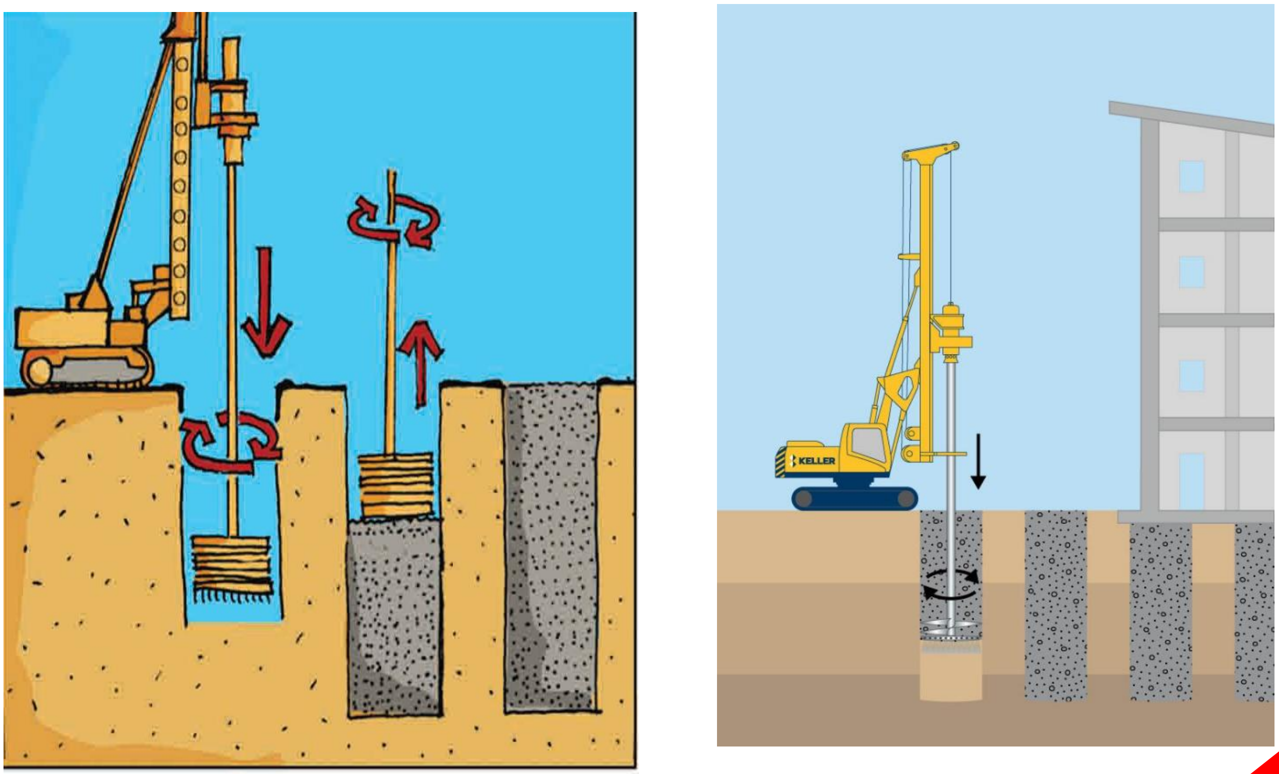


Figure 2.8: Shows the Process of Inserting and Mixing Cement at a Deep Depth

❖ ***<u>The Steps of the Method Can be Defined as Such:</u>***

- Step 1: Putting the auger rig in place at the pile
- Step 2: Tungsten carbide drill bits are utilized for auguring with the appropriate size auger.
- Step 3: Aging and combining with cement grout pumping
- Step 4: Mechanical agitation is used to mix using auger rotation.
- Step 5: Rotate the mixing and withdrawing auger counter clockwise.
- Step 6: The grout mix pile installation is finished

These steps are summarized as a simple drawing which is shown in the Figures 2.9 and 2.10 below

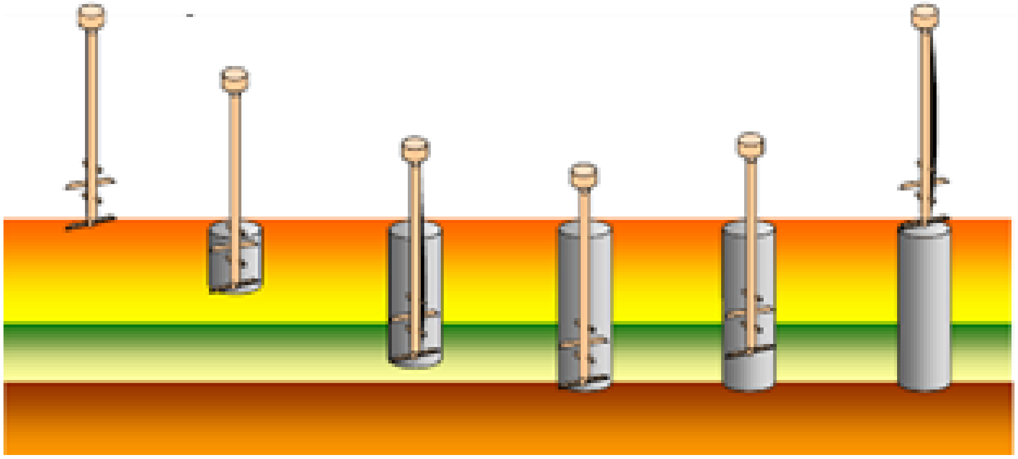


Figure 2.9: Shows the Steps of Deep Soil Mixing Method

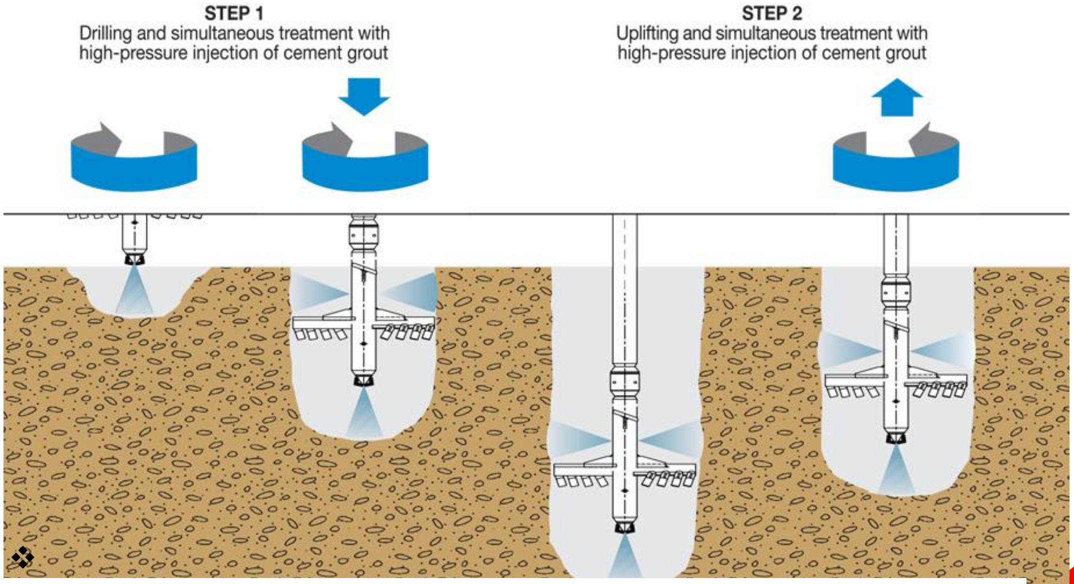


Figure 2.10: Shows Other Way to Deep Soil Mixing Steps

❖ ***Advantages of DSM:***

- Relatively affordable
- Friendly to the environment (in-situ materials).
- Low vibration
- Low noise.
- Ground heave at the minimum.
- Fast speed of installation.
- Adaptable to many types of soil conditions.
- Watertight retaining wall

2.1.4 Soil Freezing

When there is a problem with subsurface high-water pressure and unstable soil condition, the use of frozen soil for tunneling applications during construction has become a prominent technology. (AGF) applications for soil and rock were first used in the mining and shaft industries. Later, with the introduction of horizontal drill excavation, the technique was used in drifts and subsurface areas. The procedure is economically advantageous for use in large-scale and long-term confinement facilities. After the frozen barrier is created, maintenance costs are minimal. Ground freezing helps to establish a secure, impermeable, and solid working front during the extension of underground tunnels or widening of connection segments between underground places. By installing horizontal or vertical freezing pipes, the full circumference of the temporary trench is often frozen in this manner.

There are various types of ground freezing that can be described. Brine, Liquid nitrogen, ammonia and carbon dioxide is rarely used.

The first type we will talk about is Brine, for brine freezing, a watery saline solution primarily composed of calcium chloride ($CaCl_2$) is employed as a refrigerant. In reality, a freezing facility reduces the temperature of the brine solution to between -30 and -38 degrees Celsius. The brine solution is then fed through insulated pipe lines and freeze pipes by rotary pumps into a closed circuit. Through a down pipe, the freezing pipes are supplied with the chilled brine solution. It then condenses and flows back into the return pipe and cooling unit through the annular space between the down pipe and the freeze pipe outer casing. The temperature of the brine increases by 2 to 3° C between leaving the down pipe and entering the return pipe. There are freezing plants available with refrigeration capacities ranging from 100 to 500 kW that were specifically created for ground freezing operations.

To prevent the refrigerant from coming into direct contact with the ground, the freeze pipes work in conjunction with the cold insulated pipe lines to create a closed system that is completely impermeable. To remove compression heat from the freezing plant, a cooling unit has been installed. A cooling tower that uses either water or air is employed depending on the local conditions, or the system can be directly cooled by river or well water. When working on lengthy, large-volume freezing projects, brine freezing is typically used as shown in Figure 2.11 below.

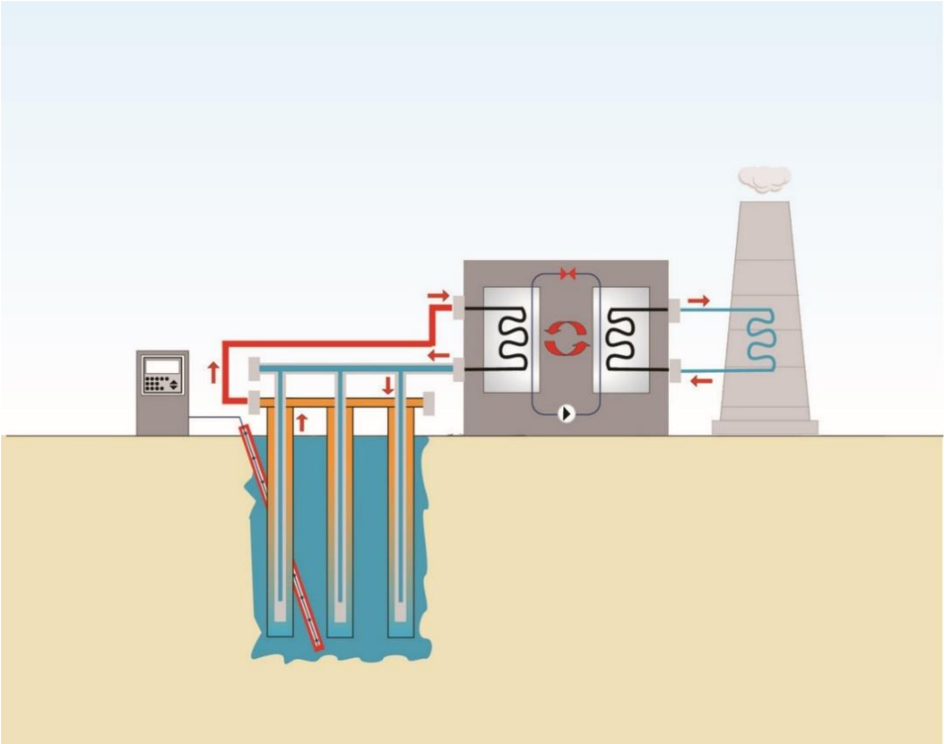


Figure 2.11: Shows the Concept of Brine Soil Freezing Method

The second type is Ground freezing with liquid nitrogen, Deep-cold liquid nitrogen is used as a refrigerant to freeze nitrogen. In air liquefaction facilities, it is produced in massive quantities. Air contains 78% of the non-toxic, non-flammable gas known as nitrogen. At a pressure of 1 bar, the temperature of liquid nitrogen is -196° C.

As shown in Figure 2.12 below, liquid nitrogen is delivered to the construction site in special vacuum-insulated tankers and is momentarily held there in tank facilities. The down pipes are then fed with high-quality, insulated tubes.

When the extremely cold liquid contacts the relatively warm freeze pipes as it leaves the down pipe, it begins to evaporate and eventually escapes the pipe as gas. The ground freezes as a result of this evaporation process, which draws energy from the surrounding soil. Shock freezing is the term for the extremely rapid freezing process that occurs when utilizing nitrogen as a refrigerant.

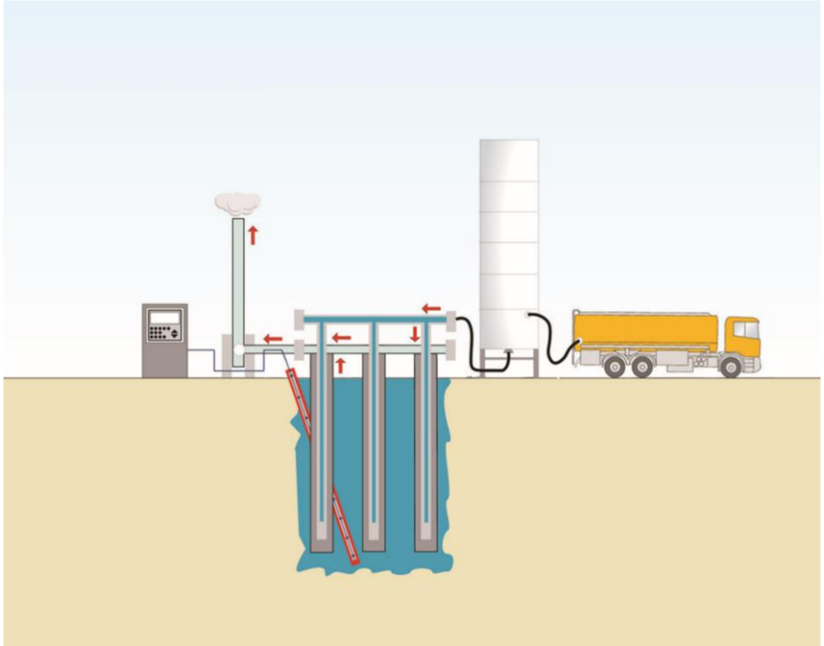


Figure 2.12: Shows the Concept of Soil Freezing using Nitrogen

❖ ***<u>Advantages of Ground Freezing:</u>***

- Versatility
- Strength
- Impermeability
- Stability
- Non-polluting
- Safety
- Cost efficiency

2.1.5 Caissons

A caisson is a type of structure that is used to support a bridge, a building, or other large structures. It is a watertight chamber that is used to create foundations for these structures by sinking them deep into the ground. As shown in Figure 2.13, caissons are typically made of steel or concrete and are used in situations where the ground is too soft or unstable to support the weight of the structure.

There are two main types of caissons: open caissons and closed caissons. Open caissons are used in the construction of bridges and other structures that are built over water or soft ground. These caissons are open at the top and are sunk into the ground using a process called "dry excavation." Closed caissons, on the other hand, are used in the construction of buildings and other structures on land. These caissons are sealed at the top and are sunk into the ground using a process called "wet excavation."

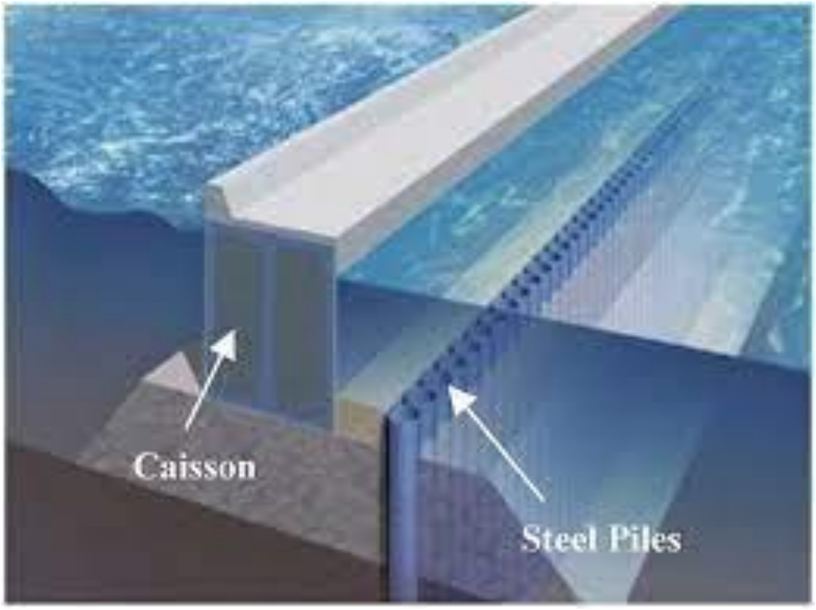


Figure 2.13: Shows the Caisson

The process of sinking a caisson into the ground is a complex and time-consuming process. It involves drilling or excavating a hole in the ground to the required depth, then filling the hole with concrete or other materials to create a solid foundation. Once the caisson is in place, it is used to support the structure that is being built on top of it.

Caissons are an important part of many large construction projects and are used to create solid foundations for a wide range of structures, including bridges, buildings, and even offshore platforms. They are an essential part of the construction process and play a critical role in ensuring that these structures are safe and stable.

There are a few potential disadvantages to using caissons in construction:

1. Cost: Caissons are a labor-intensive and time-consuming process, which can drive up the cost of a construction project.
2. Limited soil types: Caissons are most effective in soft or unstable soil types, and may not be suitable for use in hard, rocky soil.
3. Risk of collapse: If not properly designed and constructed, caissons can collapse, which can be dangerous and costly
4. Environmental impact: The process of sinking a caisson into the ground can disturb and potentially damage the surrounding environment, including soil and water.
5. Noise and vibration: The process of sinking a caisson into the ground can produce noise and vibration, which can be disruptive to nearby residents or businesses.
6. Limited accessibility: Once a caisson is in place, it can be difficult to access for maintenance or repair work.

Figure 2.14 below shows the caissons before being installed.

Figure 2.14: Shows the Installation of Caissons

Overall, while caissons can be an effective solution for creating foundations in certain situations, they also come with a number of potential disadvantages that need to be carefully considered before deciding to use them in a construction project.

2.1.6 Grouting and Injection

Grouting and injection are two important techniques used in the construction and repair of structures. Both techniques which are simplified in Figure 2.15, involve the use of specialized materials and equipment to fill and seal voids or cracks in concrete, masonry, or other building materials. While they may seem similar at first glance, there are important differences between grouting and injection that make each technique better suited for certain applications.

Grouting: is a process that involves filling a void or cavity with a flowable, often cement-based, material. Grouting is often used to fill gaps between building materials, such as those found in walls or foundations. It can also be used to stabilize and reinforce structures, such as bridge piers or retaining walls, by filling voids within the structure and increasing its overall strength.

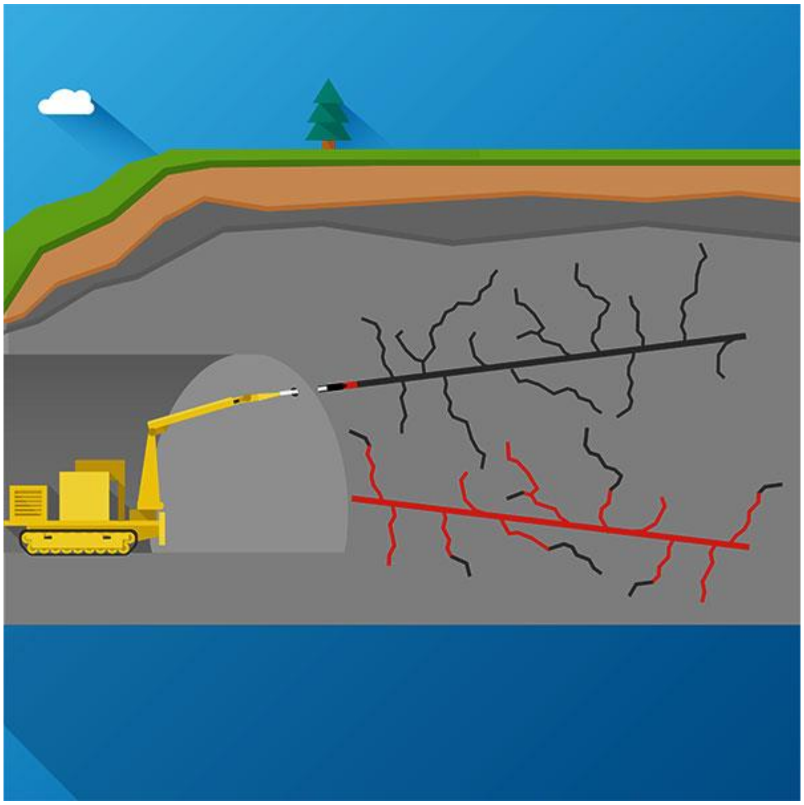


Figure 2.15: Shows a Simplification of Grouting and Injection

There are several types of grouting materials that can be used, including cement grout, epoxy grout, and polymer grout. Each type of grout has unique properties and is best suited for different applications.

Cement grout, for example, is a common choice for filling voids in concrete structures because it is strong and durable. Epoxy grout, on the other hand, is often used in applications where chemical resistance and high strength are required, such as in chemical plants or laboratories.

Injection: is a process that involves injecting a specialized material into a crack or void in a structure. Injection is often used to repair cracks in concrete or masonry structures, such as walls or foundations. It can also be used to seal leaks or to stabilize and reinforce structures.

