

**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF CIVIL**  
**AND ENVIRONMENTAL ENGINEERING**



**COMPARATIVE STUDY ON REINFORCED CONCRETE PILE WALL -AND-  
SOLDIER PILE WALL WITH TIMBER LAGGING  
(SHORING)**

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**PROJECT IN GEOTECHNICAL ENGINEERING**

**By HELEN WORKINEH**

**June ,2017 G.C**

**Addis Ababa**

**PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING  
IN GEOTECHNICAL ENGINEERING**



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*A project submitted to: The School of Graduate Studies, Addis Ababa institute of  
Technology, in partial fulfillment of the requirements for the degree of Master of  
Engineering in Civil Engineering under Geotechnical Engineering.*

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## UNDERTAKING

I certify that research work titled “**comparative study on reinforced concrete pile wall -and- soldier pile wall with timber lagging (shoring)**” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Helen Workineh

## ABSTRACT

In the recent year the construction of high rise buildings are significantly increasing in our country. Those buildings require large parking area, stores and other facilities that can only be fulfilled by constructing basements. For the construction of basements and underground passes have created need to go deep excavations into ground. Deep excavations are supported by shoring systems or pile walls. The project seeks to find out the better option between reinforced concrete pile wall and soldier pile wall with timber lagging in cost savings and feasibility of internal stabilized which have advantage like material availability, construction cost effectiveness, durability, easy construction and corrosion resistance and so on, for our country context.

To achieve this objectives design reinforced concrete pile wall and soldier pile wall with timber lagging at different pile spacing (0.6m,0.9m ,1.2m,1.5m and 1.8m)and first anchor level (3.5m,3.7m,4.0m,4.5m and 5.0m) using deepXcav software, excel spread sheet and hand calculation done and based on the outputs form these analysis have been done cost estimation (bill of quantity) preparation for the purpose of cost comparison.

Finally, the comparison of the two shoring system is carried out based on safe design and the cost efficient. The cost analysis and the optimum design disclose that the cost of soldier pile higher than reinforced concrete pile wall.

**Keywords:** deep excavation; reinforced concrete pile wall; soldier pile with timber lagging; anchor, bill of quantities, shotcrete.

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## LIST OF SYMBOLS

$\Phi$ = angle of internal friction

$Z_t$ = tension zone

$C$ = cohesion

$\sigma$ = lateral stress

$q_s$  = vertical surcharge stress

$T$ = anchor load

$\Theta$  = angle of internal friction

$d$ = embedment length

$H$  = depth of excavation

$T_v$  = vertical component of the anchor load

$L$  = length of the wall

$T_h$  = horizontal component of the anchor load

$DL$ = anchor design load

$I_{xx}$ = moment of inertia

$P$ = pressure distribution

$A$ = cross section area

$W$ = width of the wall

## CHAPTER ONE

### 1. Introduction

#### 1.1 Background of the study

In Ethiopia, the high rate of construction of, high rise building and transport facilities, from previous time in urban area makes excavation very common. Deep excavations are widely used in urban areas for the development of underground space, e.g. Passageway stations, basements for high-rise buildings, underground car parks and shopping centers. Deep basements extensively constructed especially in the recent years to effectively utilize the underground space for car parking and other usage in the congested urban area. To avoid damage to adjacent properties caused by excavation diaphragm walls are commonly used as retaining walls.

The introduction of vertical shoring wall system that uses reinforced concrete pile and tieback anchors which ahead popularity in recent years. In line with the construction boom within Addis Ababa, developers are opting to construct on boundary edges where heavy structures already exist in adjacent plot in order to excavate at these boundaries the safest and most economical foundation solution system is shoring pile wall system.

Shoring is a term used to describe a system that functions to retain earth, water, and adjacent structures when an excavation is required. Shoring design can be a very complicated matter. The designer has to content with many unknowns and factors that influence of the behavior of the excavation shoring. Typically there are two systems in excavation shoring that must be designed: A) the earth retention system that contains the earth i.e the support wall and B) the internal and external bracing such as rakers, struts or tiebacks that support the earth retention system.

Performing detailed calculation for both systems can be a very time consuming process, especially when parameters have to be changed. In addition, many current software programs do not offer an integrated platform of structural and geotechnical analysis requires to design shoring excavations. As a result, the designer is forced to use numerous software programs to analyze the excavation and the structural system separately. With the exception of finite element analysis, there is very little theoretical solution for calculating lateral soil pressers from complex surface profiles. Furthermore, the designer has to save under different filenames different stages for the same excavation. As a result, the whole process can become unnecessarily complicated and time consuming. DeepXcav addresses most of these issues and provides an integrated structural and geotechnical platform for designing deep excavations.

Among different Shoring types can be select and designed reinforced concrete shoring and soldier pile wall by DeepXcav software, excel spread sheet and hand calculation. The project covers the design of both a reinforced concrete pile wall and soldier pile wall and computation of respective costs, to inform whether it will be cheaper to introduce anchored reinforced concrete pile wall and soldier pile wall.



**Figure 1:** soldiers with timber lagging and reinforced concrete pile wall

## 1.2 Background information

Zemen Bank have inked a deal with a foreign construction company to erect its headquarters at the heart of Ethiopia's financial district, along Ras Abebe Aregay Street, at a cost of 1.23 billion Birr project a contract value. This project has inclusive one main tower of 30 floors above the ground 2 floors underground.