There are several types of injection materials that can be used, including epoxy, polyurethane, and acrylic. Each type of injection material has unique properties and is best suited for different applications. Epoxy, for example, is a common choice for repairing cracks in concrete because it is strong and durable. Polyurethane is often used to seal leaks because it is flexible and can expand and contract with the movement of the structure. Figure 2.16 below shows the cement or jet grouting technique.

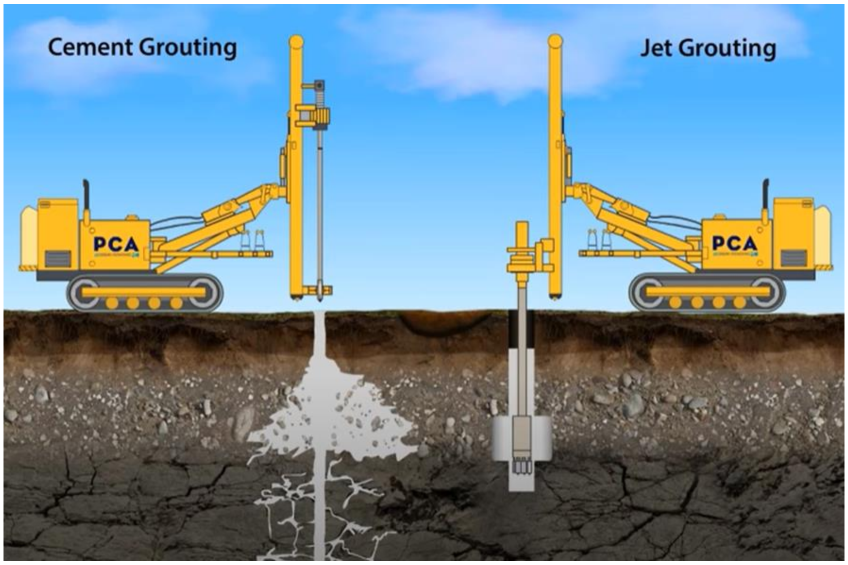


Figure 2.16: Shows Cement and Jet Grouting technique

There are several advantages to using grouting or injection as a construction technique:

1. used to fill and seal voids in foundations, walls, and other structures, which can help to improve the stability and strength of these structures.
2. It can be used to stabilize soil, which can help to prevent erosion and landslides.
3. It can be used to seal leaks, which can help to prevent water damage and improve the structural integrity of a building.
4. relatively quick and simple process, and can be done with minimal disruption to the surrounding area

However, there are also some potential disadvantages to using grouting:

1. Grouting materials can be expensive, especially if large quantities are needed.
2. difficult to control, as it can be difficult to predict exactly where the grouting material will flow and fill.
3. If the grouting material is not properly mixed or applied, it can result in a weak or uneven fill, which can compromise the stability and strength of the structure.
4. messy and time-consuming to clean up, especially if the grouting material is not properly contained.

Overall, the advantages and disadvantages of grouting will depend on the specific application and the needs of the project. It is important to carefully consider all of the potential pros and cons before deciding whether or not to use grouting in a construction project.

2.2 Locally Excavation Supporting Systems

There exist several main locally excavation supporting systems as follows:

2.2.1 Open Cut

The majority of local excavations, whether they are shallow or deep, are left unsupported. The excavations are often vertical, although occasionally there are spaces surrounding the excavation site. And occasionally a tiny recipe or excavation is carried out on the stalks, as in Figure 2.17. This approach is simple, inexpensive, and does not require an expert; nonetheless, many of these excavations have caused major issues and collapse that have led to injuries, fatalities, and physical damage to the site and the surrounding area.

Figure 2.17: Shows Excavation without Supporting System

2.2.2 Gravity and Semi Gravity Retaining Walls

It comprises of a gravel and concrete, and in Figure 2.18 it can be seen that occasionally a steel reinforcement is utilized on the side of the embankment. As seen in Figure 2.18, several walls are constructed as soon as possible on top of one another. As shown in Figure 2.20, the margin is occasionally divided into numerous parts, and the walls are constructed in shape of slides. Particularly when close to the drilling area's infrastructure, such as buildings, roadways, or other installations, this method is not very safe. Even in the summer, the soil has frequently crumbled during building, causing fatalities, injuries, and damage to the infrastructure surrounding the dig site. Additionally, because of the enormous wall's thickness, using this sort of wall decreases the amount of building area needed. Retaining wall is defined as an earth retaining structure supporting at least 2 m of ground, the soil level in front of the wall is ≥ 2 m lower than the soil level behind the wall.

Figure 2.18: Shows a Gravity Retaining Wall

In geotechnical engineering, gravity retaining walls are used to secure slopes that do not have long-term stability for providing lateral soil load resistance. This paper deals with masonry retaining walls consisting of stones with bedded concrete of low compressive strength. In designing gravity retaining walls, stability conditions such as sliding, overturning, eccentricity and bearing capacity are evaluated using selected wall dimensions. If the initially selected dimensions do not satisfy the stability conditions, new dimensions are selected and reevaluated until the stability conditions are satisfied. .

Gravity walls are widely used as earth retaining systems supporting fill slopes adjacent to roads and residential areas, also in regions prone to earthquake. Many researchers have developed design methods for retaining walls during earthquakes by using different approaches, Though the quest for rational design methods of retaining structures has been pursued for several decades, though the quest for rational design methods of retaining structures has been pursued for several decades.

The possible failure modes:

Sliding mechanism; the gravity wall slides over the bottom layer once the ground acceleration threshold for slide is exceeded, it consists of two wedges, the soil wedge and the retaining wall wedge. This failure mechanism is geometrically specified by wall height, backfill soil slope, and the angle that planar failure surface makes.

Economical design of gravity retaining wall systems subject to earthquake can be achieved by recognizing that although modest earthquake acceleration may bring the wall system to limiting equilibrium, the criterion for satisfactory performance is the residual displacement of the wall after the earthquake motion ceases. The reason for this is that it is often too expensive to construct a wall with proportions that will not move during a design earthquake. So, the criterion for satisfactory performance becomes the accumulated outward movement of the wall during the course of the earthquake.

2.2.3 Big Boulders Retaining Walls

In some situations when building walls near to drilling is extremely risky, walls composed of large stone blocks are used, with the encouragement that they be filtered by a bulldozer. This minimizes the risk to workers but requires a significant amount of land. A wall must be operated in front of the boulders, especially if the wall is part of the structure, as in Figures 2.19 and 2.20.

Figure 2.19: Shows the Installation of Big Boulders

Figure 2.20: Shows casting a Cantilever Retaining Wall in front of Big Boulders Wall

2.2.4 Cantilever Retaining Walls

It can be used as a replacement for gravity retaining walls, and the construction procedure is identical, but typically the drilling area's soil is more stable, and workers can be positioned behind the wall between the wall and the cutting limit. When compared to gravity walls, the wall is typically integrated into the origin and does not encroach as much on the site. Figure 2.21 show slide-built walls and multiple walls on various floors, respectively. The overall stability assessment of retaining walls needs to consider different failure modes as well as sources of uncertainty and variability in backfill soil, construction tolerances and the sections shall also be optimally proportioned.

Figure 2.21: Shows a Retaining Wall of several slides

Reliability-Based Designs

Whitman 2000 and Duncan 2000 indicated that the factor of safety alone is not a sufficient measure for risk assessment and it is hard to evaluate how much safer a retaining wall becomes as the factor safety increases. The probabilistic analysis way is used where uncertainty in the design parameters is considered because its main advantage is a direct linkage between uncertainty in the design parameters and probability of failure/reliability.

Reliability-Based Design Optimization:

Optimization is concerned with achieving the best outcome of a given objective and simultaneously satisfying certain constraints. It is observed that the deterministic optimum design does not necessarily have high reliability. To ensure that the optimum design is also reliable, the optimization formulation must include reliability constraints. Such a formulation is referred to as the reliability-based design optimization RBDO

3 CHAPTER THREE

Collapses and Failures in Excavation Processes

Excavation isn't only a way to dig up ground, but also to build roads, foundations and other structures. In many countries, there are strict regulations regarding the excavation process and its safety standards.

The most common cause of excavations failure is excessive depth. The soil in an excavation may be compacted by heavy equipment and even machinery, which causes unevenness in its mechanical structure. This can lead to failure of the soil due to excessive load on it. If left exposed for too long, this unevenness will become more pronounced with time as water seeps through cracks or fissures in the ground. As shown on Figure 3.1 two men have fallen due to the collapsing of trench excavation.

Figure 3.1: Shows a Trench Collapse and two workers are being rescued near Knoxville

In addition, the load on the soil may exceed its bearing capacity. This means that it cannot support the weight of whatever is placed on it without collapsing. It is important to note that this condition may vary depending on location and soil type.

For example, sand is more susceptible to failure than clay. When excavating in sandy soil, it is important to use caution when removing the load on the ground by slowly removing the weight and allowing time for consolidation.

The soil may also be unsuitable for excavation due to the presence of underground utilities. The most common example is when digging near power lines, which can lead to an explosion if they come into contact with each other.

The soil can be clay, marl or sand. The excavation can also be deep and weak due to its loose nature. This makes it prone to collapse if not properly managed by professionals who know how to make sure that no one gets hurt during this procedure.

- ***Prevention is better than cure***

The importance of this statement cannot be overemphasized, especially in the case of excavations. Collapses in local excavations are due to many factors including:

- ✓ Inadequate planning and oversight;
- ✓ Poor quality construction; or
- ✓ Inadequate safety procedures during excavation work.

- ***The explosive onset of construction excavations***

Construction excavations are often made in soil, and the soil can be clay, marl or sand. The excavation can also be deep and weak due to its loose nature. This makes it prone to collapse if not properly managed by professionals who know how to make sure that no one gets hurt during this procedure.

- ***Excessive excavation depth***

The depth of an excavation depends on the type of soil and purpose. In general, deep excavations are more difficult to control than shallow ones because they require greater effort to ensure that the sides do not collapse. A surveyor or engineer should be involved in any deep excavation project to ensure that proper precautions are taken so as not to endanger workers or damage surrounding structures.

Uneven mechanical structure of the soil

This occurs when the soil is uneven, with large voids that do not support structures properly.

An example of an uneven structure would be if there exists large rocks or stones scattered throughout the excavation site. These rocks may have been left behind by previous construction projects or even natural processes like earthquakes and landslides. In addition to being unstable themselves, these objects create other problems such as, breaking up the ground surface underneath them which makes it harder for workers and equipment like trucks driving into them (even with heavy duty tires on them). This makes it difficult for people working onsite because they could get stuck in mud holes created by these rocks during rainy weather conditions; plus, there's no way anyone could find those holes if they hadn't already been covered up several weeks ago.

Figure 3.2 shows the collapsing of a retaining wall at a construction site.

Figure 3.2: Shows a Case of Retaining Wall Getting Collapsed at a Construction Site

- ***Heavy equipment exerting excessive load on the soil***

Heavy equipment should be used with care, so that it does not exert an excessive load on the soil. Excessive loads can cause soil to collapse, slide and liquefy.

- ***Leaving the soil at the bottom of an excavation exposed for too long***

The soil should be covered with a waterproof material. This is because the weather will cause it to shrink and crack. It's also important that the area is not too wet, as this could lead to rot or fungus growth on the soil coverings.

4 CHAPTER FOUR

Safety in Excavation and Safety Codes

Excavation is an inherently dangerous job. There are many pathogens and hazards in the work environment that can cause harm to the workers, especially if they are not properly protected by safety equipment and trained on how to use it. In addition, a number of safety issues arise during excavation due to poor planning and lack of experience. These issues include landslides or earth flows caused by rainfalls, sinkholes caused by water drainage into underground cavities such as cave passages or tunnels, unstable ground surfaces from excessive loading from excavation equipment such as backhoes and bulldozers, slippery slopes due to rainwater runoff after heavy rains (or even snow melt), potential cave-ins where soil walls collapse under high pressure from excavators pushing forward with their blades raised above their shoulders at various angles as they try to clear blocked paths through mud-filled trenches filled with loose rocks).

As we all know from past experience, excavation can be an exciting process that provides plenty of opportunity for breaking ground and creating new spaces that may or may not have been previously available. However, most of the digging done today does not meet the safety requirements of a professional excavation company and as such, risks are very high. Here are some tips on how to stay safe when digging or working near construction excavations.

4.1 Safety Codes

In the United States, excavations are defined by the Occupational Safety and Health Administration (OSHA) as “any man-made cut, cavity, trench, or depression in an earth surface, formed by earth removal.” Excavation work performed improperly can be deadly. The primary objective of this material is to offer readers a simplified (and global) working knowledge of US Federal OSHA regulations (Hayslip, 2013)

The April issue of SA Builder (Van Vuuren, 2009) reports that Colin de Kock, the Executive Director of the Gauteng Master Builders Association (GMBA) in South Africa, says many building contractors are still implementing low levels of H&S standards. Two months later, the Construction Industry Development Board (cidb) (2009) report entitled ‘Construction Health and Safety in South Africa Status and Recommendations’ reports that construction has the third highest fatality rate and the ninth highest permanent disability rate per 100 000 full-time equivalent workers out of twenty-three industries. The frequency of excavation accidents and the number of related fatalities and injuries engendered the research reported on in this paper. Accordingly, the research investigated the: importance of H&S to respondents’ organizations a (Jasmina Radosavljevic, 2021)nd to all contractors; the extent to which excavation interventions are taken; the performance of the construction industry relative to various excavation aspects; the extent to which aspects constitute barriers to H&S, and the extent to which interventions could contribute to an improvement in H&S.

There are many codes that speak of public safety and safety at excavation sites, including: Trenching and Excavation Safety, OSHA, 2015, Health and Safety Executive (HSE), Health and Safety in Construction, 2006, International Labour Office, Safety and Health in Construction, 1992, Safe Work Australia, Construction Work, 2018, Work Safe, Excavation Safety.

4.1.1 Osha Code

Knowing the regulations and hazards that come with trenching or excavation projects is key to keeping your employees safe. Fortunately, OSHA has set out a list of guidelines for all employers to follow. Here is a quick breakdown of the main points:

OSHA requirements for trenching and excavation safety:

An excavation is defined by OSHA as "a man-made cut, cavity, trench, or depression in an earth surface." This definition even extends to sunken utility lines such as water, sewer lines, fiber optic cables, and pipelines. The requirements listed below apply to all excavations that are deeper than 5 feet. (OSHA, 2015)

Employers are required to provide the following equipment for all trenching and excavating projects.

When OSHA regulations state a maximum depth, employers must make sure that this depth is also supported by an engineering control such as shoring. Employers must also be aware of the fact that Access/egress issues may not be resolved with guardrail systems alone. OSHA requires that employers provide "the safest means practicable" to ensure worker safety.

Once an excavation or trench is started, you must take precautions to keep your employees safe. The following items must be covered by a trenching and excavation permit or PPE:

If there is any chance of reaching the ground with a ladder, the ladder should be supported by an A-frame system in accordance with OSHA requirements.

Employers are also required to have a competent person available to monitor all trenches and excavations. This person must be on-site during all operating hours and must have previous experience in tunneling as well as knowledge of excavation hazards. This competent person is also required to inspect each piece of excavating equipment before use.

In summary, employers are legally responsible for providing their employees with a safe work environment. If a trench is started without proper safety measures, you can be held responsible for the following:

- Ladder Safety
- Bolts and Nuts
- Slings
- Swinging Ladders

Falls from Height: Employers need to be aware that employees working at heights have a higher chance of falling than usual. In particular, employees working at heights have a higher chance of falling from ladders if there are no ladders nearby to get on or off. Employers need to ensure that employees have a ladder both at the job site and at the worksite itself.

Employers are able to require employees to use ladders or other appropriate size equipment as long as they can see, hear and communicate with their employees while they are working. For example, if you have an excavating crew on site who isn't using a bucket truck, then you must be able to see where their bucket truck is at all times.

Employers need to ensure that all employees are wearing the required Personal Protective Equipment. This includes hard hats, safety glasses, and safety boots made of either steel or polyethylene.

Whenever workers are working at heights, employers also need to follow OSHA requirements on fall protection and access. That means that you must make sure that employees can safely get in and out of the trench, and do not have to climb up or down ladders to get into or out of the trench; this must be done properly using the proper equipment.

4.1.2 HSE Standards

The Health and Safety Executive is a United Kingdom government agency tasked with improving the health and safety of Great Britain's workforce. HSE was established in 1974 with the aim to safeguard people from work related illness, injury, or death by setting strict safety standards for all aspects of daily life. (HSE: Health and Safety Executive, 2008)

According to the Health and Safety Executive (HSE) (2008), fatal accidents associated with excavations contributed to 14% of reported fatalities due to demolition/collapse from April 1997 to March 2008 in the UK. The April issue of SA Builder (Van Vuuren, 2009) reports that Colin de Kock, the Executive Director of the Gauteng Master Builders Association (GMBA) in South Africa, says many building contractors are still implementing low levels of H&S standards. Two months later, the Construction Industry Development Board (cidb) (2009) report entitled 'Construction Health and Safety in South Africa Status and Recommendations' reports that construction has the third highest fatality rate and the ninth highest permanent disability rate per 100 000 full-time equivalent workers out of twenty-three industries. The frequency of excavation accidents and the number of related fatalities and injuries engendered the research reported on in this paper. Accordingly, the research investigated the: importance of H&S to respondents' organizations and to all contractors; the extent to which excavation interventions are taken; the performance of the construction industry relative to various excavation aspects; the extent to which aspects constitute barriers to H&S, and extent to which interventions could contribute to an improvement in H&S. (HSE Construction Intelligence Report, 2008)

4.2 Workers' Safety During Excavation

Any construction project, whether it be in civil engineering or building construction, must include earthworks. Excavation, earthmoving, earth transport, and earth compaction are some of the construction tasks carried out during earthworks. During earthworks, the excavation site is vulnerable to dangerous, combustible, or toxic materials, damage to subterranean utilities, the earth collapsing, and many other dangers. (Jasmina Radosavljevic, 2021)

Therefore, the deployment of sufficient safety measures is necessary for construction activity including trenching and excavation. The safety precautions for workers during earthworks that involve excavations up to and beyond one meter deep are covered in this essay. Risk arises from the sheer number of people working in construction, as well as from the complicated relationships and connections between materials, tools, machinery, and activities.

Construction workers are susceptible to occupational injuries that are sometimes fatal and serious and are caused mostly by poor working conditions and a lack of suitable personal protective equipment.

Any civil engineering or building construction project must include earthworks. No form of a construction project can be completed without earthworks, whether as a foreground, background, auxiliary, or finishing operation. Earthworks can be carried out on top of the soil, below it, or underwater.

The following construction tasks are performed during earthworks:

Ground (surface) subsurface (tunneling), and underwater excavations; removal and transportation of excavated material to a specified location; and compacting the removed earth to a design compactness.

When building atop excavations, the following negative events are probable:

Groundwater, the presence of hazardous, flammable, and harmful materials, collapses, slips, and cave-ins, and damage to underground installations (water supply, sanitation, district heating, gas lines, etc.).

It is essential to make sure that all safety precautions are taken both before and during the excavation if the earthworks are being done close to a structure from which materials and other objects could fall and endanger the safety of the workers

If the excavation is done close to or on a road, where people or moving cars could endanger the workers, safety precautions must also be taken.

4.3 Safety During Earthworks in Trenching and Excavation

If the soil material remains in balance at a given construction slope when its natural moisture changes in contact with the air, when there is groundwater present, or when the site is affected by surface water and vibrations from road traffic or construction machinery, no additional occupational safety measures are necessary.

If there is no movement of the surrounding soil mass and no hazards to the nearby structures or the region, additional occupational safety precautions are also not necessary. Additionally, if there are no above-ground or subsurface installations inside the work zone, additional safety precautions are not necessary.

The excavated earth is prone to collapsing when earthworks are carried out on excavations deeper than 1 m. The use of retaining wall support - as shown in Figure 4.1 below- benching excavation, if the material can be vertically stable at lower heights; trench shoring (formwork with its internal elements); and sloping excavation at an angle that is lower than the angle of the material's slip circle

Figure 4.1: Securing Trench Walls: Sloping Excavation and Shoring

By building unsupported free slopes, it is possible to execute excavation and trenching up to 3.0 m deep. No matter how deep they are, sloped unsupported excavations need to be stabilized using vacuum drainage and protected against erosion using geothermal membranes. Slides and mass soil flows are possible if slopes are not sufficiently secured or stabilized. If the slope is above the level of the groundwater, it can be at a 45° angle without being thoroughly tested for safety. The strength and fluidity of the soil determine the slope's height and angle. Flows are more likely to occur in low-plasticity soils, especially if sand or silt are present. Wall support structures are used in the development of infrastructure in large cities, particularly in the excavated space for subterranean railroads, but they are also used in underground parking garages, shopping malls, different warehouses, and other structures of a similar kind.

Some of the typical wall support strategies for stabilizing excavations are shown in Figure 4.2

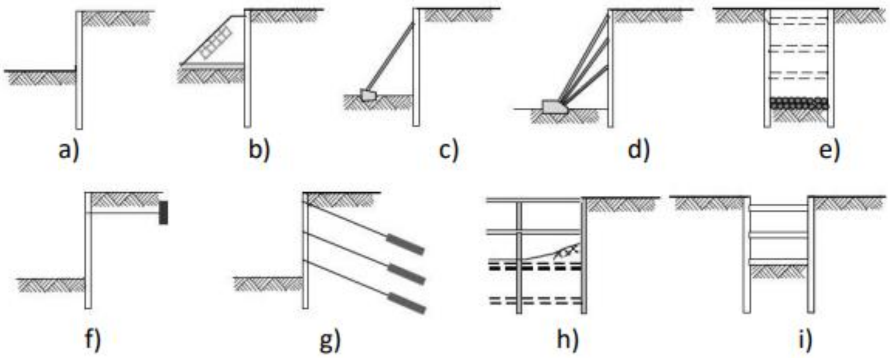


Figure 4.2: Common Types of Wall Support Schemes: (a) Cantilever wall; (b) Berm and slab; (c

Retaining walls with beaches or stays, diaphragms, steel and concrete slabs, sheet piles, grouting, and other wall support systems are some examples of wall support systems for guaranteeing excavation stability.

The type of excavation is determined by the type of soil, the presence and level of groundwater, the proximity to other structures and roadways, the depth and stages of the excavation, the maximum permitted deformation, etc.

Formwork and internal elements are the structures used to support excavations deeper than 1.0 m. As seen in Figure 4.3, the formwork is positioned to withstand and transfer pressure from the soil excavation walls to the internal shoring components. Because of the spacings, the formwork must be evenly spaced out to prevent the surrounding ground from collapsing into the trench. In order to prevent formwork deformation brought on by earth pressure, the formwork elements are forced against one another if the soil is loose, and the soil holes on the exterior of the formwork are filled.

Figure 4.3: Shoring with propped formwork

Interior horizontal shoring elements must maintain their position while being under force, so they must be securely attached to one another and, if necessary, located in between horizontal longitudinal girders. The interior shoring components and formwork are placed while the excavated material is being removed, and the shoring is done progressively and synchronously with the excavation from the top edge downward. To stop materials, tools, and some other items from slipping into the excavation, the formwork must extend at least 20 cm above the top edge.

Concurrent with the backfilling, the formwork is removed from the placement in the opposite sequence. The shoring material utilized must adhere to the technical specifications and norms for materials used in load-bearing structures.

The excavation width is designed so that the clean opening between the shoring elements has a minimum cross-sectional width of 60 cm.

4.4 Personal Protective Equipment for Workers

It is recognized that hazardous, flammable, or explosive elements can be found during excavation work. Additionally, if the earthworks are carried out at a site where electricity, telephone, water and sanitation, and other systems are located, significant or fatal worker accidents may happen. To protect the safety of the workers, careful adherence to the recommended safety procedures is required during excavation work. Personal protective equipment, such as overalls, helmets, gloves, boots, respiration masks, and earplugs, is another component of the safety measures.

Personal protective equipment is a must for any excavation site. It's used to protect workers from hazards such as electrical shock, noise, and dust during the digging process. There are many different types of PPE that can be purchased, depending on the project and job site conditions. For example, if you're working in an environment with high levels of vibration or noise then ear plugs may be required. However, if your job requires wearing heavy gloves then you will need stronger hearing protection than just earplugs alone could provide for you.

4.5 Machine Trenching

Implementing safety procedures to protect workers and other personnel who move or operate close to the equipment is necessary for machine trenching. Non-employees, vehicles, installations, items, or structures must be kept away from the danger zone surrounding operational machinery because they could put themselves at risk or result in unsafe machine operation. Figure 4.4 shows an excavating machine matching the required requirements.

Figure 4.4: Shows Construction Machinery Excavation Compliant with All the Requirements

Excavation-related construction equipment can only be used once all conditions for its safe operation and movement have been met. It implies that there will be secure access, the necessary room to move around, a safe area for ideal operative placement, unobstructed lines of sight, etc. The use of construction machinery is forbidden in soft, slick, or steep terrains, as well as in areas where heavy equipment could sink, move abruptly, or become unstable.

Machine activities must be stopped when the weather is bad and visibility is low because else the operator risked losing control of the device

4.6 Training, Supervision and Competency

Training and supervision are important, but it's important to know when to stop. If you've been trained to do something, then you must be competent in that task. If your trainer has experience in the specific task they are training people to do, then they should be able to demonstrate that skill while giving instructions on safe practices. They need also to have enough experience with their own tasks so as not to make mistakes or cause injury through inexperience alone

4.7 Site Operations

- Check the stability of the ground. The soil should be firm, but not too hard or loose.
- Keep an eye on your excavator's feet and arms. A person can easily slip and fall if they are not careful around equipment, so make sure you watch where they're walking at all times!
- Don't over-excavate: If there's too much dirt pulled up from an area before it has been thoroughly examined for signs of valuable artifacts, this could lead to damage or lost items in later stages of construction (if done right). You also want to avoid digging into areas that aren't stable enough; otherwise, you risk damaging foundations or causing other problems down the road!
- Don't dig too fast: This may seem counterintuitive since we've already talked about how important it is not overdoing things...but rushing through an excavation will only cause more problems than taking care with each step taken along this course."

4.8 Safety When Excavating

You should always be sure to stay safe when excavating. It’s important to understand the dangers of excavation, as well as what steps you can take to avoid them.

The following are some examples of situations where tunneling presents hazards:

- Tunnels that run through the unstable ground or unstable rock formations. If your tunnel passes through an area with high water tables or weak soil, it may collapse due to flooding or instability in the ground above it. * Tunnels that have been built without proper ventilation (i.e., poor air circulation). This can lead to poor worker health and safety conditions for everyone involved. * Tunnel linings made from materials such as wood rather than concrete could cause cave-ins if they are not properly supported by walls and other supports.

5 CHAPTER FIVE

Methodology

It has been decided to take a case in Nablus city in order to be studied and to design an excavation support system for it. A site has been found and visited by the work team, this site is located near AL-Baik Sweets store, where exists Leddawi's Building. Before starting building it, excavation works have been performed to level the ground, but unfortunately, a failure has occurred in the soil surface.

It has been decided to visit this site and take a look at the building, the work team has visited the site and met the site engineer - Eng. Noor -, a set of engineering drawings have been obtained in addition the required information about the site and the building. First off, the work team has reviewed the soil investigation report regarding this site and studied it to conclude the soil capacity and its parameters and other related information such as the borehole logs, the seismicity of the site, the suggested type of foundations and so on.

Secondly, the work team has gained the design report of the support system which Dr. Isam Jaradaneh has suggested and designed for the failure surface in the site, Jaradaneh has designed sheet piles consisting of two rows of piles of a diameter of 80 cm for each pile and a 1.2 m center to center spacing between each adjacent pile.

Another important data has been collected from the site such as the necessary dimensions of the building and the nearby structures, number of stories of Leddawi's building, number of stories for Takroori's building which will be used later to determine the surcharge load of these structures in order to be included in the upcoming analysis.

Also, the work team has gathered the site plan in order to get the required elevations and the street width which will be also used in the analysis that will be performed.

The idea is the conduct analysis on the currently existing support system that was designed by Dr. Jaradaneh using a new finite element analysis which is Plaxis 2D and to get the soil and the results such as the forces: Axial, shear and bending moment diagrams and values of the sheet piles, deformations and deflection values of the sheet piles. Then a decision will be made according to the results to replace this system by another system using one row of piles. The second part is to design an entire new excavation support system for the upper part of the site in between Takroori's building and Leddawi's building where exists big boulders in order to prevent any future failures within the soil surface while excavating.

PLAXIS 2D software is a finite element geotechnical engineering software which can be used for 2D analysis of deformation and stability in geotechnical engineering and rock mechanics. PLAXIS is used worldwide by top engineering companies and institutions in the civil and geotechnical engineering industry. PLAXIS 2D is ideal for a range of applications from excavations, embankments, and foundations to tunneling, mining, oil and gas, and reservoir geomechanics.

It includes all the essentials to perform deformation and safety analysis for soil and rock that do not require the consideration of creep, steady state groundwater or thermal flow, consolidation analysis, or any time-dependent effects.

6 CHAPTER SIX

Data Collection

This chapter will be talking about the set of the collected data related to the site, these data include the soil investigation report, the design report of the current existing sheet piles system, the required and needed dimensions of the building and nearby structures and the road width that will be all included in the analysis performed using PLAXIS 2D software.

6.1 Soil Investigation Report

The work team has collected the soil report of the site included in this study case; this report has been made by Hijjawi Construction Labs on June, 2022. This report has been made for the proposed Leddawi's Building for Mr. Mohammad Fehmy Leddawi. Parcel No. 105 + 106 and Block No. 24060.

This report is to provide the geotechnical parameters to design the foundation of the proposed AL-Leddawi Multi-storage Building, located at Rafedia street– Nablus, Basin No24060. The proposed Building will have a plan area of 600-1100 square meters and will be consisted of at most of two basement and 10 stories (of total 12 stories).

The procedure that was carried out to determine the above purpose was as follows:

Four boreholes were dug out in the site using soil mechanics boring machine, two boreholes were dug out to depth of 11 m, and one borehole was dug out to depth of 16m, the last one was dug out to depth of 5m.

Note that each of these boreholes were increased by 3m due to the basement will be excavated later; Location of boreholes is shown below.

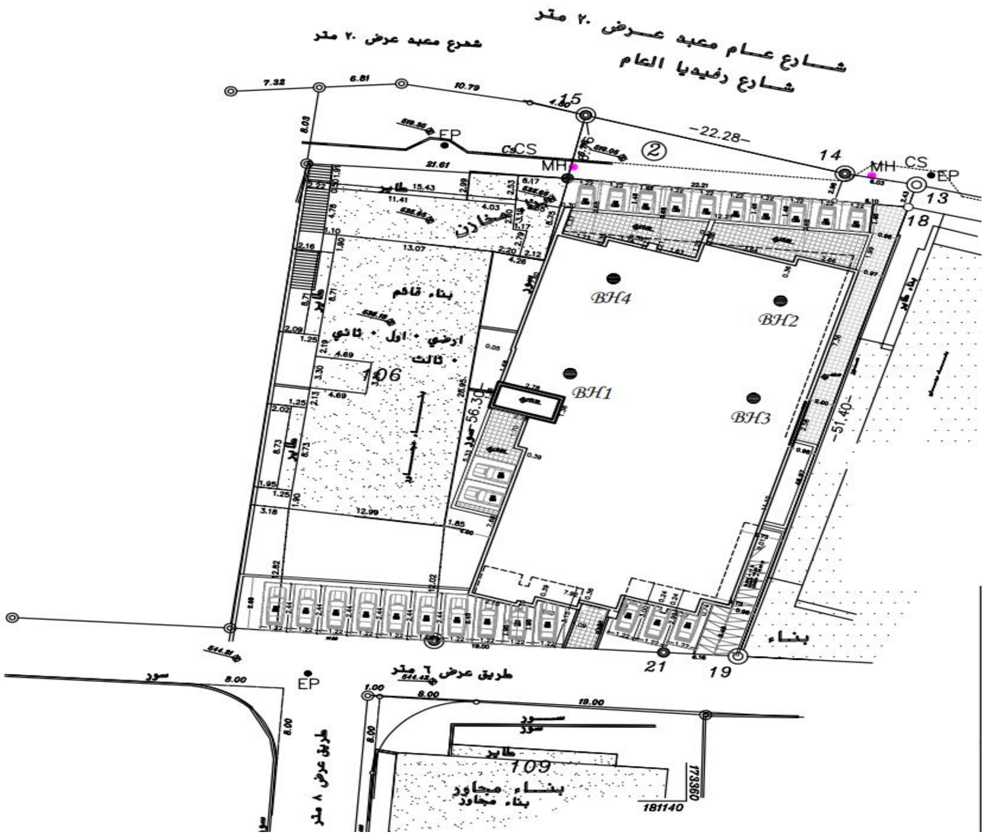
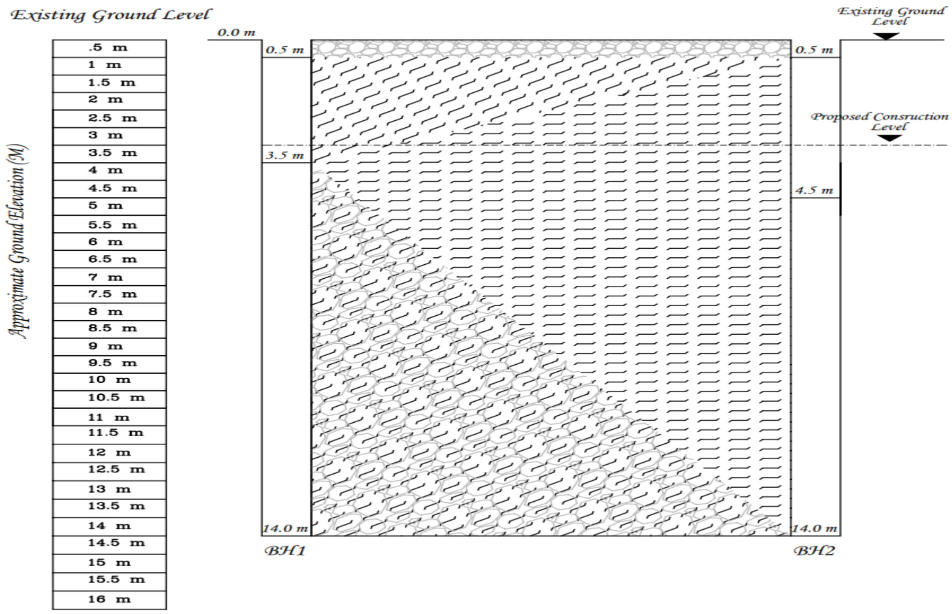
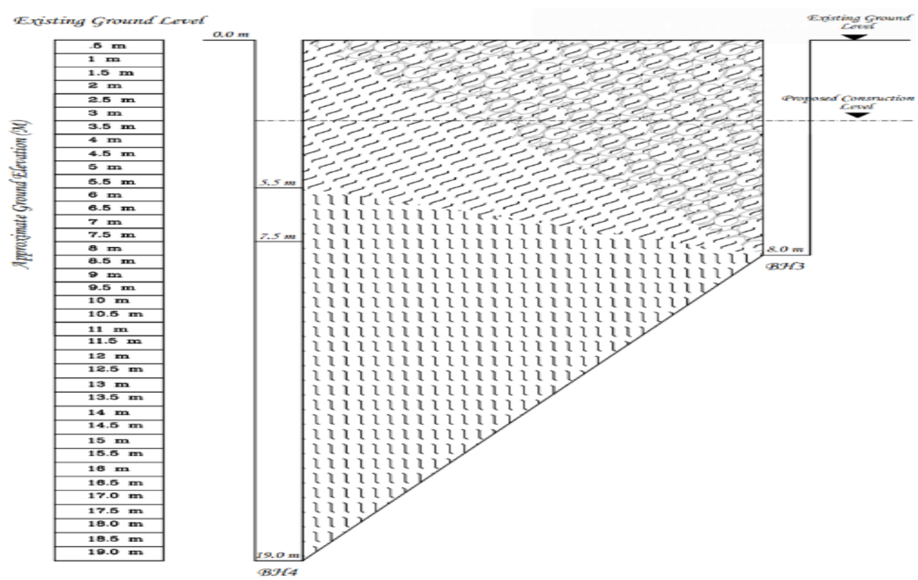


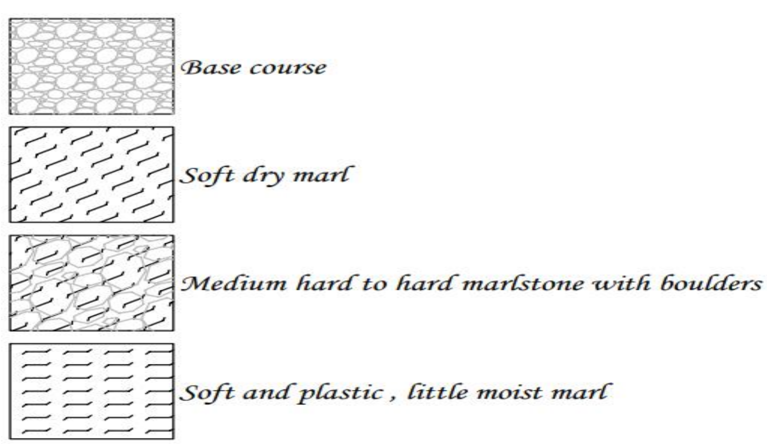
Figure 6.1: Shows the Boreholes Location

Geological Condition:

Through the drilling of boreholes, it was found that the soil of the site in general consists of soft, dry marl soil, followed by medium hard to hard marlstone, rarely mixed with stones at the full-excavated depth, in the borehole #2, the soil is composed of soft and plastic marl, it is rarely wet over the entire excavated soil.


Existing Ground Level
Approximate Ground Elevation (M)
0.0 m
0.5 m
3.5 m
14.0 m
4.5 m
Existing Ground Level
Proposed Consruction Level
BH1
BH2


Existing Ground Level
Approximate Ground Elevation (M)
0.0 m
5.5 m
7.5 m
19.0 m
8.0 m
Existing Ground Level
Proposed Consruction Level
BH3
BH4


Base course
Soft dry marl
Medium hard to hard marlstone with boulders
Soft and plastic , little moist marl

Type of foundation:

Isolated or continuous foundation is recommended to be used for this site, at depth not less than 3m from the existing ground surface, in this case the allowable bearing capacity = 250 kN/m^2 (2.5 kg/cm^2) and the foundation depth should be at least 3 m below the existing ground surface, with relative density 98%.

Parameters of soil:

The following table summarizes the Soil parameters:

Table 6-1: Soil Parameters

BH No.	Sample No.	Depth m	Natural Moisture Content %	Plasticity Index	Cohesion kN/m^2	Angle of Internal Friction (φ°)
1	1	0.0 – 0.5	-	-		
	2	0.5 – 3.5	68	7.1	**12**	**22**
	3	3.5 – 14	-	NP	**7**	**25**
2	1	0.0 – 0.5	-	-		
	2	0.5 – 4.5	81	13.2	**14**	**19**
	3	4.5 – 14	78	11.4		
3	1	0.0 – 8	64	6.9	**10**	**22**
4	1	0.0 – 5.5	72	7.5	**11**	**22**
	2	5.5 – 19	-	NP		

6.2 PLAXIS 2D Software

PLAXIS 2D is a user-friendly, finite-element package that provides you with the ability to model diverse geotechnical problems from a single, integrated application. Analyze the deformation and stability of projects ranging from excavations, embankments, and foundations to tunneling, mining, and geomechanics.

PLAXIS 2D includes all the essential functionalities to perform everyday deformation and safety analysis for soil and rock that do not require the consideration of creep, steady state groundwater or thermal flow, consolidation analysis, or any time-dependent effects.

PLAXIS is an interactive 3D software that facilitates the design of mechanical systems. It's a unified environment for modeling, solving, and animating rigid body dynamics simulations.

A "fully-coupled" analysis means that both contact forces and material nonlinearities are solved when analyzing your design. And thanks to its thorough support of virtual reality headsets, you can play around with your system in a real-world environment.

PLAXIS 2D is a straightforward and efficient CAD tool for mechanical engineers. It can be used to design products in the following areas:

It provides a user interface that allows you to input and view geometry, validate designs, and simulate your results. The software has been used in many different industries including automotive, consumer electronics, medical devices and consumer durables.

PLAXIS 2D can be used to design plastic and metallic parts. It has a parametric modeling functionality that provides instant updates on geometry changes.

PLAXIS 2D has a flexible and intuitive UI that allows you to create both 2D and 3D CAD applications.

The software provides a range of analysis methods, including linear static, modal dynamic, contact analysis, nonlinear dynamic (including sprung-mass), impact analysis etc. It also supports different types of calculations, including finite element methods, FEM simulation and elastic modal analysis.

The software can import and export files in most popular CAD formats like IGES. The software's integrated materials editor allows you to specify material properties and properties of the parts constituting the system, such as elasticity coefficients and deformability.

7 CHAPTER SEVEN

Data Analysis

7.1 Soil Mode – Material Definitions

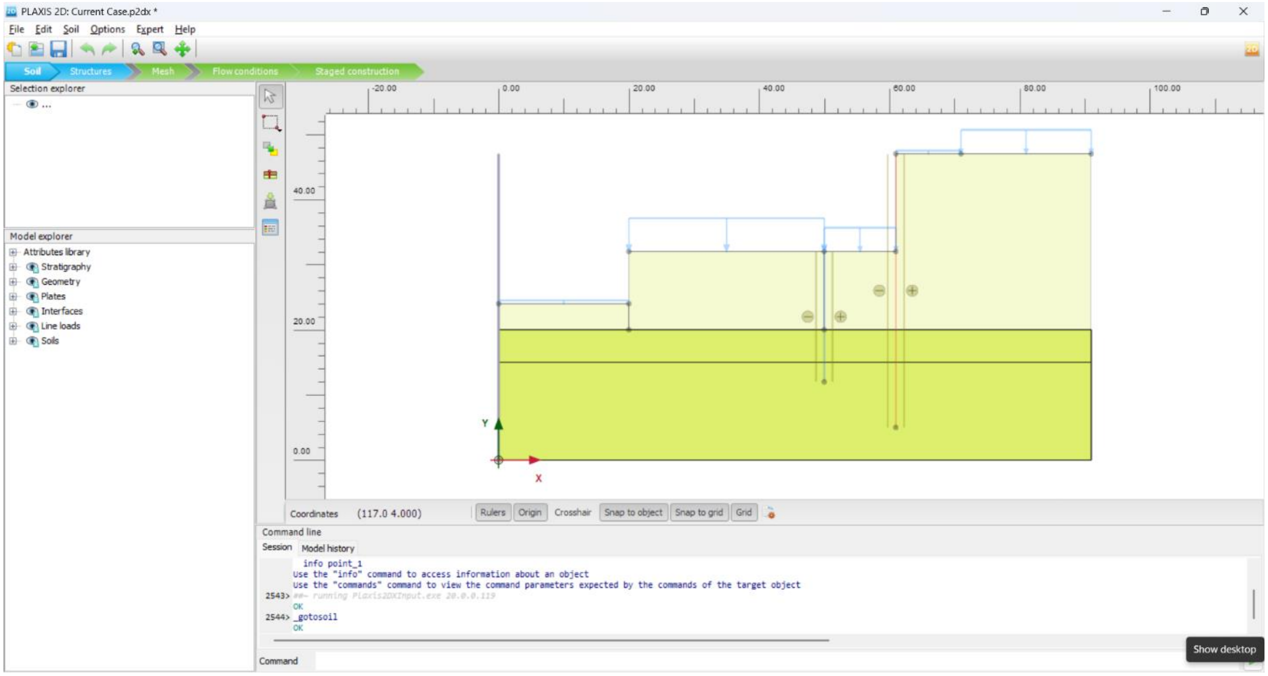


Figure 7.1: View of the project in the Soil mode

Boreholes are locations in the drawing area at which the information on the position of soil layers and the water-table is given. If multiple boreholes are defined, PLAXIS 2D will automatically interpolate between boreholes, and derive the position of the soil layers from the borehole information. Each defined soil layer is used throughout the whole model contour. In other words, all soil layers appear in all boreholes. The top and the bottom boundaries of the layers may vary through boreholes, making it possible to define non-horizontal soil layers of non-uniform thickness as well as layers that locally have a zero thickness.