**Figure 2** the study area map

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### 1.3 Research Question

Can the research in such an area motivate and facilitate Engineers design reinforced pile wall shoring and soldier shoring by **deepXcav software** and **excel spread sheet** for safe and accurate design perspectives? And which one of economical shoring type?

### 1.4 Objectives

The objective of the project is to design and cost comparison of reinforced concrete pile wall and soldier pile wall with timber lagging

### 1.5 Specific Objective

To Design reinforced concrete pile wall and soldier pile with Timber Lagging by using deepXcav software, excel spread sheet and hand calculation

- a) Detail design soldier and reinforced concrete pile wall (shoring) system with anchor
- b) Preparing bill of quantities
- c) To compare of the cost between soldier wall pile and reinforced concrete pile wall
- d) To compare of the cost between different anchor level and pile spacing for both type of shoring

### 1.6 Methodology

- a) Collect geological investigation and soil test result (secondary data)
- b) Gathering of soil parameters from the soil investigation reports done in the lab and using different correlation techniques are also used to determine soil parameters that are not included in the soil investigation report.
- c) Once we get all the required soil parameters, by using deepXcav , excel spread sheet and hand calculation design soldier and reinforced shoring type
- d) Prepare bill of quantity and cost breakdown for comparing cost for two types of shoring system for different anchor level and spacing.

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## 1.7 Scope of the study

Design of two different types of shoring system

- design of soldier pile with timber lagging shoring and anchor ( i.e design twenty soldier pile wall on different level of anchor and pile spacing )
- design reinforced pile shoring wall with anchor ( i.e design twenty reinforced concrete pile wall on different level of anchor and pile spacing )

This research also studies which is the cost effective

- prepare detail bill of quantities of the two different types of shoring system for each trial (i.e twenty (20 ) shoring for each type)

## 1.8 Organization of the paper

The thesis is organized in the following five main chapters.

- Chapter one has the introduction part, objective, method, scope of the study and Challenges faced during the study.
- Chapter two deals with the literature review about soldier pile with timber lagging and anchored reinforced pile wall design theory.
- Chapter three describes in detail the methodology that is used for both the deepXcav and excel spread sheet for the two types of walls such as the input, conditions and process & output of the methods.
- Chapter four describes in detail design for two types of walls that are covered by this paper & their design by using deepXcav software and excel spread sheet and presents the results & discussion of the analysis. In addition cost comparison of the two different pile wall or shoring system at different anchor level and pile spacing
- Chapter Five deals with Conclusion based on the results and the recommendation for further research topics.

## 1.9 Challenges faced during the study.

There were various challenges experienced during the study which included the following:-

- Time taking for familiar with deepXcav software
- Unit rate was not easy to get from local market

---

## CHAPTER TWO

### 2. Literature review

#### 2.1 General

In the construction industry, deep excavation works are becoming very popular as high rise buildings constructed and the creation of underground transportation increases. A deep excavation into the ground is indispensable to create additional space to meet increasing space requirements for parking of multi-story buildings and for underpass roads at the city centers. Numbers of deep excavation pits in city centers are increasing every year. Structures in the immediate vicinity of excavations, dense traffic scenario, presence of underground obstructions and utilities have made excavations a difficult task to execute. An excavation is basic phase in the construction of foundations, basements or underpass way. The process of an excavation may encounter different kinds of soils underneath the same excavation site from soft clay to hard rocks. During excavation, some soil types pose greater problems than the others. [6, 12]

It is not to be denied that design and construction of deep excavation becomes more difficult as excavation depth is deeper and surrounding environment becomes more complicated. Therefore, the construction project team must consider a wide variety of information to assess environment impact when managing risks and making project decisions. The goal of monitoring data management is to provide useful scientific information about the status and trends of various factors affecting the environmental impact of a project. [10, 9]

New construction with multi-story basements for parking and storage facilities calls for deep open excavation accompanied by the risk of damage to adjacent buildings. The drilling of the tiebacks supporting the structure, large displacement of the supporting wall due to unexpected high loads or driving of piles in the excavation and piping might create settlement and tilting of neighboring structures. [1]

More than several types of in-situ walls are used to support excavations. The criteria for the selection of type of wall are size of excavation, ground conditions, groundwater level, vertical and horizontal displacements of adjacent ground and limitations of various structures, availability of construction, cost, speed of work and others. One of the main decisions is the water-tightness of wall. The following types of in-situ walls are the common types of walls [15].

1. Braced walls, soldier pile and lagging walls
2. Sheet-piling or sheet pile walls
3. Pile walls (contiguous, secant)
4. Diaphragm walls or slurry trench walls

- 
5. Prefabricated diaphragm walls
  6. Reinforced concrete (cast-in-situ or prefabricated) retaining walls
  7. Soil nail walls
  8. Cofferdams
  9. Caissons

## **2.2 Solider pile and lagging**

Soldier pile and lagging retaining walls with tieback anchors are used to support open construction excavations and restrict lateral movements of the surrounding soil. The wall provides a factor of safety to nearby structures against any loss of bearing capacity as the result of lateral movements with the use of tieback anchors, an unobstructed excavation for construction can be provided [13].

The concept of an anchored wall system is to create an internally stable mass of soil that will resist external failure modes at an adequate level of serviceability. The design of anchored walls concentrates on achieving a final constructed wall that is secure against a range of potential failure conditions [7].