To define the needed materials in this project, the icon shown in the Figure below is used to define materials, which are soil and piles.

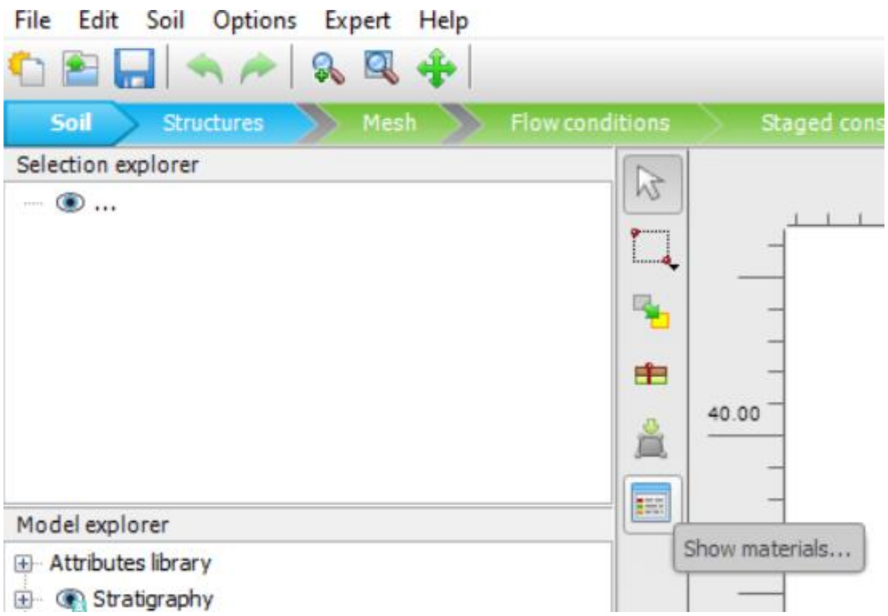


Figure 7.2: Material Sets Icon

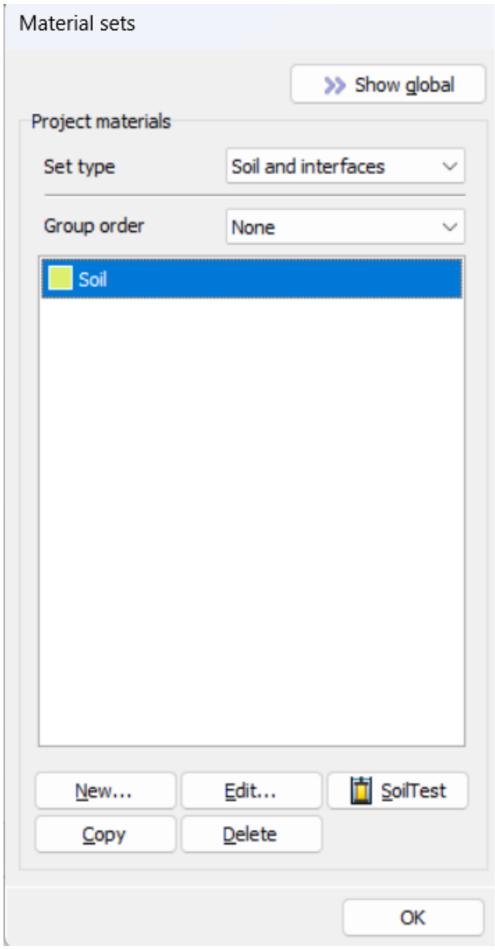
7.1.1 Soil Definition

According to the collected data from the field, the soil is a sandy soil with the following parameters.

- Unit weight of the soil $(\gamma) = 18\ kN/m^3$
- Pasion's Ratio $(v) = 0.3$
- Cohesion $(C) = 21\ kN/m^3$
- $Angle\ of\ internal\ friction\ (\emptyset) = 28°$
- No groundwater table was found in the site

Mohr-Coulomb soil type has been selected from the window that fits our required analysis.

The following figures show the steps of defining the soil of the site



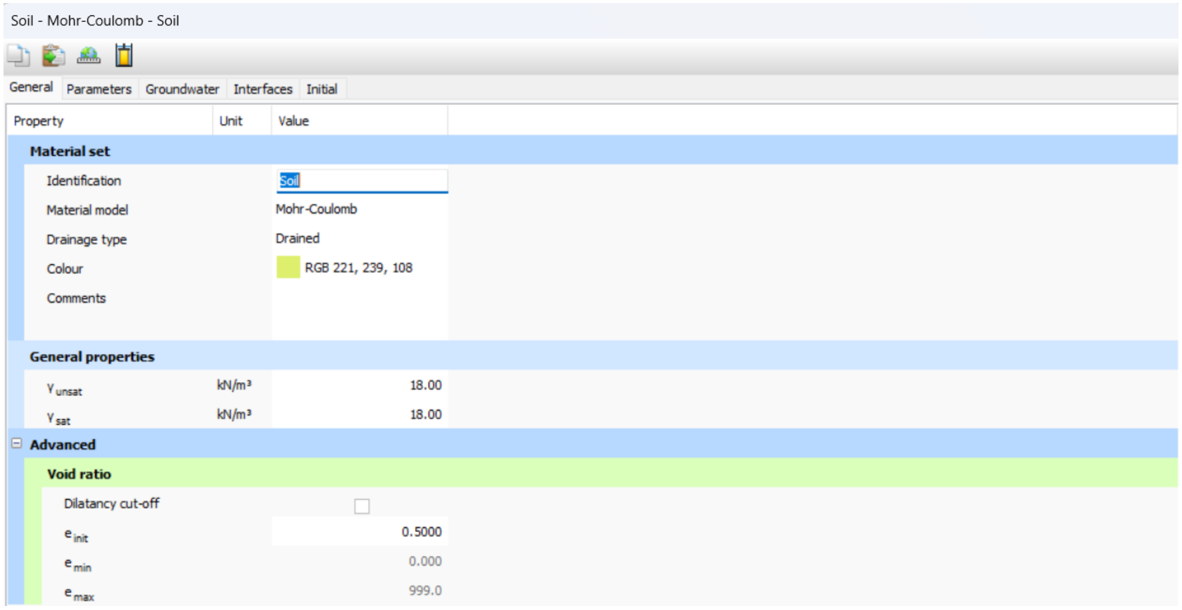


Figure 7.3: Shows Soil General Parameters Inputs

Soil Stiffness and Strength Properties

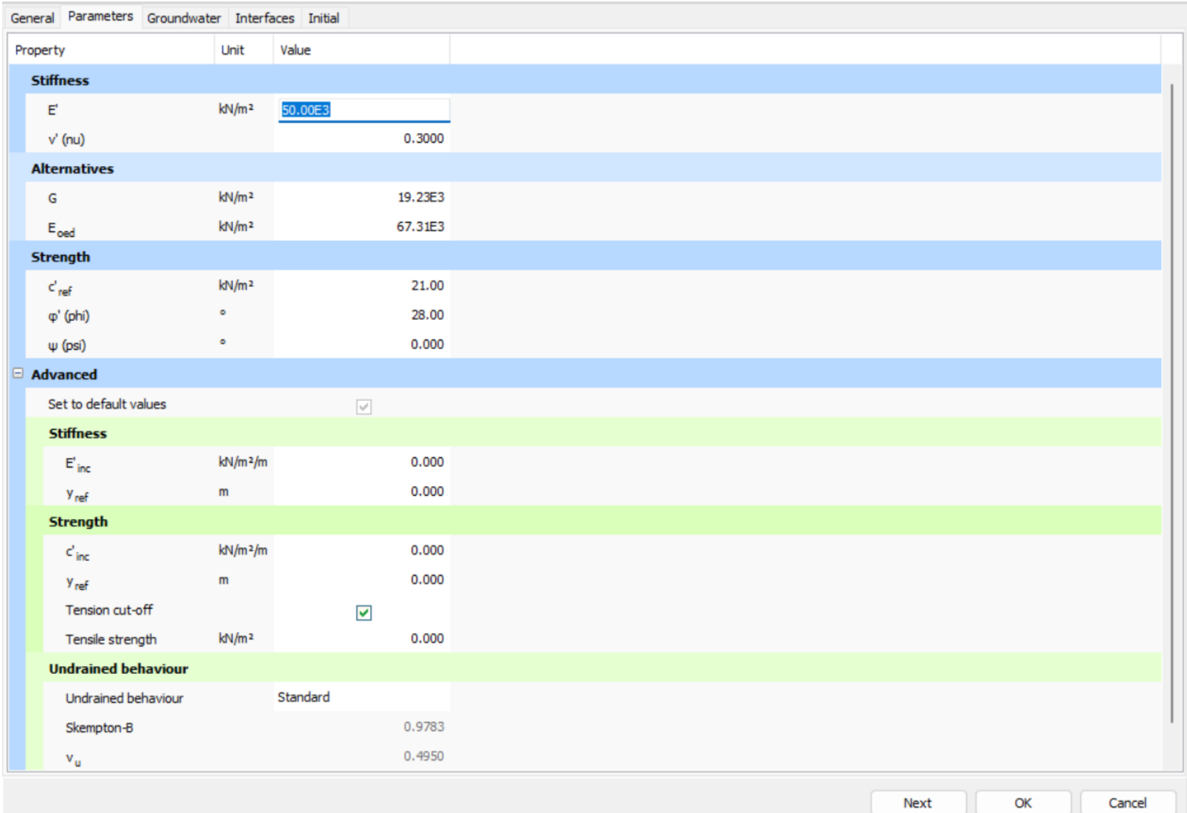


Figure 7.4: Shows Soil Stiffness and Strength Properties

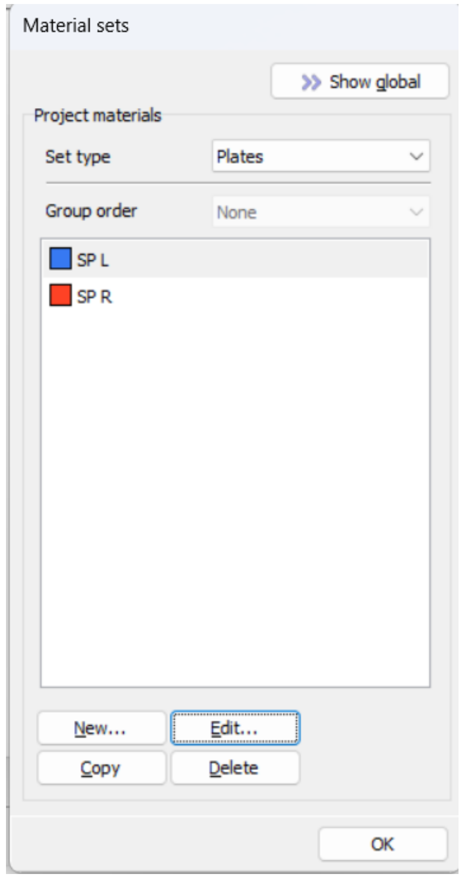
7.1.2 Piles Definitions

In PLAXIS 2D, piles are simulated as plater materials that has specific strength and stiffness properties in terms of the diameter and the material it's made out of.

The material type which will be dealing with is Elastic. The current existing sheet pile that has been designed is 0.8 m in diameter and 1.2 m center to center spacing, the piles are made out of concrete 28 MPa and made in two rows.

In order to convert the 3D model into 2D model, some necessary calculations have been performed in order to simulate these piles in PLAXIS 2D.

The needed parameters to define the piles as plate materials are the modulus of elasticity of the material – which is concrete -, the area of the sheet pile, the diameter of the piles, moment of inertia, and the weight per meter run of the sheet pile since it's a 2D analysis program.



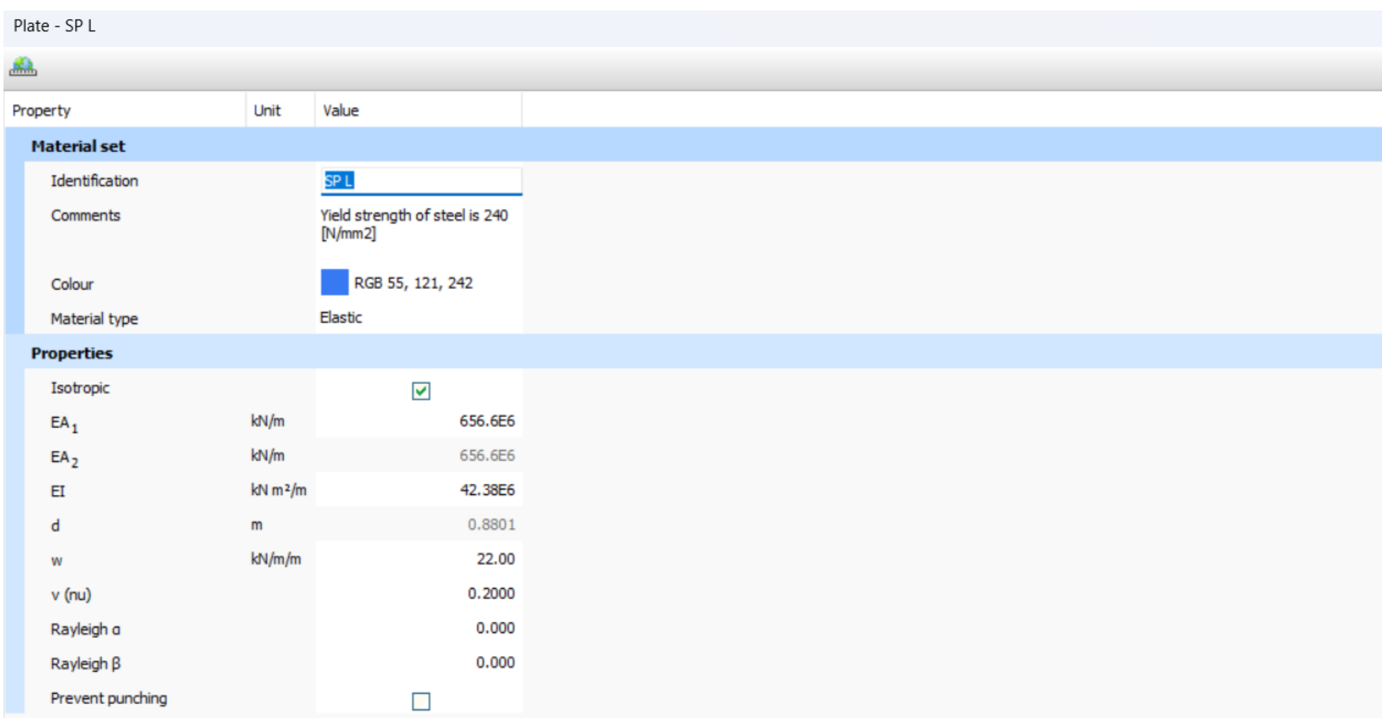


Figure 7.5: Plater Material Parameters

✪ Definitions of the needed parameters

In addition to material data sets for soil and interfaces, the material properties and model parameters for plates are also entered in separate material data sets. Plates are used to model the behavior of slender walls, plates or thin shells. Distinction can be made between elastic, elastoplastic and elastoplastic (M-κ) behavior. A data set for plates generally represents a certain type of plate material, and can be assigned to the corresponding (group of) plate elements in the geometry model.

1. Mechanical properties

The properties required for plates can be grouped into general properties, stiffness properties, strength properties (in case of elastoplastic behavior) and dynamic properties. Isotropic Different stiffnesses in-plane and out-of-plane may be considered. The latter is most relevant for axisymmetric models when modelling sheet pile profiles (which have a low stiffness in the out-of-plane direction). If this is not the case, the Isotropic option may be selected to ensure that both stiffness is equal. Prevent punching In reality vertical loads on walls for example, as a result of vertical components of anchor forces are sustained by the shaft friction and the tip resistance. A certain amount of resistance is offered by the soil under the tip, depending on the thickness or the cross-section area of the tip. Slender walls are often modelled as plates. Due to the zero thickness of the plate elements vertical plates (walls) have no end bearing. The effects of end bearing can still be considered in the calculation when the corresponding option is selected in the material data set. In order to consider end bearing at the bottom of plates, a zone in the soil volume elements surrounding the bottom of the plate is identified where any kind of soil plasticity is excluded (elastic zone). The size of this zone is determined as $\mathbf{D_{eq} = 12EI / EA}$.

Note that sheet pile walls have very little end bearing, considering that the thickness of the steel is much less than $\mathbf{D_{eq}}$, when modelling them as plates. Hence, the end bearing option shall NOT be used for sheet pile walls.

2. ***General Properties***

A plate has two general properties:

- **d:** The (equivalent) thickness (in the unit of length) is automatically calculated from the ratio of the axial stiffness EA and flexural rigidity EI.
- **w:** In a material set for plates a specific weight can be specified, which is entered as a force per unit of length per unit width in the out-of-plane direction.

For relatively massive structures the weight of a plate is, in principle, **obtained by multiplying the unit weight of the plate material by the thickness of the plate**. For sheet-pile walls the weight (force per unit area) is generally provided by the manufacturer. This value can be adopted directly since sheet-pile walls usually occupy relatively little volume.

3. ***Stiffness Properties***

For elastic behavior, several parameters should be specified as material properties. PLAXIS 2D allows for orthotropic material behavior in plates, which is defined by the following parameters:

- **EA:** For elastic behavior an in-plane axial stiffness EA should be specified. For both axisymmetric and plane strain models the value relates to a stiffness per unit width in the out-of-plane direction.
- **EI:** For elastic behavior a flexural rigidity EI should be specified. For both axisymmetric and plane strain models the value relates to a stiffness per unit width in the out-of-plane direction. In the case of Elastoplastic (M- κ) behavior, EI is automatically determined based on the first line segment in the M-κ diagram.
- **ν (nu):** Poisson's ratio

From the ratio of EI and EA an equivalent thickness for an equivalent plate (D_{eq}) is automatically calculated from the equation: $D_{eq} = \sqrt{12\frac{EI}{EA}}$

7.2 Meshing

When the geometry model is fully defined the geometry has to be divided into finite elements in order to perform finite element calculations. A composition of finite elements is called a mesh. The mesh is created in the Mesh mode.

The mesh should be sufficiently fine to obtain accurate numerical results. On the other hand, very fine meshes should be avoided since this will lead to excessive calculation times. The PLAXIS 2D program uses fully automatic generation of finite element meshes. The generation of the mesh is based on a robust triangulation procedure. The mesh generation process takes into account the soil stratigraphy as well as all structural objects, loads and boundary conditions.

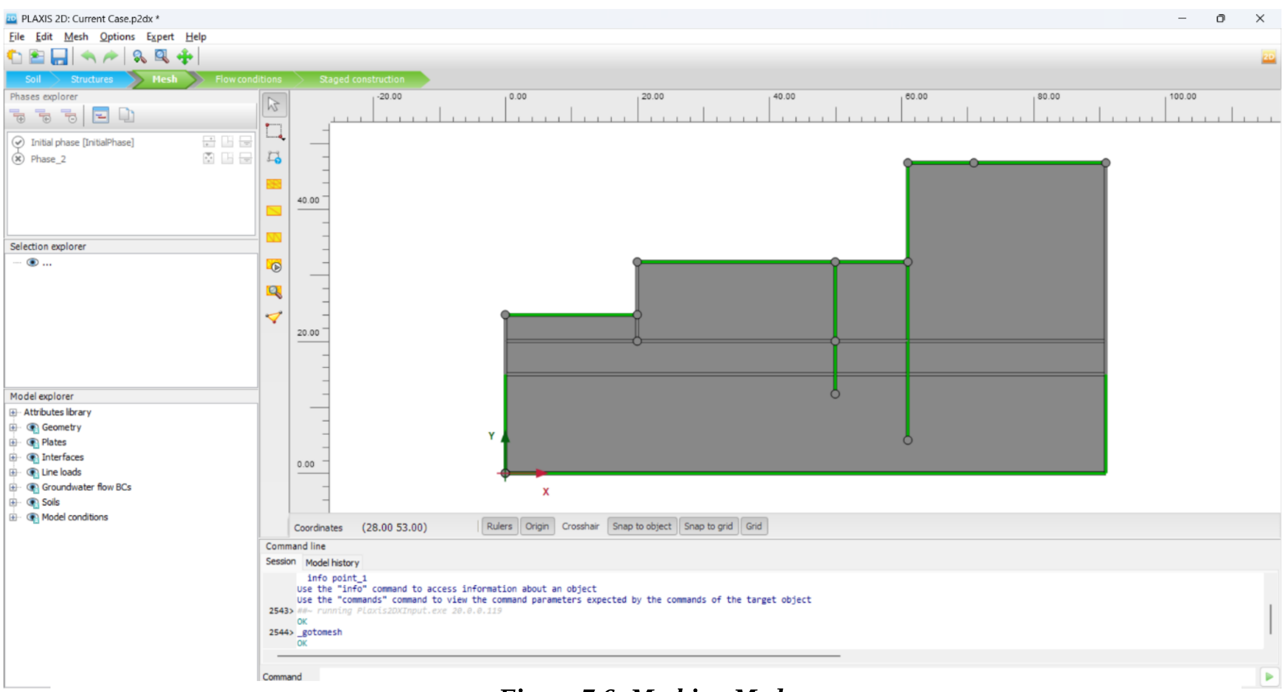


Figure 7.6: Meshing Mode

To generate the mesh, click the Generate mesh button in the side toolbar of the Mesh mode or select the corresponding option in the Mesh menu. The Mesh options window pops up where the general mesh properties can be defined.