Solider pile wall has two major components solider piles (vertical component) and lagging (horizontal component) solider piles usually consists of steel H sections and are driven to maintained in full contact with the soil its installation resistance is quite similar to the sheet pile. Solider piles provide the primary support to the retained soil and lagging serves as a secondary support to the soil face. Lagging prevent progressive deteriorations of the soil arching between piles [17].

The procedure for constructing a soldier pile wall is to drive the H-piles into the ground prior to any excavating. The piles are driven with the flanges parallel to the proposed cut. They are usually spaced between four and ten feet apart. When they have been driven down to the desired depth (typically five to ten feet beneath the proposed excavation bottom when in soil), the excavation begins in stages. The first stage of the excavation is made to the location of the uppermost stage or anchor. Timber lagging, cut to fit between the webs of adjacent soldier piles, is placed in back of the front flanges of the piles. They are set one piece of lagging on top of the other with only a small spacer between them. Straw or a geotextile may be placed between and behind the lagging to reduce seepage through the wall. Once the lagging is set down to the first strut level, a horizontal wale is installed against the piles and the struts or anchors placed at the desired spacing. The excavation then proceeds to the next strut level, with the process continuing until the final excavation is reached [11].

After installation of the soldier beams, the soil in front of the wall is excavated in lifts, followed by installation of lagging. Excavation for lagging installation is commonly performed in 1.2 to 1.5 m lifts,

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however, smaller lift thicknesses may be required in ground that has limited “stand-up” time. Lagging should be placed from the top-down as soon as possible after excavation to minimize erosion of materials into the excavation. Prior to lagging installation, the soil face should be excavated to create a reasonably smooth contact surface for the lagging. Lagging may be placed either behind the front flange of the soldier beam or on the soldier beam. Lagging placed behind soldier beam flanges is cut to approximate length, placed in-between the flanges of adjacent soldier beams, and secured against the soldier beam webs by driving wood wedges or shims. Lagging can also be attached to the front flange of soldier beams with clips or welded studs. In rare circumstances, lagging can be placed behind the back flange of the soldier beam. With either lagging installation method, gaps between the lagging or the retained ground must be backpacked to ensure good contact. Also, the concrete lagging near the anchor location may crack during anchor testing or stressing [7].

### **2.3 Anchored Reinforced Pile Walls**

In-situ pile retaining walls are very popular due to their availability and practicability. There are different types of pile walls. In contiguous (intermittent) bored pile construction, spacing between the piles is greater than the diameter of piles. Spacing is decided based on type of soil and level of design moments but it should not be too large, otherwise pieces of lumps etc. drop and extra precautions are needed. Cohesive soils or soils having some cohesion are suitable. No water table should be present. Acceptable amount of water is collected at the base and pumped out. Common diameters are 0.60, 0.80, 1.00 m. Waling beams (usually called “breasting beams”) are mostly reinforced concrete but sheet pile sections or steel beams are also used [15].

Reinforced pile method is to construct piles retaining walls by either the cast –in-situ pile method or precast pile methods. The construction of concrete piles can be drill a hole to the designed depth by machine, put the steel cage into, and fill it with concrete tremie tubes. The reverse circulation drill methods (also called the reverse method), which is to employ stabilization fluid to stabilize the hole wall during drilling. Is the most commonly used construction method for concrete piles? It is also feasible to build following the all casing method which is to drill with simultaneous casing installment to protect the hole wall. Since the wall is protected by casing, stabilizing fluid is not required. The cost of the all casing method is rather high. Nevertheless, it can be easily applied to cobble –gravel layers or soil with seepage whereas the reverse method cannot. the diameter of the concrete piles are around 60-200cm. [4].

Spacing is decided based on type of soil and level of design moments but it should not be too large, otherwise pieces of swellings etc. drop and extra precautions are needed. Cohesive soils or soils having some cohesion are suitable. No water table should be present. Acceptable amount of water is collected at

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the base and pumped out. Common diameters are 0.60, 0.80, 1.00 m. Waling beams (usually called „breasting beams“) are mostly reinforced concrete [15]

## **2.4 Design of Solider pile walls (solider piles and horizontal lagging)**

During design of earth retaining structures whether the structure is flexible or rigid determination of lateral earth pressure is a key factor. Lateral earth pressure on a retaining structure depends on number of factors. These are: the physical properties of the soil, drainage problems, the time dependent nature of the soil, amount of surcharge load, the interaction between the soil and retaining structure, location of ground water table, etc.

When the soil is on the verge of failure as it is defined by Mohr rupture envelopes lateral earth pressures will be developed. The stress induced in the soil is progressive so that it is difficult to produce a plastic equilibrium state in a soil mass.

Lateral earth pressure classified into three different categories based on the movement of soil behind the retaining structure. Earth pressure at rest refers to lateral earth pressure caused by unyielding wall preventing earth from any lateral movement. When a wall is allowed to move away from the retained soil, the soil will expand laterally and shearing resistance developed within the soil mass and act opposite to the direction of expansion and results decrease in lateral pressure refers to Active earth pressure. When the wall move to the retained soil, the soil will be compressed laterally and shearing resistance acting opposite to the lateral compression refers to Passive earth pressures.

When Terzaghi(1943) was the first considering the stability of excavations, he defined those whose excavation depths were smaller than their widths as shallow excavations while those with widths larger than their widths were deep excavations. Years later ,Terzaghi and peck 1967) and other including peck etal 1970, revised that excavations whose depths were less than 6m could be defined as shallow excavations and those deeper than that as deep excavation ,considering that use of sheet piles or solider piles grows uneconomical once the excavation depth goes beyond 6m. Generally speaking, the analysis methods for shallow excavations are comparatively simple. In fact, more and more excavation projects are located in populous urban areas. To avoid damage to adjacent properties caused by excavation diagram walls are commonly used as retaining walls [4].

Peck 1969 the experiences with performance of deep excavation support system, and the factors that are most important in controlling the performance. These factors include the type and strength of the soil around and beneath the excavation, the excavation and supporting procedure, and workmanship. Beside

the above factors, the groundwater condition, the flexibility or rigidity of the components used for construction, the time taken for construction are also important factors that influence the performance of excavations. Mana 1978 classified the factors into: parameters under designer control, parameters partially under designer control, and fixed parameters not subject to designer control. (Table 1.0)

Table 1: Factors affecting the performance of supported excavations (after Mana 1978)

<b>Parameters under designer control</b>	<b>Parameters partially under designer control</b>	<b>Fixed parameters not subject to designer control</b>
Type of support system	Method of support system construction	Subsoil conditions and properties
Stiffness of support system	Construction period	Surrounding structures
Degree of wall embedment	Method of construction of structures within excavation	Excavation shape and depth
Degree of pre-loading	Size of surcharge loads	
	Weather	

The magnitude and extent of ground movement around an excavation depends as much on the method of construction as on any of the above factor. Although the designer may specify a particular form or method of construction, the precise details of support, their sequence and timing cannot be controlled accurately since they depend on a large factor which varies from day to day on a construction site [8]

The pressures diagrams for braced cuts differ from lateral earth pressures obtained by Coulomb's or Rankine's theory. Peck (1969) derived lateral earth pressure diagrams for braced cuts in sands and clays which can be used to calculate the maximum moment and reaction forces for the design of the retaining wall system.

Primary components of a soldier pile and lagging wall are as follows:

1. Soldier piles which may be either steel H beams, steel tubular pipes, concrete piles, or cast-in place concrete piles.

2. Support system of braced struts or anchors.

Anchors may be cast-in-place dead man, piles used as anchors, sheet pile wall sections, or tieback anchors.

3. Wales which distribute the anchor force as a line load between the soldier piles. They are usually structural steel sections.

4. Wood or metal lagging which supports the soil between the piles. (Boghraat, 1989)

## 2.5 Evaluation Of Earth Pressures For Wall Design

When sufficient yielding of a retaining wall occurs, the lateral earth pressure can be approximated by Coulomb's or Rankine's theory. However, braced excavations yield differently than conventional retaining walls. Figure 3 depicts the different deflections of the two wall types. The deformation of a braced wall gradually increases with the depth of excavation. The variation of the amount of deflection will depend on the type of the soil, depth of the excavation, and construction of the wall.

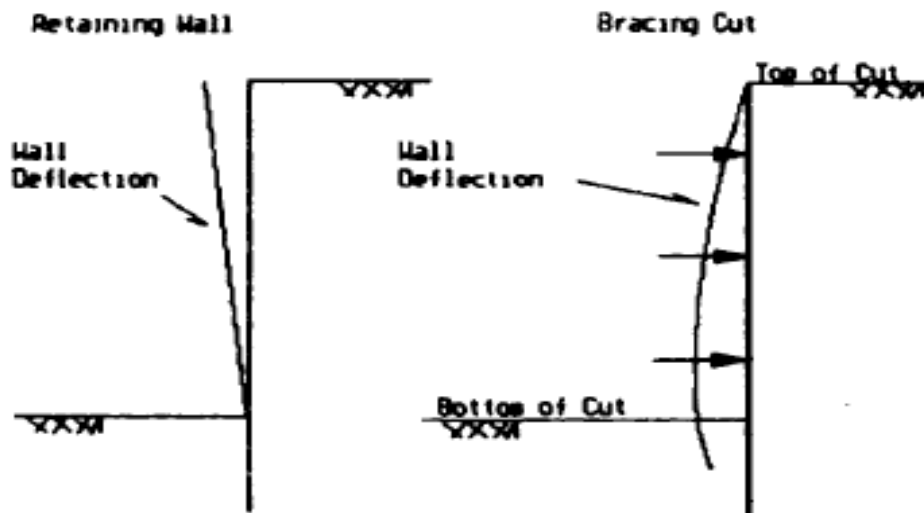


Figure 3 Nature of Yielding of Retaining Wall and Braced Cut (Das, 1990).

At the top of the excavation, deformations are small thus the lateral earth pressure approaches the at rest condition. At the bottom of the excavation, the deformations are greater, but the lateral earth pressure will be lower than Rankine's active earth pressure. Therefore the distribution of lateral earth pressure deviates from the usual linear distribution [13]. The total force exerted against the wall may be 10-15% greater than active condition. The state of stress behind a braced excavation has been described as an arching active condition [18].