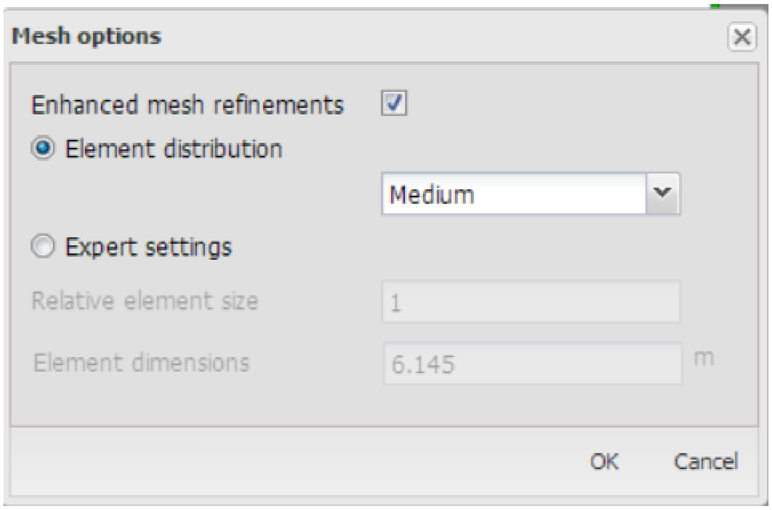


Figure 7.7: Mesh Options Window

The mesh is generated by clicking on the OK button in the Mesh options window. After the mesh was generated, the number of generated elements is displayed in the Session tab of the Command line.

To view the generated mesh, click the View mesh button in the side toolbar.

7.3 Defining Calculation Phases

Finite element calculations can be divided into several sequential calculation phases. Each calculation phases corresponds to a particular loading or construction stage. The construction stages can be defined in the Staged construction mode. The calculation phases are listed in the Phases explorer.

7.3.1 Phases explorer

The phases defined in a project are displayed in the Phases explorer. The Phases explorer is accessible in the Calculation modes. However, it is not editable in the Mesh mode. The general layout is shown

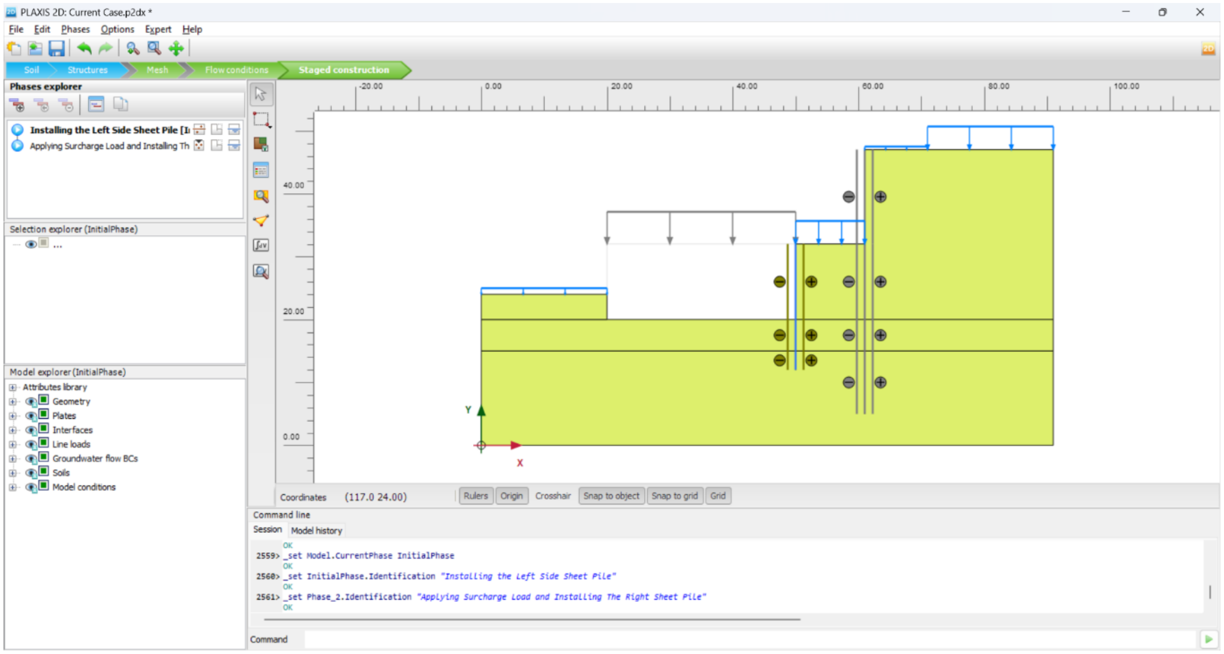


Figure 7.8: Stage Construction and Phases Explorer

7.3.2 Calculation State Indication

The calculation state of a phase is indicated by the symbol at the beginning of each line in the Phases explorer

- The phase is to be calculated.
- The phase is not to be calculated.
- The phase was calculated. No error occurred during calculation.
- The phase was calculated but an assumption is made by the program enabling the continuation of the calculation. Information is provided in the *Log info for last calculation step* box in the **Phases** window.
- The calculation failed. Information is provided in the *Log info for last calculation step* box in the **Phases** window.
- The calculation failed, but the calculation of the child phases is still possible. Information is provided in the *Log info for last calculation* box in the **Phases** window.

7.4 Input of Parameters

In this report, we have managed to analyze the current case of al AL-Baik and design a proper sheet pile and compare it to another suggested case.

7.4.1 Current Case

The current case of this site is a multi-story building is being constructed, currently there are 5 stories are already constructed. There exists the left sheet pile which was constructed and designed by Dr. Isam Jaradaneh, this sheet pile consists of 2 rows of circular piles, each has a diameter of 0.8 meter and center to center spacing of 1.2 m. These piles are 20 m long, 12m above the ground and 8m below. The current case has been modeled in order to design the second sheet pile which will be going to be constructed.

There are some calculations to be performed in order to simulate the current case as a 2D case so that it can be inserted into the program input. So that we can input every parameter as per meter run.

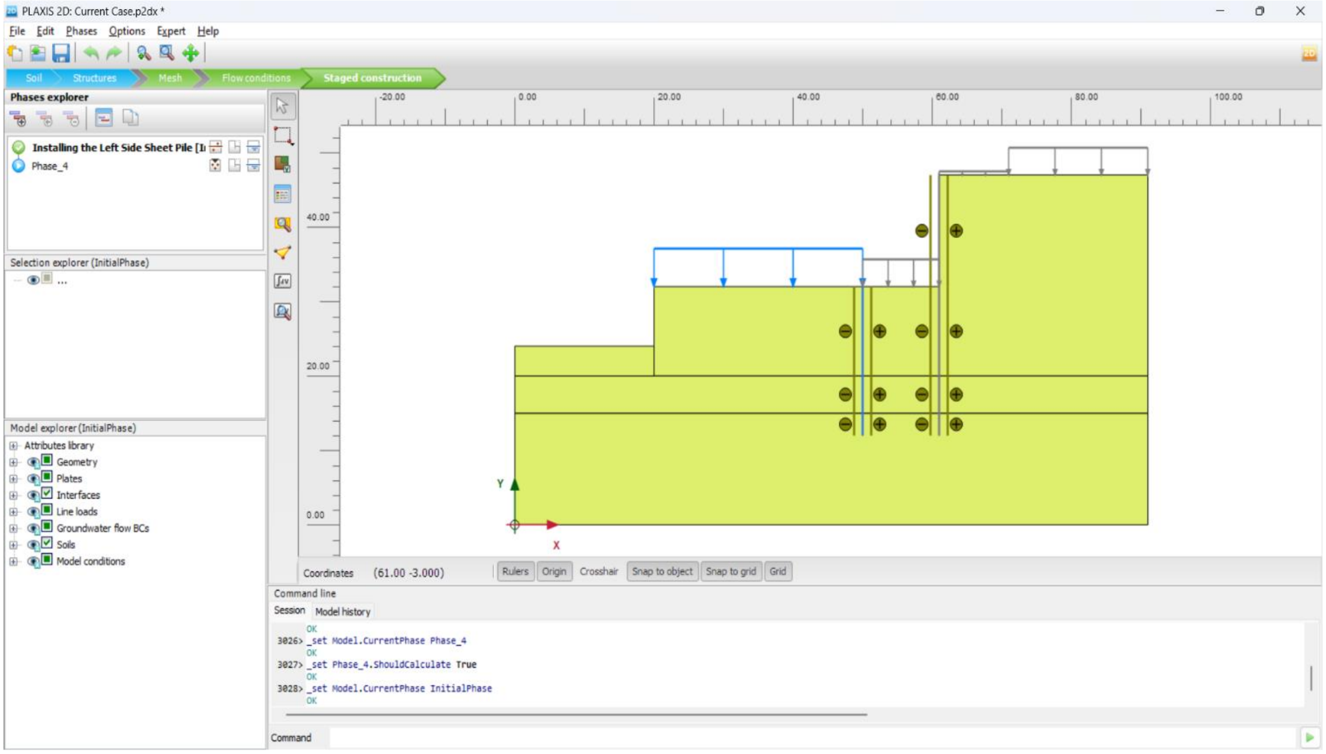


Figure 7.9: Current Case Model

8.4.1.1 Left Sheet Pile Parameters

The 2 rows of piles are distributed along 30 m distance, this implies that the number of piles equals $(n) = \frac{Total\ Distance}{Center\ to\ center\ Spacing}$ ➔ $\frac{30}{1.2} = 26\ Piles$

- ***Equivalent Thickness of Sheet Pile***

These 26 piles have a diameter of 0.8m, so in order to simulate these as a single sheet pile, an equivalent thickness of this sheet pile is calculated according to this formula

$$h_{eq} = \frac{Total\ Area\ of\ Piles}{Total\ Distance} * Number\ of\ Rows \rightarrow \frac{\frac{\pi}{4} * D^2 * n}{d}$$

- $\boldsymbol{h_{eq} = \frac{\frac{\pi}{4} * 0.8^2 * 26}{30} * 2 = 0.88\ m}$

- ***Moment of Inertia***

Moment of inertia of these sets of piles are converted as a rectangular plate having a thickness of 0.88 m and a width of 30 m.

$$\boldsymbol{I = \frac{b * h^3}{12}}$$

- $\boldsymbol{I = \frac{30 * 0.88^3}{12} = 1.704\ m^4}$

- ***Modulus of Elasticity of the Plate***

The sheet pile is made of concrete 28 MPa, which means modulus of elasticity is given by the following formula

- $\boldsymbol{E = 4700 * \sqrt{f'c} \rightarrow 4700 * \sqrt{28} = 24870062}$ **MPa**

Specific Weight of the Plate (w)

For relatively massive structures the weight of a plate is, in principle, obtained by multiplying the unit weight of the plate material by the thickness of the plate.

$$w = \gamma * h_{eq}$$

- **Where**

  w: $Specific\ weight\ (kN/m/m)$

  γ: $Unit\ wieght\ of\ the\ material\ (kN/m^3)$

  h: $Equivalent\ thickness\ (m)$

✪ $w = 25 * 0.88 = 22\ kN/m/m$

Equivalent Cross-Sectional Area of the Sheet Pile

$$A = b * h_{eq}$$

As the cross-sectional area of the equivalent sheet pile has a rectangular shape of a width of 30 m and thickness of 0.88 m

✪ $A = 30 * 0.88 = 26.4\ m^2$

Axial Stiffness (EA)

✪ $EA = 24870062 * 26.4 = \mathbf{656.570 * 10^6\ kN/m}$

Flexural Stiffness (EI)

✪ $EI = 24870062 * 1.704 = \mathbf{42.38 * 10^6\ kN.m^2/m}$

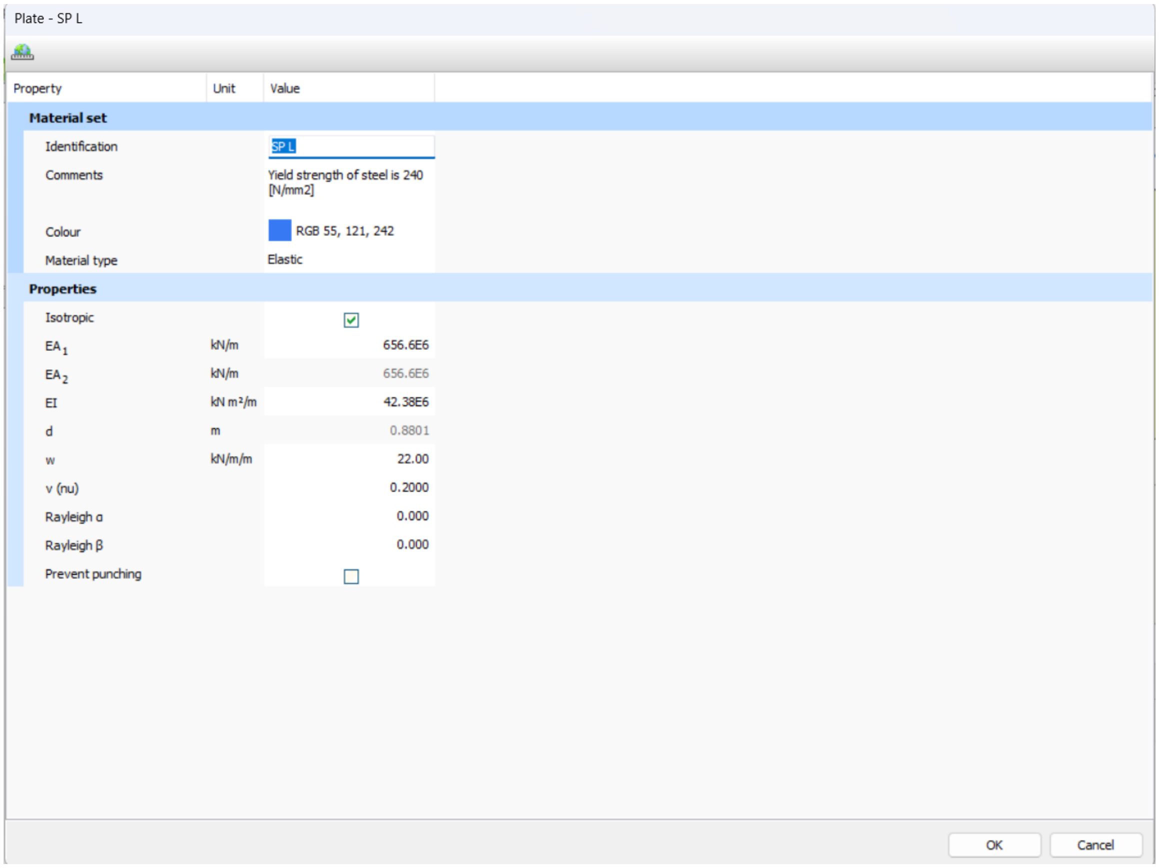


Figure 7.10: Current Case- Input Parameters of Left Sheet Pile

8.4.1.2 Right Sheet Pile Parameters

The 2 rows of piles are distributed along 30 m distance, this implies that the number of piles equals $(n) = \frac{Total\ Distance}{Center\ to\ center\ Spacing} \rightarrow \frac{30}{1.3} = 24\ Piles$

- ***<u>Equivalent Thickness of Sheet Pile</u>***

These 24 piles have a diameter of 1.3m, so in order to simulate these as a single sheet pile, an equivalent thickness of this sheet pile is calculated according to this formula

$$h_{eq} = \frac{Total\ Area\ of\ Piles}{Total\ Distance} * Number\ of\ Rows \rightarrow \frac{\frac{\pi}{4} * D^2 * n}{d}$$

- $$\boldsymbol{h_{eq} = \frac{\frac{\pi}{4} * 1.3^2 * 24}{30} * 2 = 2.14\ m}$$

Moment of Inertia

Moment of inertia of these sets of piles are converted as a rectangular plate having a thickness of 2.14 m and a width of 30 m.

$$I = \frac{b * h^3}{12}$$

- ✪ $I = \frac{30*2.14^3}{12} = 24.501\ m^4$

Modulus of Elasticity of the Plate

The sheet pile is made of concrete 28 MPa, which means modulus of elasticity is given by the following formula

- ✪ $E = 4700 * \sqrt{f'c}$ ➔ $4700 * \sqrt{28} = 24870062$ MPa

Specific Weight of the Plate (w)

For relatively massive structures the weight of a plate is, in principle, obtained by multiplying the unit weight of the plate material by the thickness of the plate.

$$w = \gamma * h_{eq}$$

- **Where**

  w: $Specific\ weight\ (kN/m/m)$

  γ: $Unit\ wieght\ of\ the\ material\ (kN/m^3)$

  h: $Equivalent\ thickness\ (m)$

- ✪ $w = 25 * 2.14 = 53.5\ kN/m/m$

Equivalent Cross-Sectional Area of the Sheet Pile

$$A = b * h_{eq}$$

As the cross-sectional area of the equivalent sheet pile has a rectangular shape of a width of 30 m and thickness of 0.88 m

- $A = 30 * 2.14 = 64.2\ m^2$

Axial Stiffness (EA)

- $EA = 24870062 * 64.2 = \mathbf{1596.658 * 10^6\ kN/m}$

Flexural Stiffness (EI)

- $EI = 24870062 * 1.704 = \mathbf{609.34 * 10^6\ kN.m^2/m}$

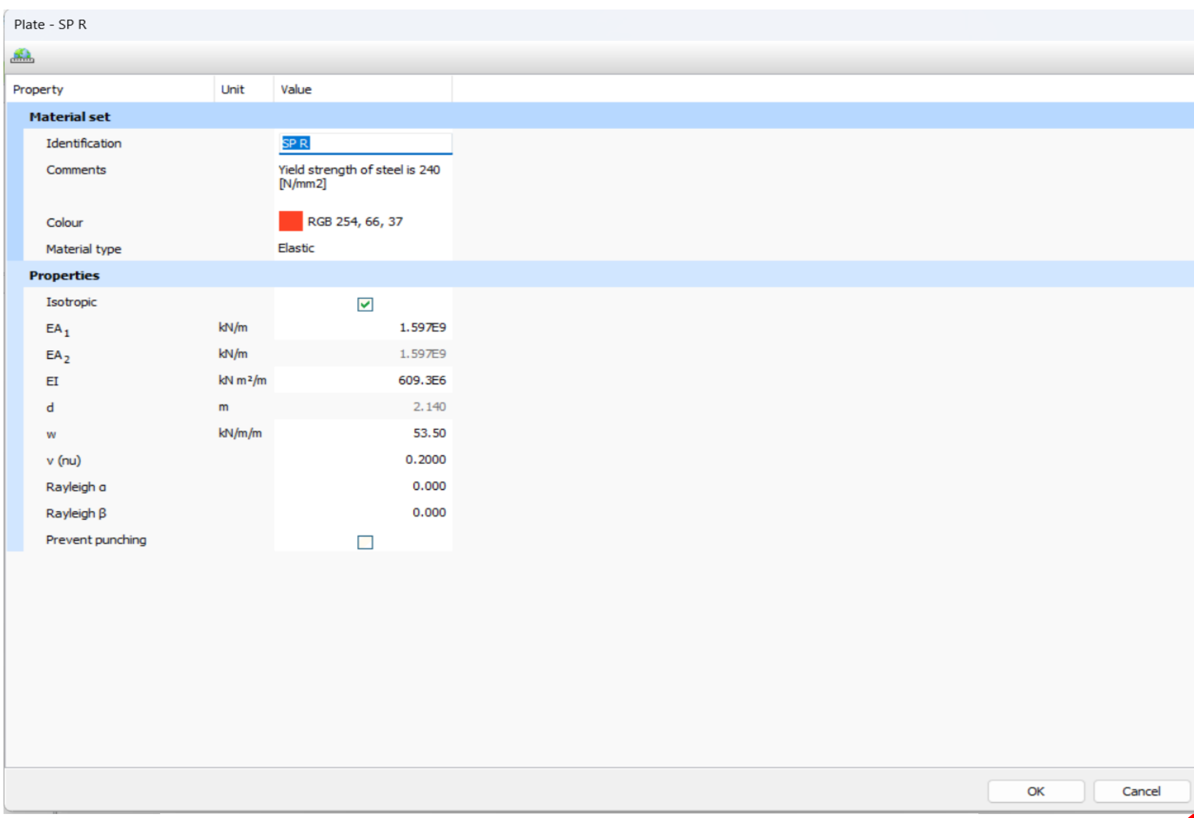


Figure 7.11: Current Case - Input Parameters of the Right Sheet Pile

7.4.2 Suggested Case

The current case of this site is a multi-story building is being constructed, our suggestion is that the right sheet pile is constructed first, after that the big boulders are excavated, this sheet pile consists of 2 rows of circular piles, each has a diameter of 1 meter and center to center spacing of 1 m. These piles are 42 m long, 27m above the ground and 15m below. The current case has been modeled in order to design the left sheet pile which will be going to be constructed before the multi-story building.

There are some calculations to be performed in order to simulate the current case as a 2D case so that it can be inserted into the program input. So that we can input every parameter as per meter run.