Apparent earth pressure diagrams are semi-empirical diagrams that were originally developed by Terzaghi and Peck (1967) and Peck (1969) to provide loadings for conservative design of struts in internally braced excavations [7] and as recommended by [16] are assumed for the design conditions within the program. The earth pressure envelopes for braced walls in sands, soft clays, and stiff clays are illustrated in Figure - 4. For stiff clays, [16] recommends horizontal stresses between  $0.2$  and  $0.4\gamma H$ . The value of  $0.4\gamma H$  is used within the program. The stability number is calculated as  $N_s = \gamma H/c$ . Where  $\gamma$  the unit weight of the soil,

$H$  is the depth of the excavation, and  $c$  is the undrained shear strength of the soil. Characteristics of these pressure envelopes include

- They apply to excavations deeper than twenty feet.
- The pressure envelopes assume the water table is below the bottom of the cut. Sands are assumed to be drained with the lowering of the ground water table behind the wall. Clays are assumed un-drained and under short-term conditions.
- Lateral stresses are apparent stresses which are to be used for the calculations of the reaction loads.
- The behavior of an excavation in clays depends on its stability number. (Lambe and Turner, 1970)

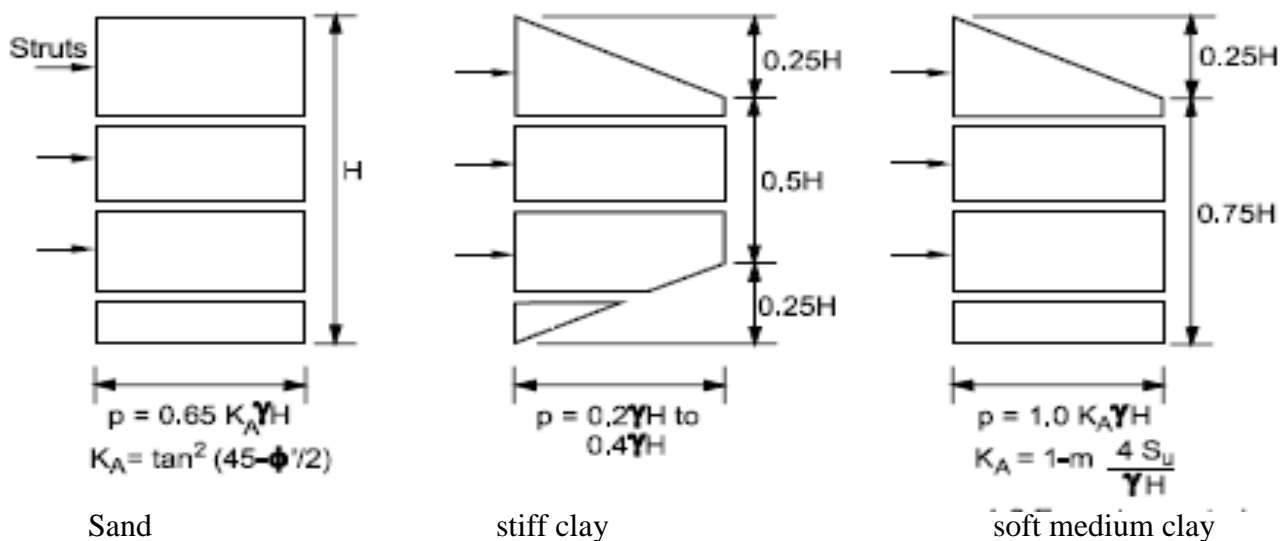


Figure 4 Pressure Distributions on Braced Excavations

The apparent stresses are for entire sand or clay layering only. Engineering judgment should be used for tills, silts, or fills; varying soil type with depth; and when hydrostatic stresses act on the wall. Lambe and Turner (1970) concluded that predicting the behavior of braced excavations cannot be made with complete confidence. This is the result of difficulty in selecting the proper soil parameters, field boundary conditions, and the details of construction. However, Ulrich (1989) concluded that the recorded pressures for over consolidated clays agree with those developed by Peck (1969). Ulrich also noted that soil stratification does not have a significant influence on the apparent earth pressure in over consolidated clays.

The apparent earth pressure diagrams described above were developed for reasonably homogeneous soil profiles and may therefore be difficult to adapt for use in designing walls in stratified soil deposits. A

method based on redistributing calculated active earth pressures may be used for stratified soils. This method should not be used for soil profiles in which the critical potential failure surface extends below the base of the excavation or where surcharge loading is irregular [7].

## 2.6 computation of wall pressures

The pressure on retaining walls, bulkheads, or buried anchorages is a function of the relative movement between the structure and the surrounding soil.

**Lateral Earth Pressures at Rest:** Any type of soil whether it is sand or clay, normally consolidated in the ground under the natural condition of no lateral deformation (i.e., vertical compression only), no friction between the retaining structures and soil under an incremental application of vertical load experiences a condition known as the earth pressure at rest. The value of the coefficient of the earth pressure at rest,  $K_0$ , can be estimated by Jacky's equation (2.1) for both cohesive and cohesion less soils

$$K_0 = \frac{\partial r_h}{\partial r_v} = 1 - \sin \varphi \dots\dots\dots \text{(Equation 2.1)}$$

For normally consolidated clay,  $K_0$  is typically in the range of 0.55 to 0.65; for sand, the typical range is 0.4 to 0.5. For lightly over consolidated clay ( $OCR \leq 4$ ),  $K_0$  may reach a value up to 1: for heavily over consolidated clay ( $OCR \geq 4$ ),  $K_0$  values may range up to or greater than 2 [7].

**Active State.** Active earth pressure occurs when the wall moves away from the soil and the soil mass stretches horizontally sufficient to mobilize its shear strength fully, and a condition of plastic equilibrium is reached. (See Figure 5) .The ratio of the horizontal component or active pressure to the vertical stress caused by weight of soil is the active pressure coefficient ( $K_a$ ).

Rankine (1857) proposed a solution for lateral earth pressure in retaining walls based on theory of plastic equilibrium. He assumed that the soil is isotropic and homogeneous; the soil is dry and cohesion less. According to Rankine the active and passive failure zone will be Mohr coulomb failure theory and the angle for active failure surface is at  $(45 + \phi/2)$  and for the passive failure surface is at  $(45 - \phi/2)$ .

$$\partial_o = \partial_v K_a - 2C' \sqrt{K_a} \dots\dots\dots \text{(Equation 2.2)}$$

$$\text{Where } K_a = \tan^2 (45 - \frac{\phi}{2}) \dots\dots\dots \text{(Equation 2.3)}$$

**Passive State.** Passive earth pressure occurs when a soil mass is compressed horizontally, mobilizing its shear resistance fully the ratio of the horizontal component of passive pressure to the vertical stress caused by the weight of the soil is the passive pressure coefficient ( $K_p$ ). The passive coefficient, as defined

here, applies only the cohesionless soil. A soil mass that is neither stretched nor compressed is said to be in an at-rest state. The ratio of lateral stress to vertical stress is calling the at-rest coefficient ( $K_0$ )[16].

Soldier pile wall will develop earth pressures approaching the active and passive states. In granular soil, the soil is assumed to be drained and active earth pressures are developed as the wall deforms laterally. This is resisted by the passive resistance which is developed as the H-beam compresses the soil acting on an effective area of three times the width of the H-beam below the bottom of the excavation. However there exists some uncertainty of how the pressures act at and below the excavation line (Bowles, 1988). The active and passive earth pressure coefficients are calculated assuming Rankine's theory. In the case of cohesive soils, un-drained conditions ( $\gamma = 0$ ) are assumed with no frictional resistance developed. The stresses in the tension zone are neglected in the design computations with the depth of the tension zone taken as  $z_t = (2 \cdot c - q) / \gamma$  [14].