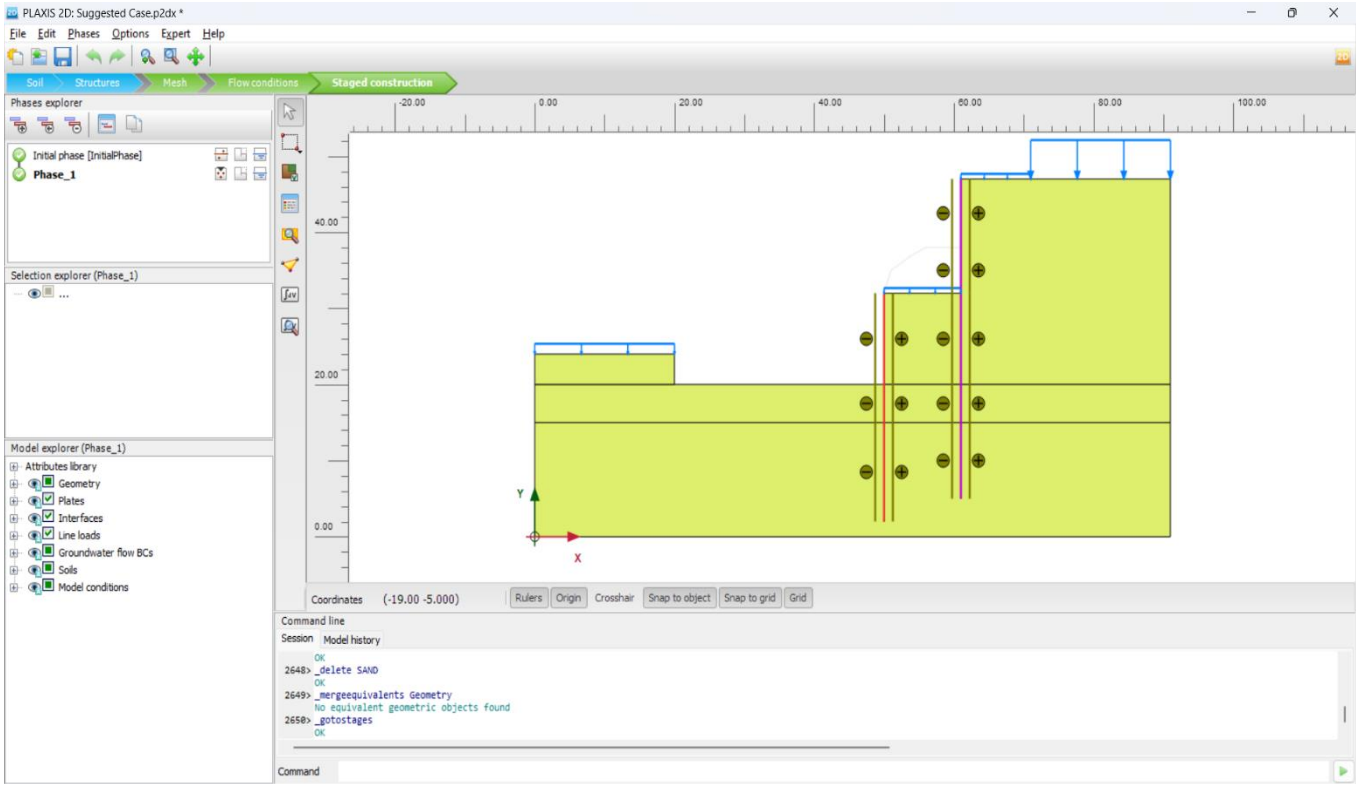


Figure 7.12: Suggested Case Model

8.4.1.2 Right Sheet Pile Parameters

The 2 rows of piles are distributed along 30 m distance, this implies that the number of piles equals $(n) = \frac{Total\ Distance}{Center\ to\ center\ Spacing}$ ➔ $\frac{30}{1} = 31\ Piles$

- ***Equivalent Thickness of Sheet Pile***

These 31 piles have a diameter of 1m, so in order to simulate these as a single sheet pile, an equivalent thickness of this sheet pile is calculated according to this formula

$$h_{eq} = \frac{Total\ Area\ of\ Piles}{Total\ Distance} * Number\ of\ Rows \rightarrow \frac{\frac{\pi}{4} * D^2 * n}{d}$$

- $\boldsymbol{h_{eq} = \frac{\frac{\pi}{4} * 1^2 * 31}{30} * 2 = 1.63\ m}$

- ***Moment of Inertia***

Moment of inertia of these sets of piles are converted as a rectangular plate having a thickness of 1.63 m and a width of 30 m.

$$\boldsymbol{I = \frac{b * h^3}{12}}$$

- $\boldsymbol{I = \frac{30 * 1.63^3}{12} = 10.827\ m^4}$

- ***Modulus of Elasticity of the Plate***

The sheet pile is made of concrete 28 MPa, which means modulus of elasticity is given by the following formula

- $\boldsymbol{E = 4700 * \sqrt{f'c} \rightarrow 4700 * \sqrt{28}}$ **= 24870062 MPa**

Specific Weight of the Plate (w)

For relatively massive structures the weight of a plate is, in principle, obtained by multiplying the unit weight of the plate material by the thickness of the plate.

$$\boldsymbol{w} = \boldsymbol{\gamma} * \boldsymbol{h_{eq}}$$

- **Where**

  $\boldsymbol{w}$: $Specific\ weight\ (kN/m/m)$

  $\boldsymbol{\gamma}$: $Unit\ wieght\ of\ the\ material\ (kN/m^3)$

  $\boldsymbol{h}$: $Equivalent\ thickness\ (m)$

✪ $\boldsymbol{w = 25 * 1.63 = 40.75\ kN/m/m}$

Equivalent Cross-Sectional Area of the Sheet Pile

$$\boldsymbol{A = b * h_{eq}}$$

As the cross-sectional area of the equivalent sheet pile has a rectangular shape of a width of 30 m and thickness of 0.88 m

✪ $\boldsymbol{A = 30 * 1.63 = 48.9\ m^2}$

Axial Stiffness (EA)

✪ $\boldsymbol{EA} = 24870062 * 48.9 = \mathbf{1216 * 10^6\ kN/m}$

Flexural Stiffness (EI)

✪ $\boldsymbol{EI} = 24870062 * 1.704 = \mathbf{269 * 10^6\ kN.m^2/m}$

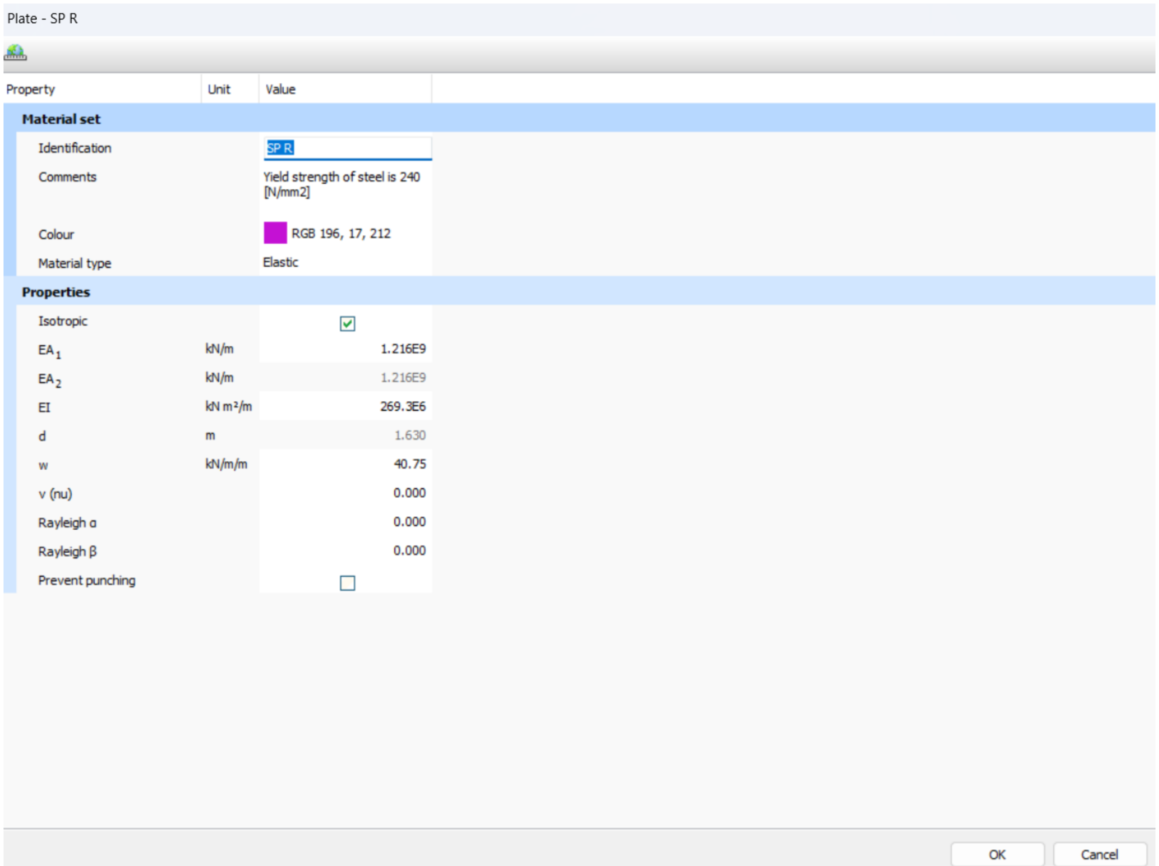


Figure 7.13: Suggested Case Input Parameters of the Right Sheet Pile

8.4.1.1 Left Sheet Pile Parameters

There is only 1 row that's distributed along 30 m distance and 32m depth, 12m above the ground and 18m below, this implies that the number of piles equals $(n) = \frac{Total\ Distance}{Center\ to\ center\ Spacing}$ ➔ $\frac{30}{1} = 31\ Piles$

- ***<u>Equivalent Thickness of Sheet Pile</u>***

These 26 piles have a diameter of 0.8m, so in order to simulate these as a single sheet pile, an equivalent thickness of this sheet pile is calculated according to this formula

$$h_{eq} = \frac{Total\ Area\ of\ Piles}{Total\ Distance} * Number\ of\ Rows \rightarrow \frac{\frac{\pi}{4} * D^2 * n}{d}$$

- $\boldsymbol{h_{eq} = \frac{\frac{\pi}{4} * 1^2 * 31}{30} * 1 = 0.82\ m}$

Moment of Inertia

Moment of inertia of these sets of piles are converted as a rectangular plate having a thickness of 0.82 m and a width of 30 m.

$$I = \frac{b * h^3}{12}$$

- $I = \frac{30*0.82^3}{12} = 1.379\ m^4$

Modulus of Elasticity of the Plate

The sheet pile is made of concrete 28 MPa, which means modulus of elasticity is given by the following formula

- $E = 4700 * \sqrt{f'c} \rightarrow 4700 * \sqrt{28} = 24870062$ MPa

Specific Weight of the Plate (w)

For relatively massive structures the weight of a plate is, in principle, obtained by multiplying the unit weight of the plate material by the thickness of the plate.

$$w = \gamma * h_{eq}$$

- **Where**

  w: $Specific\ weight\ (kN/m/m)$

  γ: $Unit\ wieght\ of\ the\ material\ (kN/m^3)$

  h: $Equivalent\ thickness\ (m)$

- $w = 25 * 0.82 = 20.5\ kN/m/m$

Equivalent Cross-Sectional Area of the Sheet Pile

$$A = b * h_{eq}$$

As the cross-sectional area of the equivalent sheet pile has a rectangular shape of a width of 30 m and thickness of 0.88 m

- $A = 30 * 0.82 = 24.6\ m^2$

Axial Stiffness (EA)

- $EA = 24870062 * 24.6 = \mathbf{611.8 * 10^6\ kN/m}$

Flexural Stiffness (EI)

- $EI = 24870062 * 1.704 = \mathbf{34.30 * 10^6\ kN.m^2/m}$

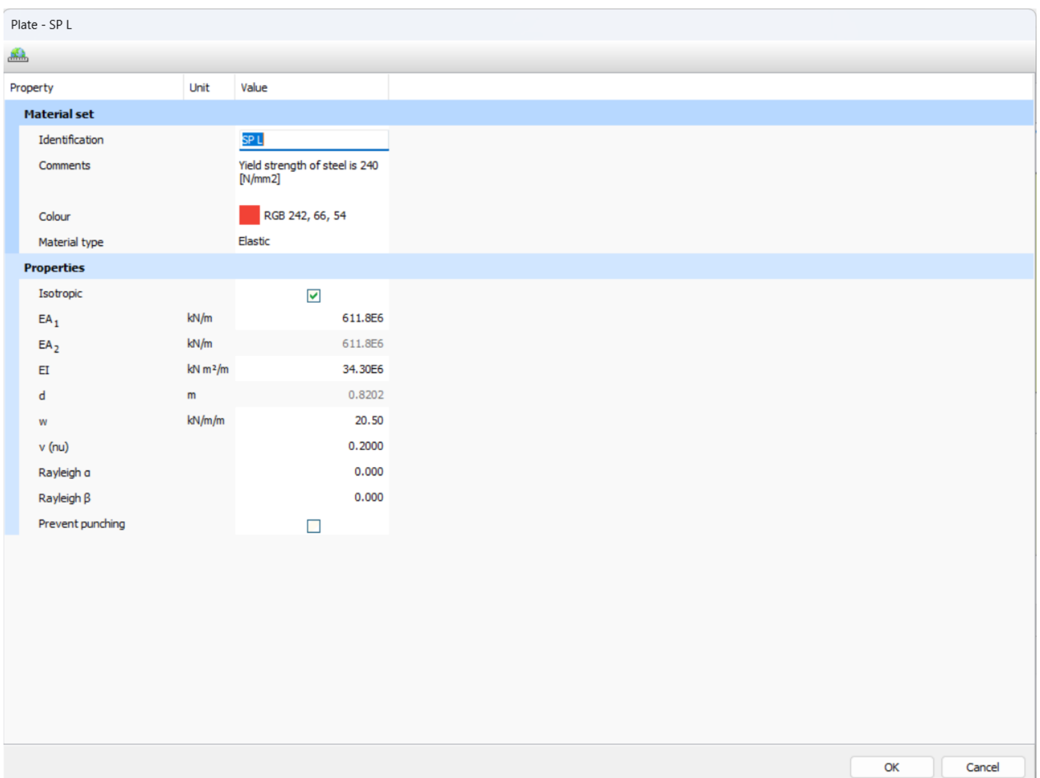


Figure 7.14: Suggested Case - Input Parameters of the Left Sheet Pile

8 CHAPTER EIGHT

Results and Discussion

8.1 Comparison between Cases

Table 8-1: Comparison between Suggested and Current Case

#	Left Sheet Pile					Right Sheet Pile				
	Rows	*Dia (m)*	*S (m)*	*h (m)*	*Depth (m)*	*Rows*	*Dia (m)*	*S (m)*	*h (m)*	*Depth (m)*
Current Case	2	0.8	1.2	0.88	20	2	1.2	1.4	1.7	25
Suggested Case	1	0.8	1	0.44	21	2	1	1.1	1.49	42

It's noticed that in our suggested case, the left sheet pile could be designed by only 1 row of piles of 1m diameter of each pile and 1m center to center spacing, this leads to an equivalent thickness of the sheet pile of 0.82 m with 30m depth. As well as, the right sheet pile also would be designed economically of 2 rows of piles but with 1m diameter and 1m center to center spacing which gives a 1.63m equivalent thickness of the sheet pile with 47m depth.

8.2 Current Case

8.2.1 Deflection

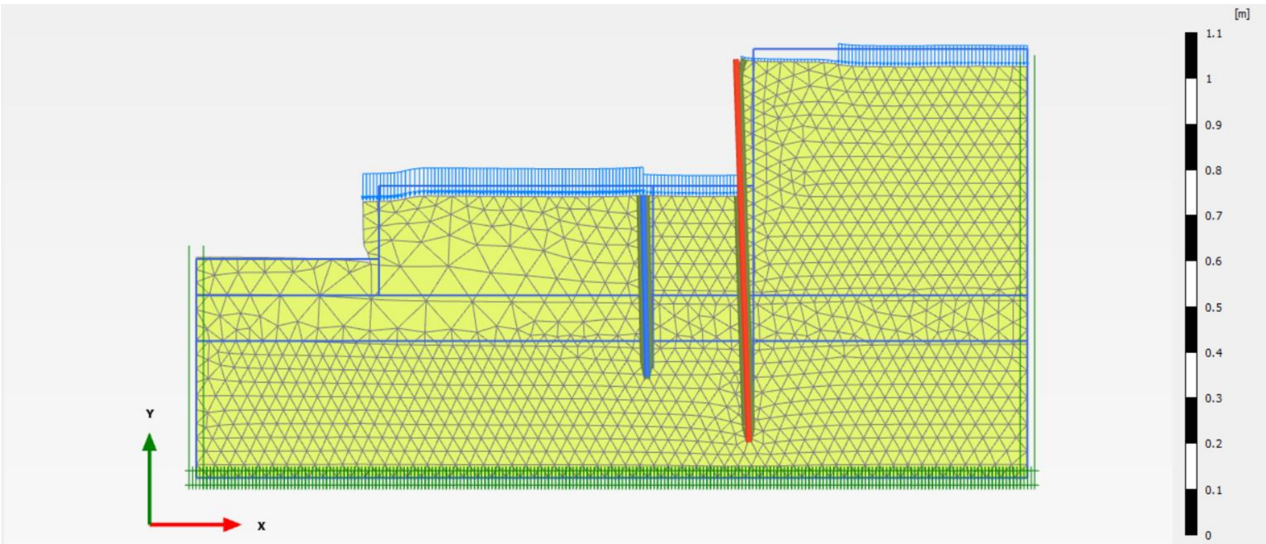


Figure 8.1: Deflection Shape of the Current Case

8.2.1.1 Left Sheet Pile

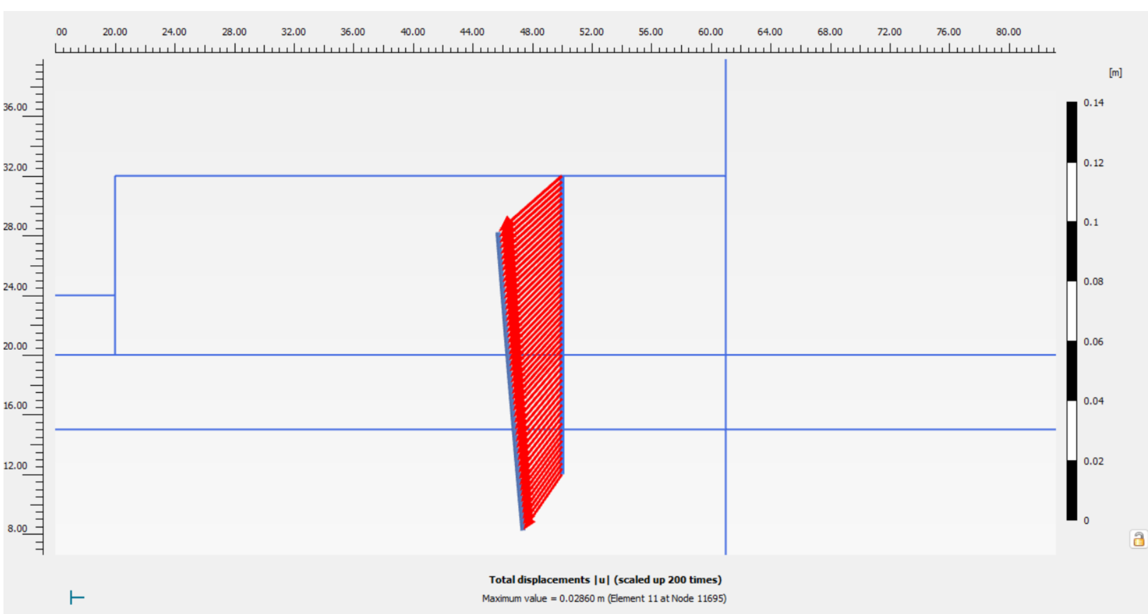


Figure 8.2: Deflection Shape of the Left Sheet Pile - Current Case

As shown in the figure above, the maximum displacement is about 3 cm at the top of the piles. Here is a clearer shot of the distribution of the displacement values along the sheet pile.