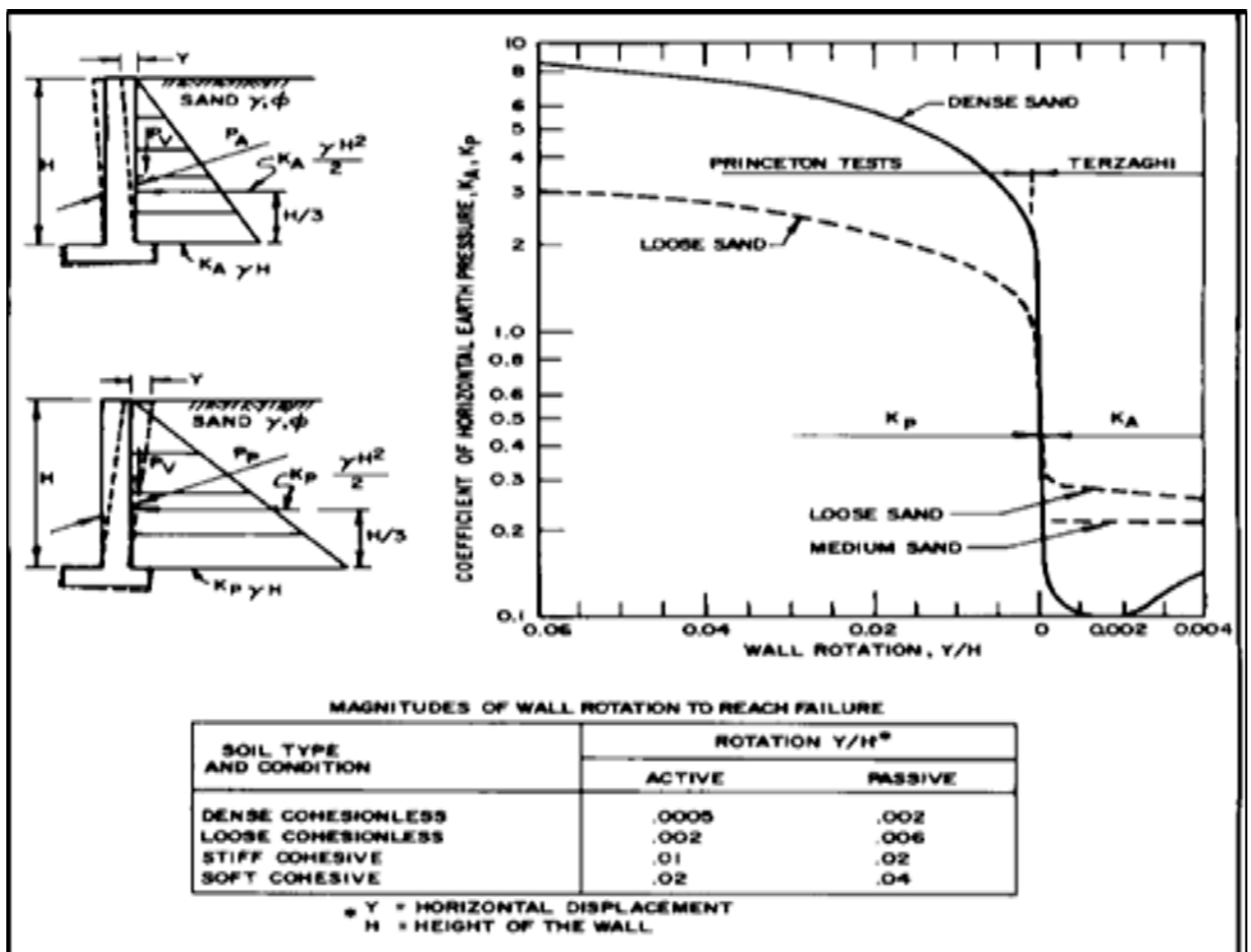


Figure 5 effect of wall movement on wall pressure

## 2.7 Hydrostatic Pressure

Permanent anchored soldier beam and lagging walls are typically not designed to resist large water loads. For these wall systems, drainage from the surface of the retained soil is collected in ditches at the top of the wall while subsurface water is collected using prefabricated drainage elements placed between the wall and the permanent facing. A typical flow net for a retaining wall in homogeneous soil is shown in figure 6 [7]

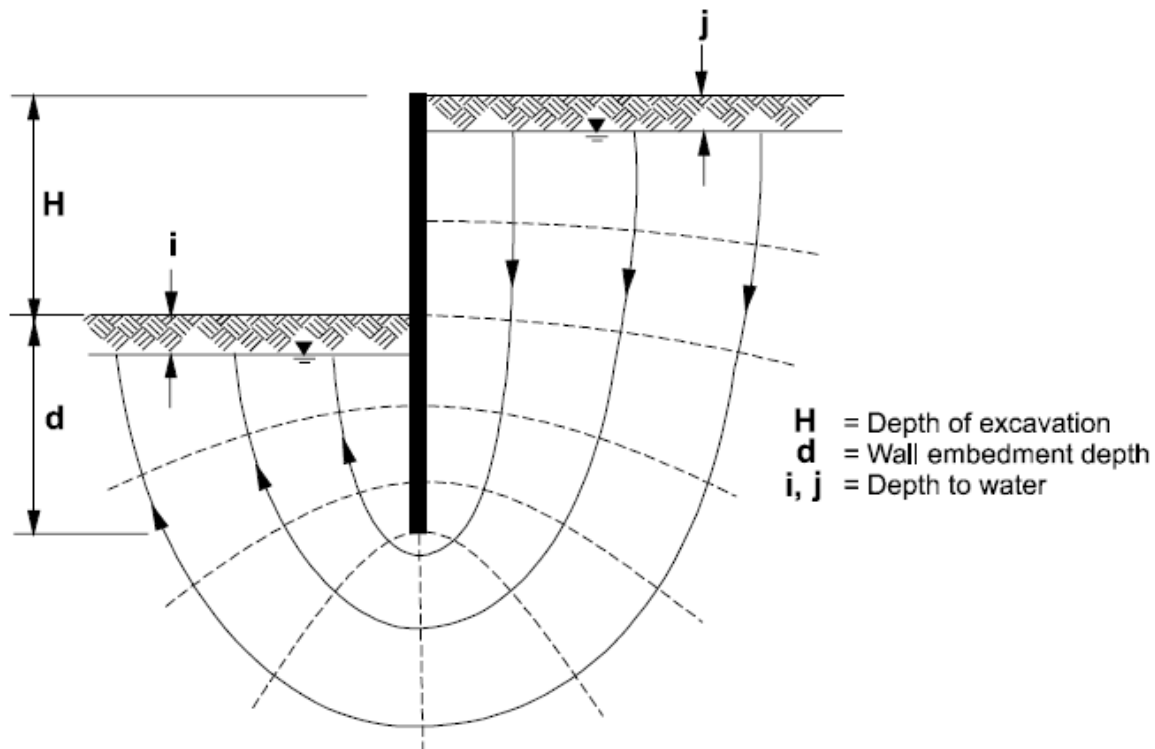


Figure 6 Flow net for a retaining wall (after CIRIA, 1984).

## 2.8 Surcharge Pressure due to a Uniform Surcharge Loads

Surcharge loads are vertical loads applied at the ground surface which are assumed to result in an assumed uniform increase in lateral stress over the entire height of the wall. The increase in lateral stress for uniform surcharge loading can be written as:

$$\sigma = Kq_s \dots \dots \dots \text{(Equation 2.4)}$$

Where:  $\Delta\sigma_h$  is the increase in lateral earth pressure due to the vertical surcharge load,  $q_s$  is the vertical surcharge stress applied at the ground surface, and  $K$  is an appropriate earth pressure coefficient. Standard SI units are:  $\Delta\sigma_h$  (kPa),  $K$  (dimensionless), and  $q_s$  (kPa). When traffic is expected to come to within a distance from the wall face equivalent to one-half the wall height, the wall should be designed for a live load surcharge pressure of approximately 12 kPa (AASHTO, 1996). For temporary walls that are not

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considered critical, actual surcharge loads may be evaluated and considered in the design as compared to using this prescriptive value. Both temporary and permanent wall designs should account for unusual surcharges such as large material stockpiles and heavy cranes. Calculated lateral pressures resulting from these surcharges should be added explicitly to the design earth pressure envelope. Loads from existing buildings need to be considered if they are within a horizontal distance from the wall equal to the wall height. [7],

### **2.9 Ground Anchor Design**

Anchored walls derive additional lateral resistance from one or more levels of anchors. The anchors may be ground anchors (tiebacks) consisting of drilled holes with grouted in pre-stressing steel tendons extending from the wall face to an anchor zone located behind potential failure planes in the retained soil or rock mass. The anchors may also be structural anchors consisting of reinforced concrete anchors, driven or drilled in vertical pile anchors or a group of driven piles consisting of battered compression piles and vertical tension piles connected with a reinforced concrete cap. These anchors are located behind potential failure planes in the retained soil and are connected to the wall by horizontal tie rods

Ground anchors are suitable for situations requiring one or more levels of anchors whereas anchors utilizing tie rods are typically limited to situations requiring a single level of anchors. The ground anchor tendons and tie rods must be provided with corrosion protection.