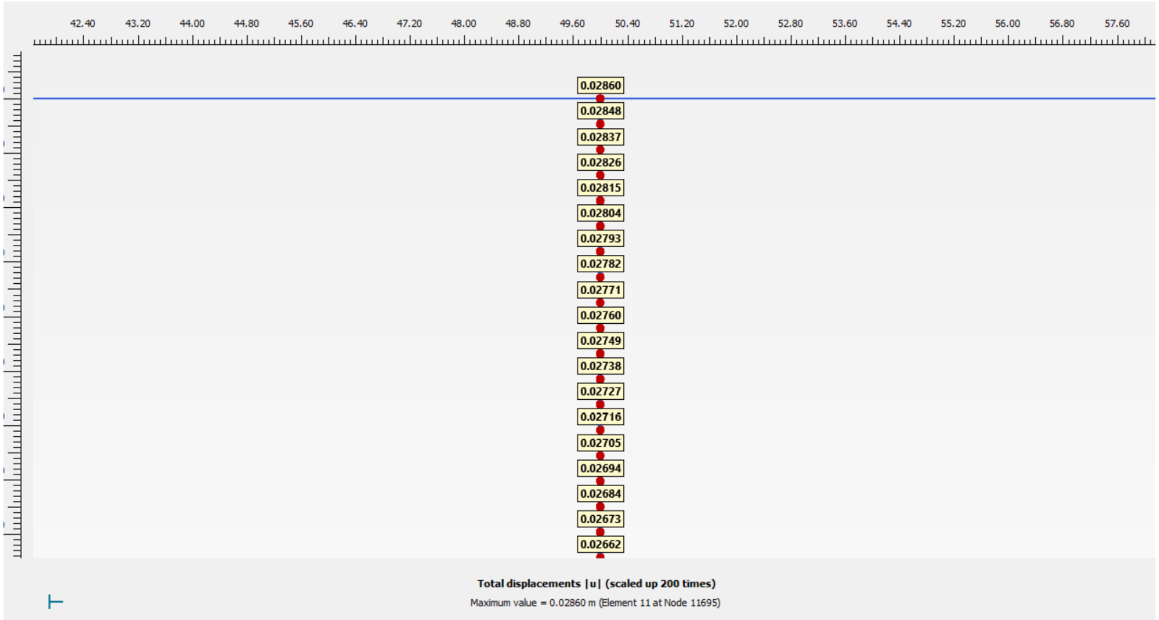


Figure 8.3: Deflection Distribution Values over the Left Sheet Pile

8.2.1.2 Right Sheet Pile

Figure 8.4: Deflection Shape of the Right Sheet Pile - Current Case

It's noted that that maximum deflection is about 4 cm as shown in the next detailed figure

Figure 8.5: Deflection Values Distributions along the Right Sheet Pile - Current Case

8.2.2 Axial Force

8.2.2.1 Left Sheet Pile

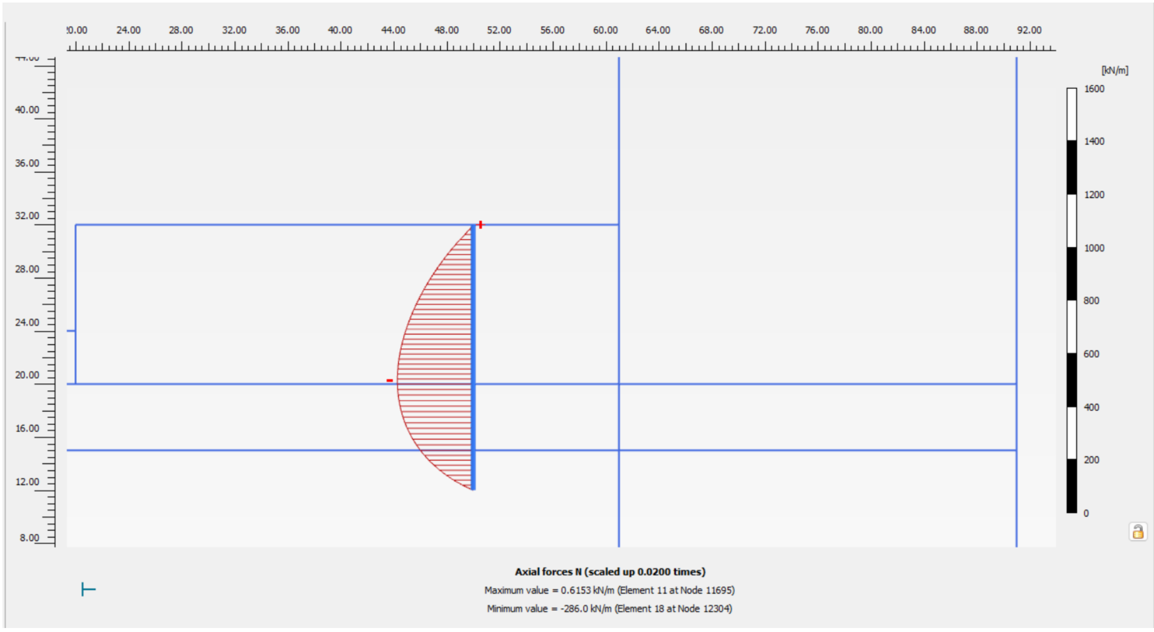


Figure 8.6: Axial Force Diagram of the Left Sheet Pile - Current Case

The Figure above shows the axial force diagram of the left sheet pile, it's noted that the maximum axial force generated equals 286 kN/m.

8.2.1.2 Right Sheet Pile

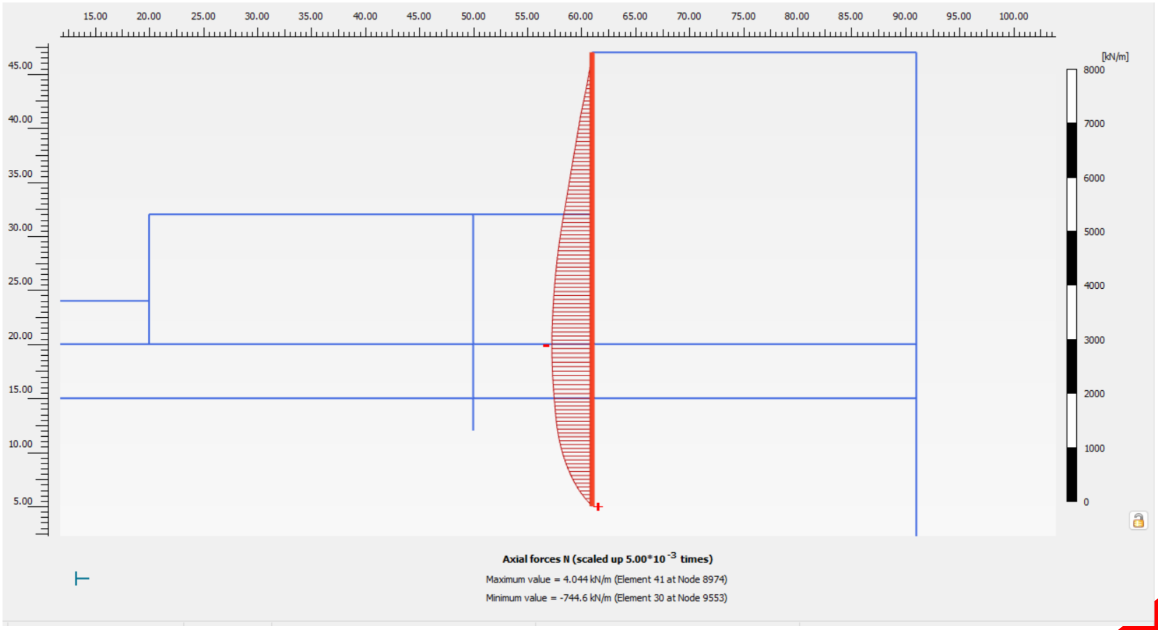


Figure 8.7: Axial Force Diagram of the Right Sheet Pile - Current Case

The Figure above shows the axial force diagram of the left sheet pile, it’s noted that the maximum axial force generated equals 745 kN/m.

8.2.3 Shear Force

8.2.3.1 Left Sheet Pile

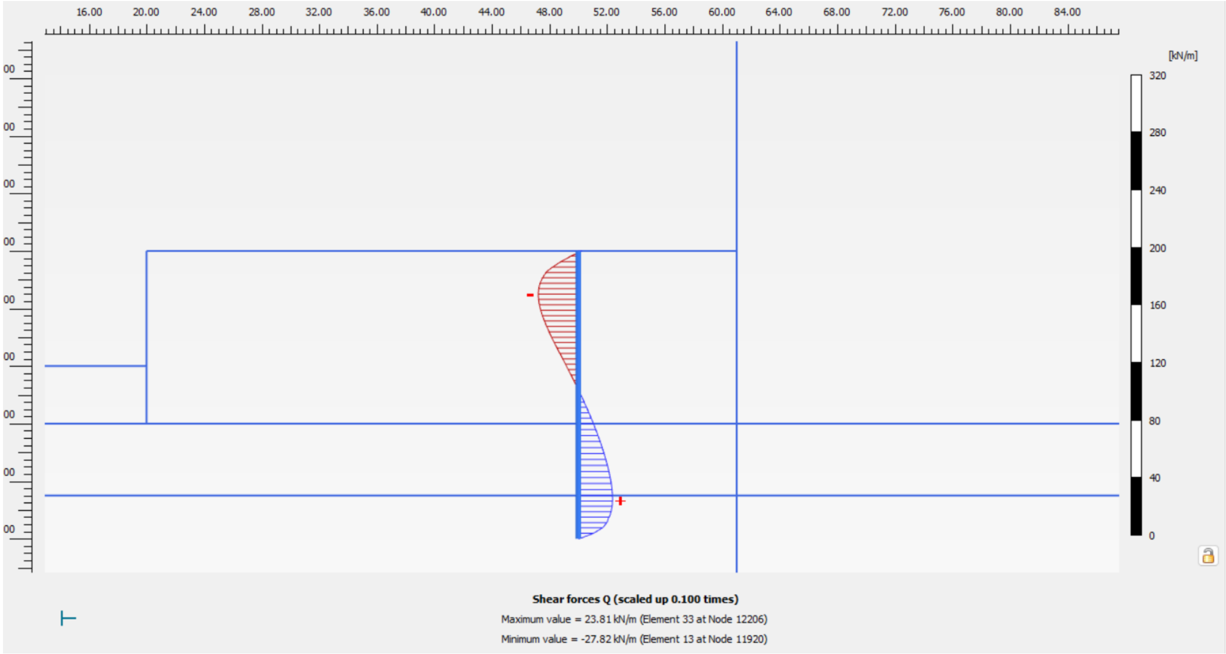


Figure 8.8: Shear Force Diagram of the Left Sheet Pile - Current Case

The Figure above shows the shear force diagram of the left sheet pile, it’s noted that the maximum shear force generated equals 27.8 kN/m.

8.2.3.2 Right Sheet Pile

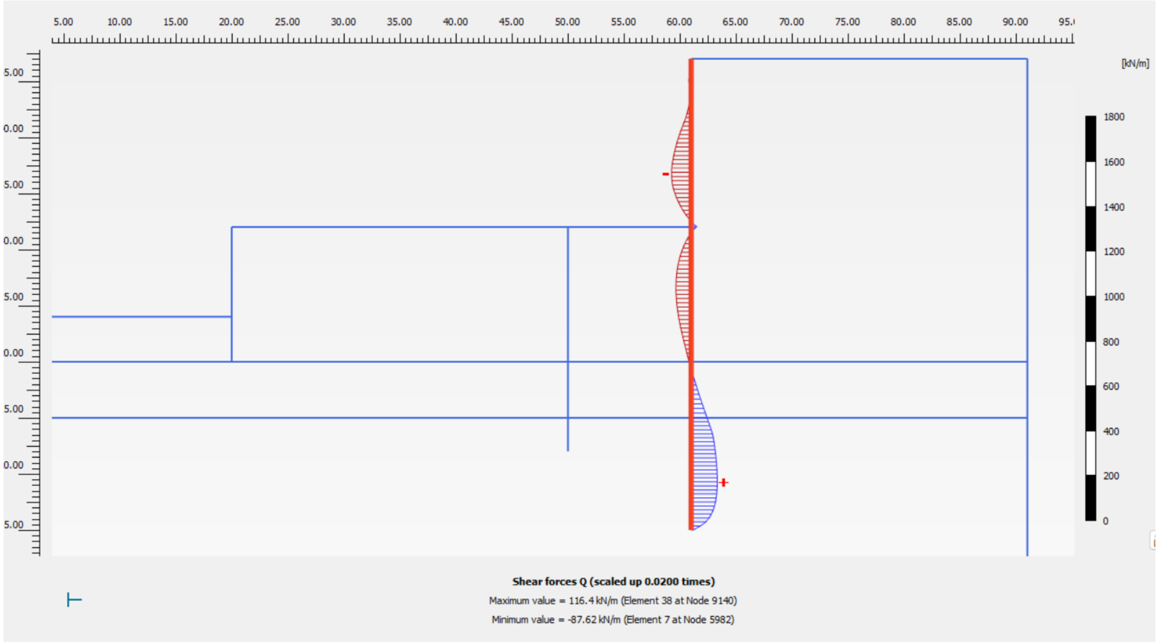


Figure 8.9: Shear Force Diagram of the Right Sheet Pile - Current Case

The Figure above shows the shear force diagram of the left sheet pile, it’s noted that the maximum shear force generated equals 116 kN/m.

8.2.4 Bending Moment

8.2.4.1 Left Sheet Pile

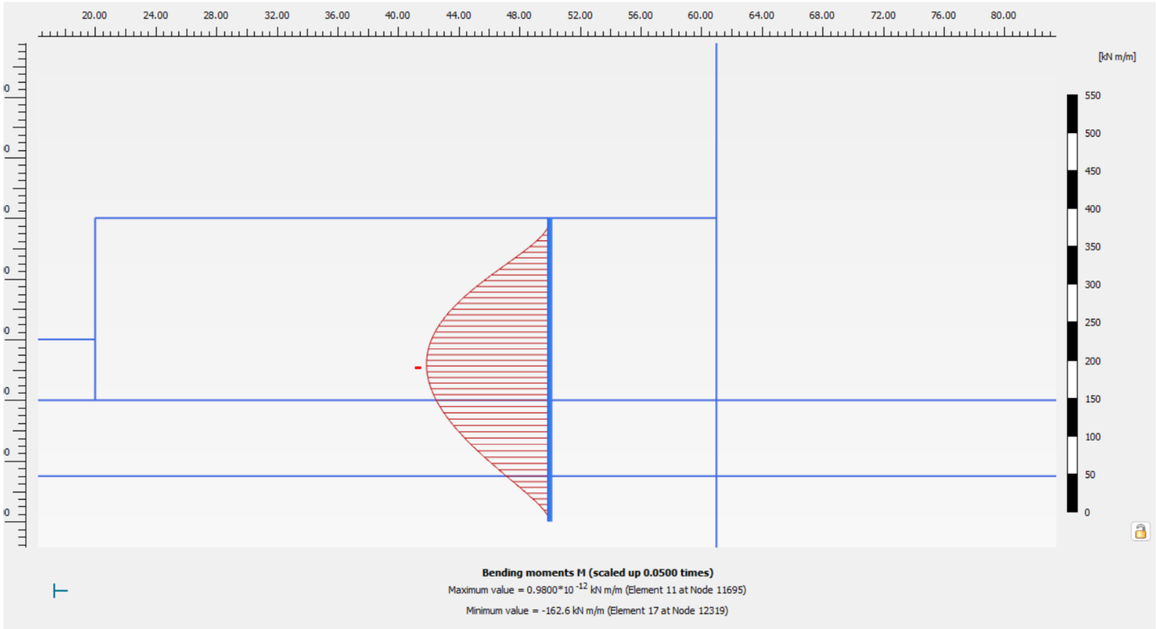


Figure 8.10: Bending Moment Diagram of the Left Sheet Pile - Current Case

The Figure above shows the maximum bending moment diagram of the left sheet pile, it’s noted that the maximum moment generated equals 163 kN.m/m.

8.2.4.2 Right Sheet Pile

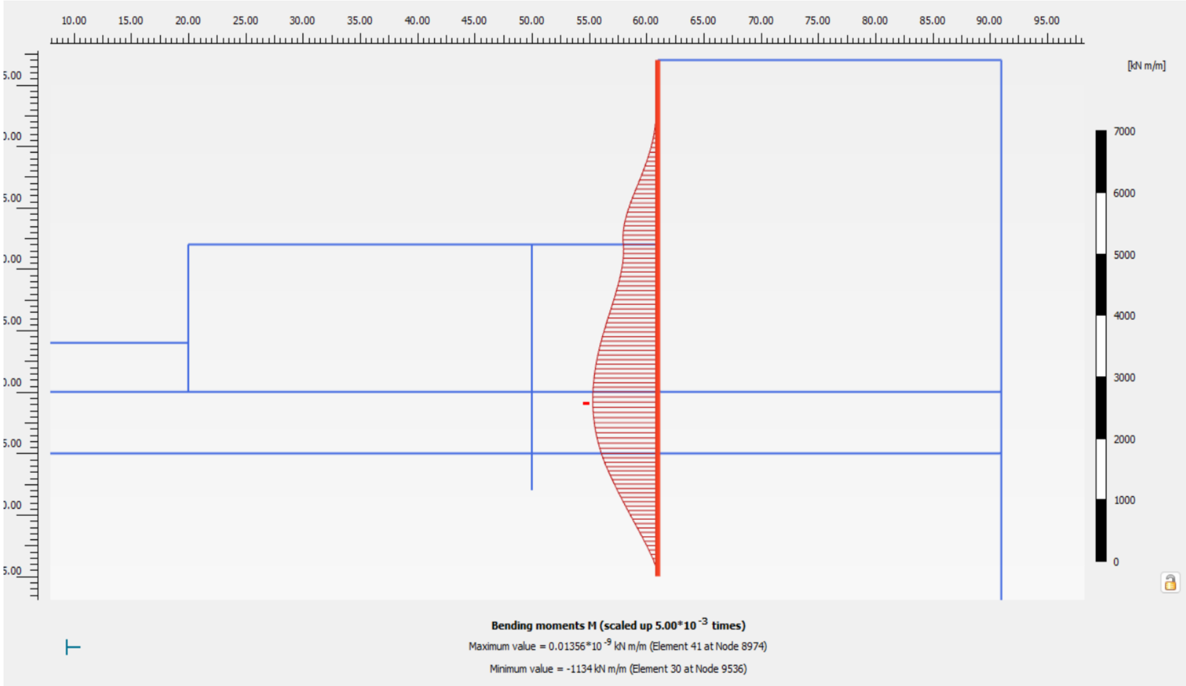


Figure 8.11: Bending Moment Diagram of the Right Sheet Pile - Current Case

The Figure above shows the bending moment diagram of the left sheet pile equals 1134 kN.m/m.

8.3 Suggested Case

8.3.1 Deflection

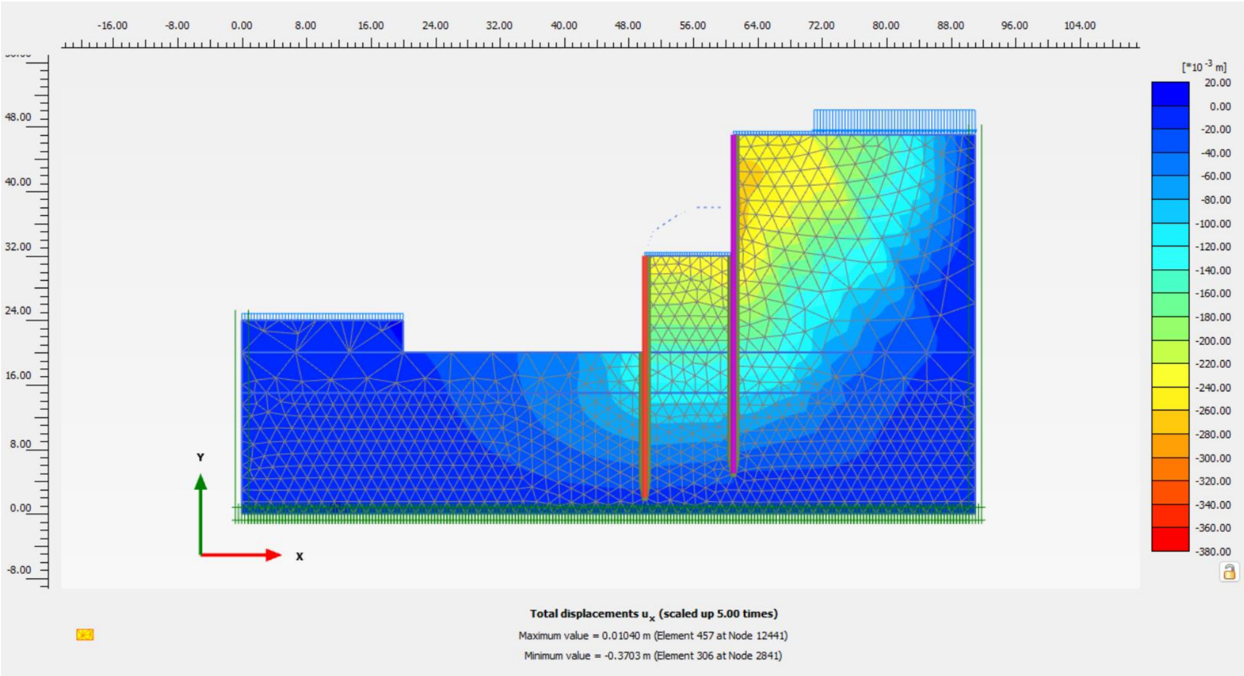


Figure 8.12: Deflection Shape of the Current Case

9.2.1.1 Left Sheet Pile

Figure 8.13: Deflection Shape of the Left Sheet Pile - Suggested Case

As shown in the figure above, the maximum displacement is about 25 cm at the top of the piles. Here is a clearer shot of the distribution of the displacement values along the sheet pile.

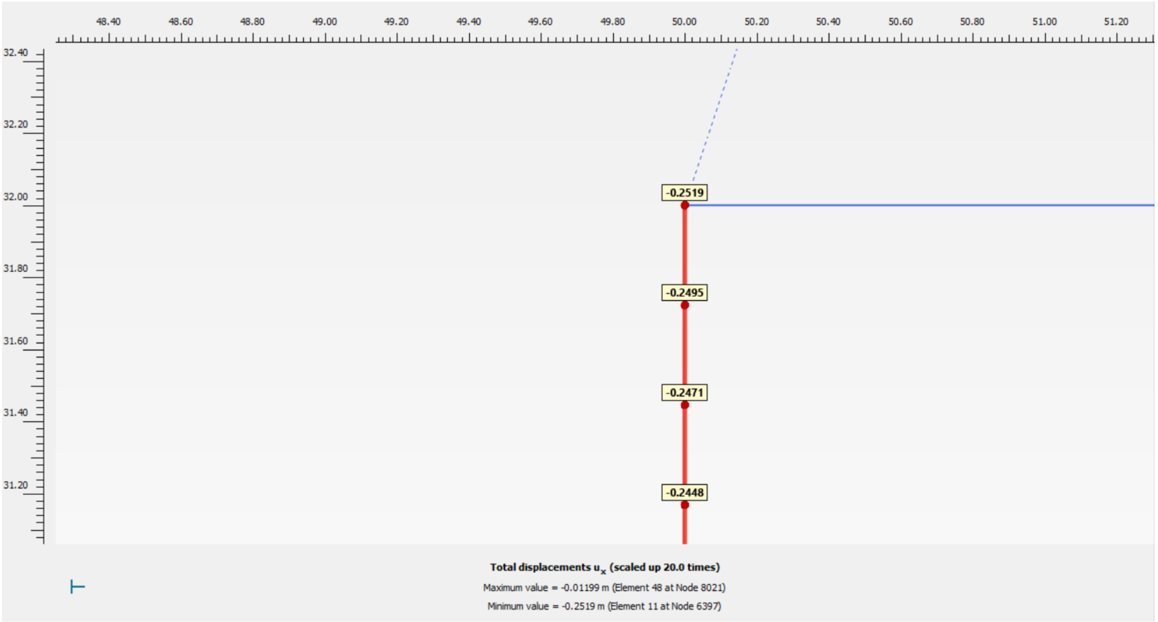


Figure 8.14: Deflection Distribution Values over the Left Sheet Pile

9.2.1.2 Right Sheet Pile

Figure 8.15: Deflection Shape of the Right Sheet Pile - Suggested Case

It's noted that that maximum deflection is about 37 cm as shown in the next detailed figure

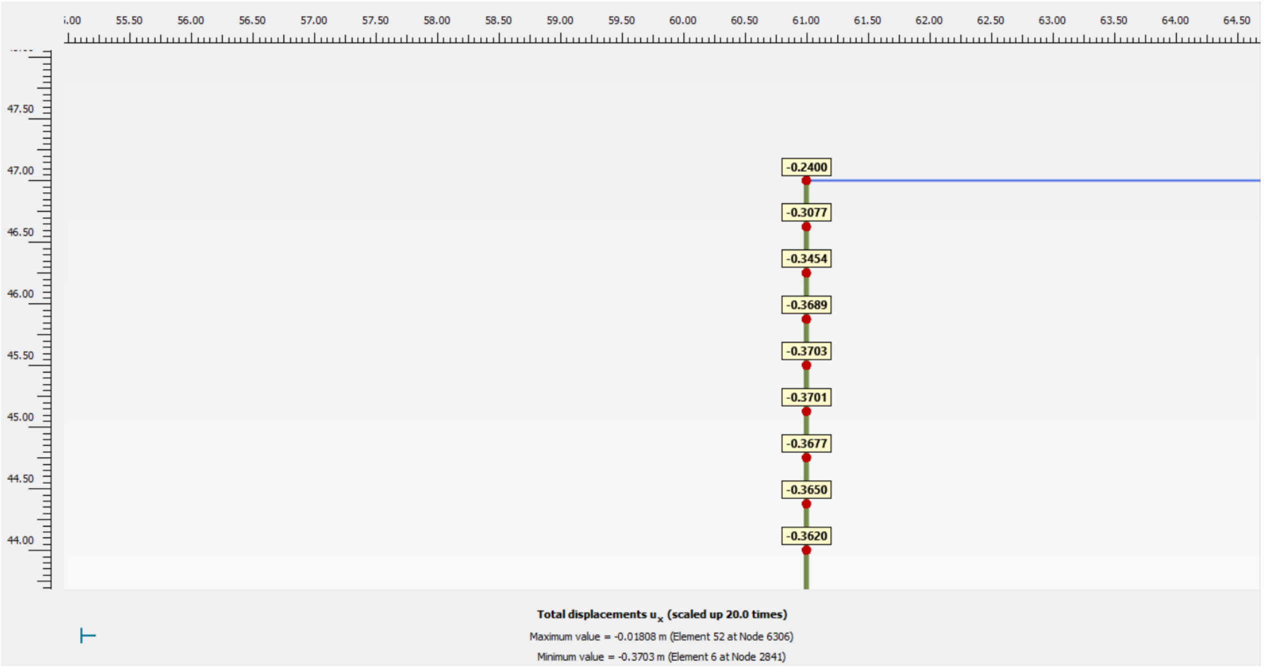


Figure 8.16: Deflection Values Distributions along the Right Sheet Pile - Suggested Case

8.3.2 Axial Force

9.2.2.1 Left Sheet Pile

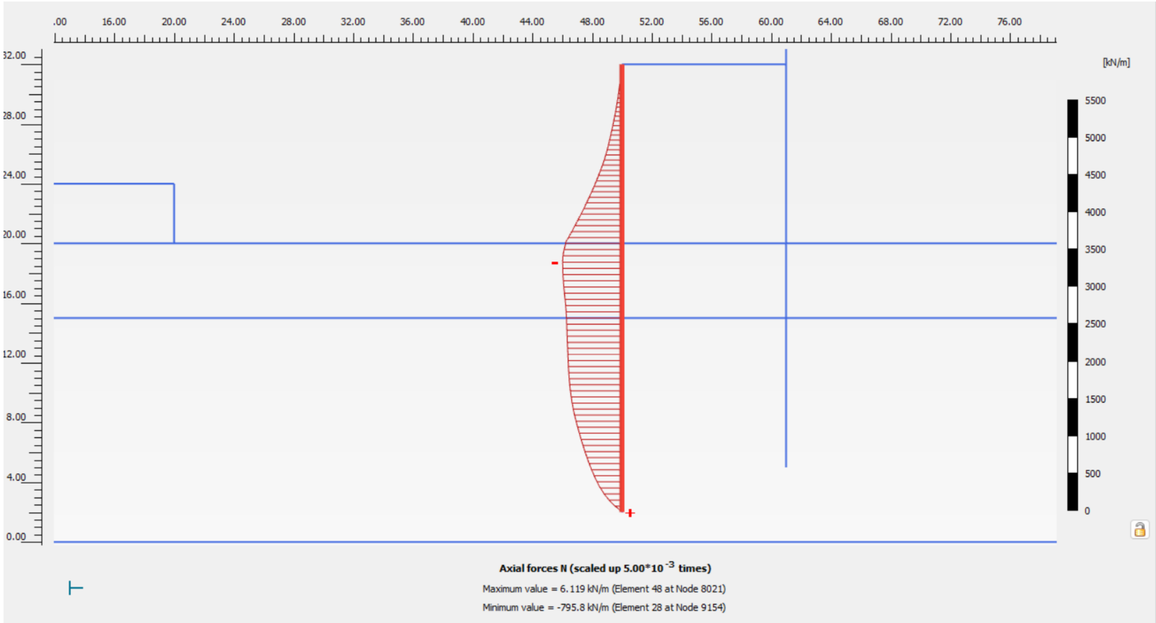


Figure 8.17: Axial Force Diagram of the Left Sheet Pile - Suggested Case

The Figure above shows the axial force diagram of the left sheet pile, it’s noted that the maximum axial force generated equals 796 kN/m.

9.2.1.2 Right Sheet Pile

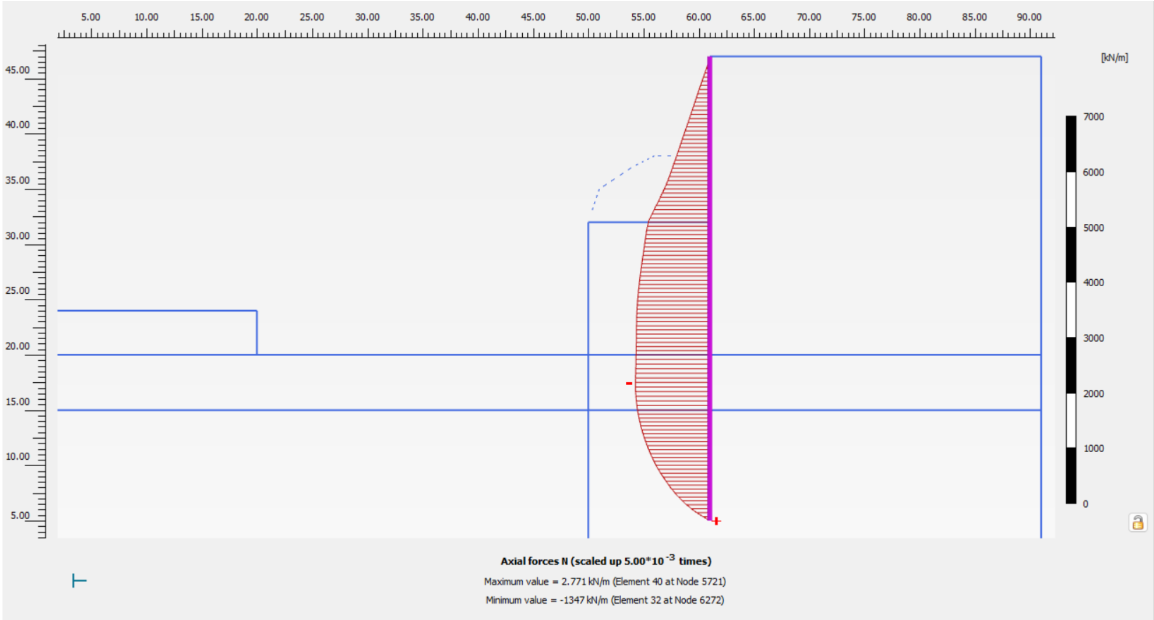


Figure 8.18: Axial Force Diagram of the Right Sheet Pile - Suggested Case

The Figure above shows the axial force diagram of the left sheet pile, it's noted that the maximum axial force generated equals 1347 kN/m.

8.3.3 Shear Force

8.2.3.1 Left Sheet Pile

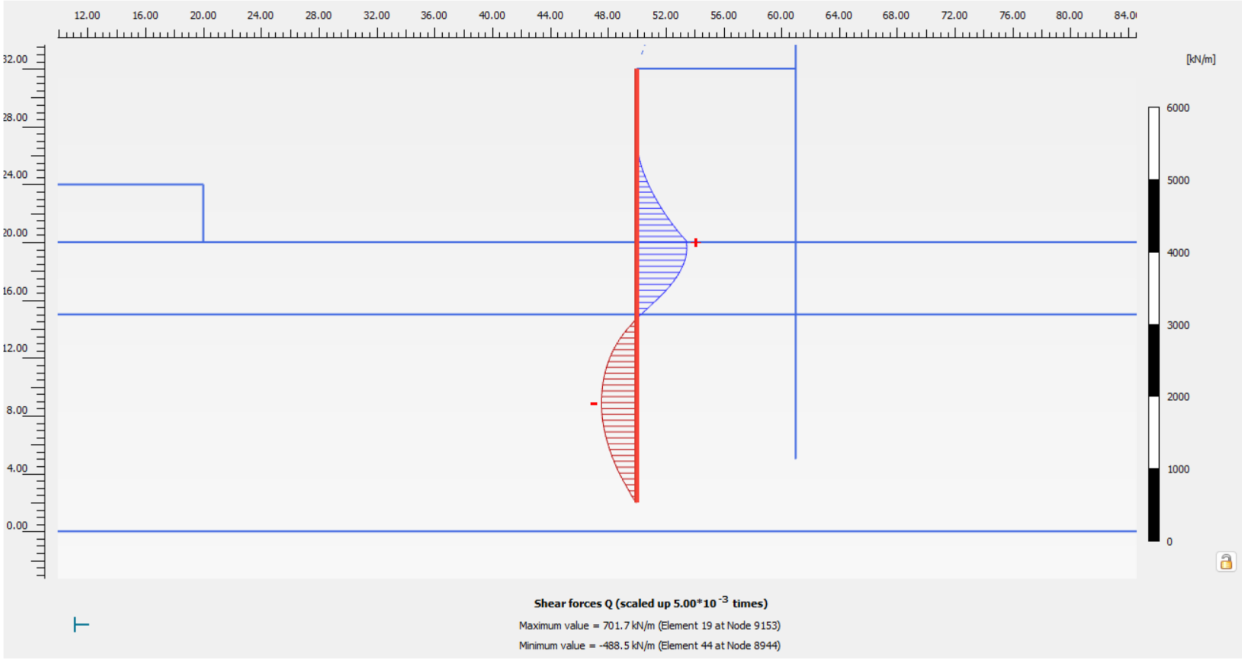


Figure 8.19: Shear Force Diagram of the Left Sheet Pile - Suggested Case

The Figure above shows the shear force diagram of the left sheet pile, it's noted that the maximum shear force generated equals 702 kN/m.

9.2.3.2 Right Sheet Pile

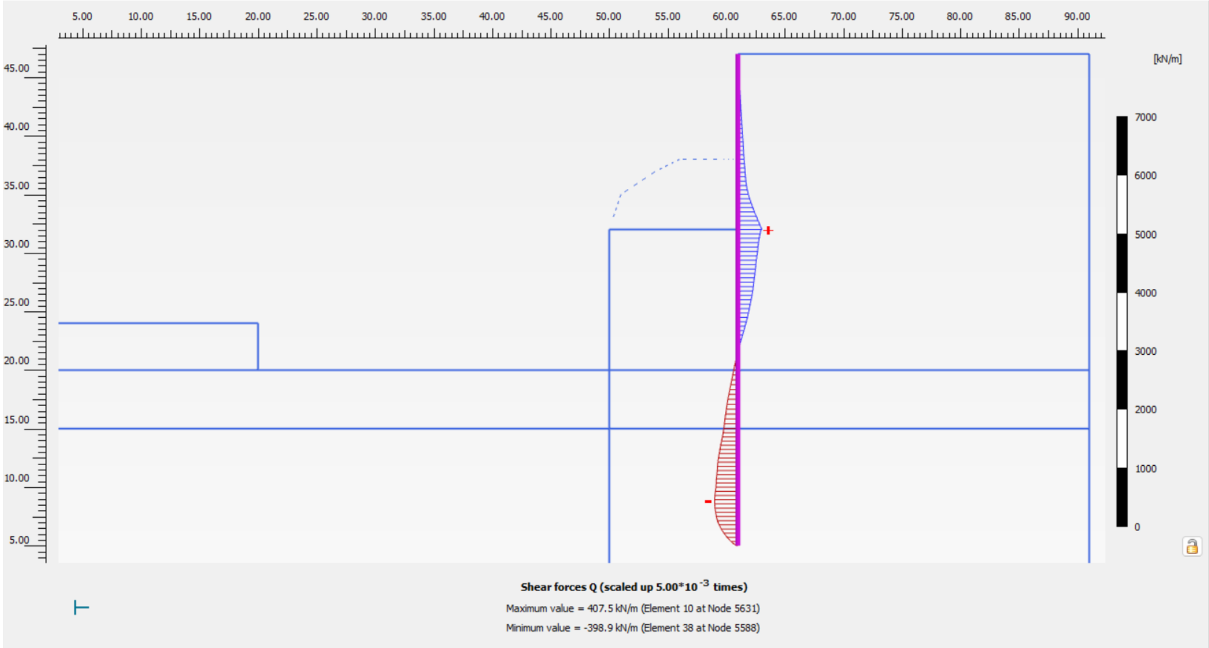


Figure 8.20: Shear Force Diagram of the Right Sheet Pile - Current Case

The Figure above shows the shear force diagram of the left sheet pile, it’s noted that the maximum shear force generated equals 408 kN/m.

8.3.4 Bending Moment

8.2.4.1 Left Sheet Pile

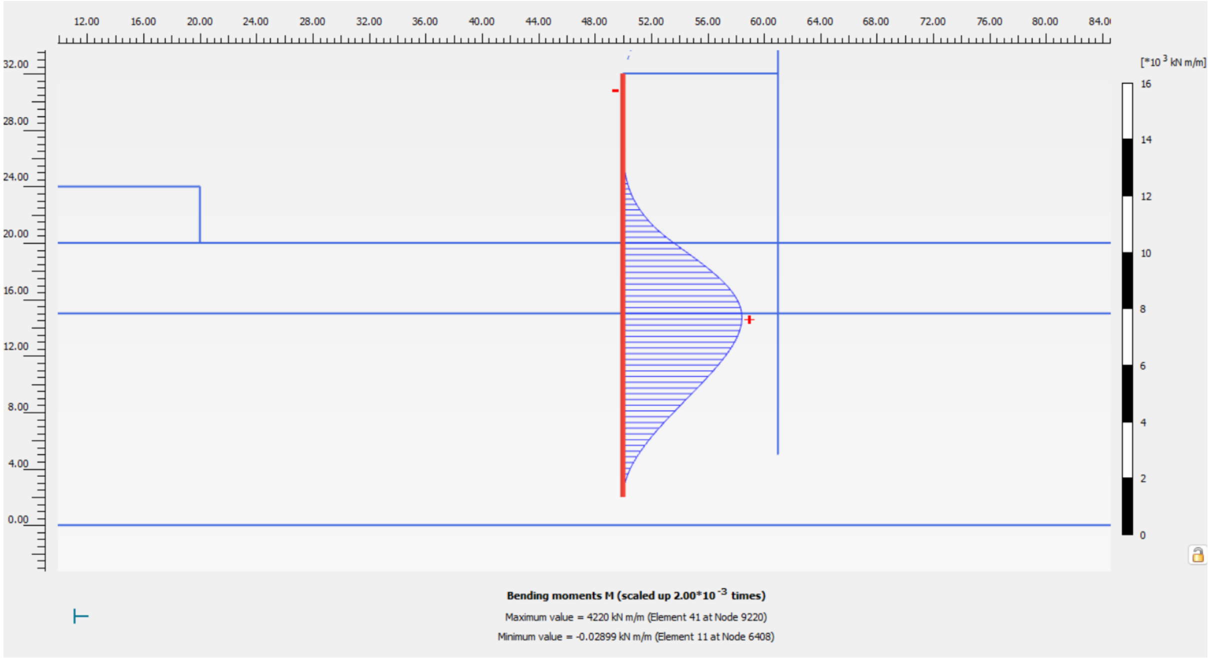


Figure 8.21: Bending Moment Diagram of the Left Sheet Pile - Suggested Case

The Figure above shows the maximum bending moment diagram of the left sheet pile, it’s noted that the maximum moment generated equals 4220 kN.m/m.

9.2.4.2 Right Sheet Pile

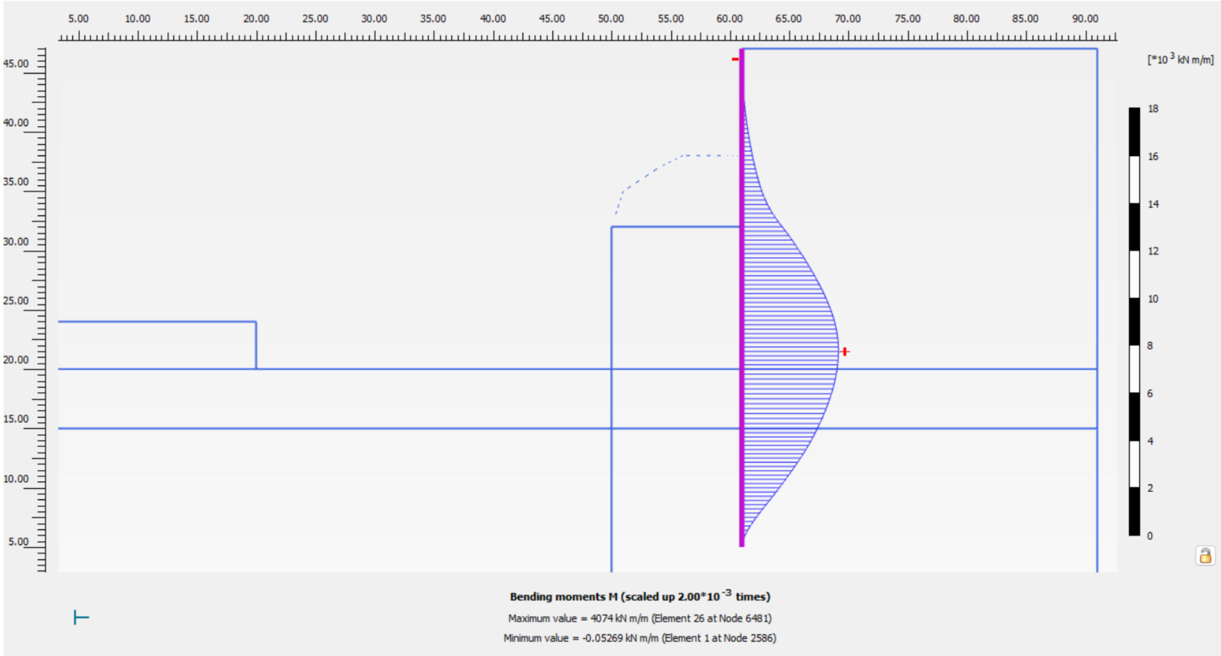


Figure 8.22: Bending Moment Diagram of the Right Sheet Pile - Current Case

The Figure above shows the bending moment diagram of the left sheet pile equals 4074 kN.m/m.

8.4 Summary

Table 8-2: Summary of the Design

#	Left Sheet Pile				Right Sheet Pile			
	Deflection cm	*Axial Force kN/m*	*Shear Force kN/m*	*Bending Moment kN.m/m*	*Deflection cm*	*Axial Force kN/m*	*Shear Force kN/m*	*Bending Moment kN.m/m*
Suggested	30	586	378	1963	40	745	116	2134
Current	25	634	542	2874	37	1347	390	4074

9 CHAPTER NINE

Conclusion

From the results above, it’s noticed that our current suggested case could be better than the current one, since there’s only a need for one row of piles in the suggested case with the same diameter and spacing.

The difference is that constructing the right sheet pile at first, reduces the loads acting on the left sheet pile since it protected the above zone.

Although there are differences in the values of the deflection between the current and suggested case, but these values are relatively low with respect of the depths of the sheet piles.

If the earth remains balanced during excavation of earthworks up to 1.0 m below the ground surface, extra safety measures are not necessary. It is essential to safeguard the excavation margins against cave-ins if the excavation activity is done at depths greater than 1.0 m. Sloping excavation, benching excavation, shoring, or wall support systems can all be used to stop cave-ins. The rigidity/flexibility, material type, and design technology of wall support schemes for excavation stability vary. The usage of personal protection equipment is one of the many safety precautions that must be taken during excavation earthworks to safeguard the safety of the workers.

The most important thing to remember when excavating is that there are risks involved. If you want to avoid injury or death, it's best to be prepared in advance. Depending on your job duties, it may be necessary for you to wear heavy protective equipment such as hard hats or boots if there are any risks associated with being underground on an excavation site.

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