The distribution of lateral earth pressure on anchored walls is influenced by the method and sequence of wall construction and the anchor pre-stressing. Ground anchors are generally pre-stressed to a high percentage of their design tension force whereas anchors with tie rods are secured to the wall with little or no pre-stress force.

Anchored walls are typically constructed in cut situations in which construction proceeds from the top down to the base of the wall. For situations where fill is placed behind the wall special consideration in the design and construction is required to protect the ground anchors or and fill settlement.

The vertical wall elements should extend below potential failure planes associated with the retained soil or rock mass. Where competent and stable foundation material is located at the base of the wall face, only minimal embedment of the wall may be required (soldier pile-less design) [3]

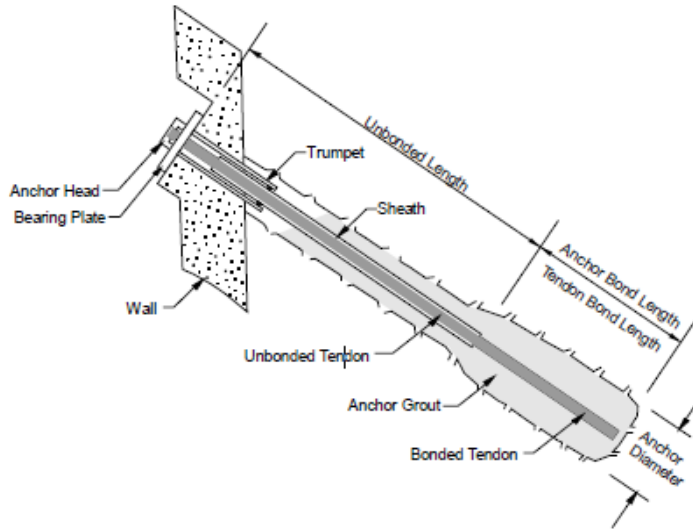


Figure 7 Component of ground anchor

For the purposes of preliminary design, the ultimate load transferred from the bond length to the soil may be estimated for a small diameter, straight shaft gravity-grouted anchor from the soil type and density (or SPT blow count value) (table 2). The maximum allowable anchor design load in soil may be determined by multiplying the bond length by the ultimate transfer load and dividing by a factor of safety of 2.0. [7]

Table 2 : Presumptive ultimate values of load transfer for preliminary design of small diameter straight shaft gravity-grouted ground anchors in soil.

Soil type	Relative density/Consistency (SPT range) <sup>(1)</sup>	Estimated ultimate transfer load (kN/m)
Sand and Gravel	Loose (4-10)	145
	Medium dense (11-30)	220
	Dense (31-50)	290
Sand	Loose (4-10)	100
	Medium dense (11-30)	145
	Dense (31-50)	190
Sand and Silt	Loose (4-10)	70
	Medium dense (11-30)	100
	Dense (31-50)	130
Silt-clay mixture with low plasticity or fine micaceous sand or silt mixtures	Stiff (10-20)	30
	Hard (21-40)	60

Note: (1) SPT values are corrected for overburden pressure.

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## CHAPTER THREE

### 3. Design methodology of reinforced concrete pile wall and soldier pile wall with timber lagging

#### 3.1 General

As mentioned roughly in the introduction part of this paper the main objective is design of a reinforced pile wall and soldier pile wall by using deepXcav software, excel spread sheet and hand calculation methods. In this section these analyses methods methodology is in detail discussed.

#### 3.2 Design Consideration

##### 3.2.1 Depth of Penetration below Excavation

The depth of penetration of vertical wall elements based on lateral capacity is generally calculated using a factor of safety with respect to lateral capacity of 1.5.

##### 3.2.2 Vertical pile spacing

The AASHTO method indicates that the adjusted pile width may be up to 3 times the effective pile width.

##### 3.2.3 Design of the Un-bonded Length

The minimum un-bonded length for rock and soil ground anchors is 4.5 m for strand tendons and 3 m for bar tendons. These minimum values are intended to prevent significant reductions in load resulting from seating losses during transfer of load to the structure following anchor load testing.

$$T = \frac{T_h}{\cos \theta} \dots\dots\dots \text{(Equation 3.1)}$$

$$T_V = T \sin \theta \dots\dots\dots \text{(Equation 3.2)}$$

Longer un-bonded lengths may be required to: (1) locate the bond length a minimum distance behind the critical potential failure surface; (2) locate the anchor bond zone in appropriate ground for anchoring; (3) ensure overall stability of the anchored system; and (4) accommodate long term movements. In general, the un-bonded length is extended a minimum distance of H/5 or 1.5 m behind the critical potential failure surface to accommodate minor load transfer to the grout column above the top of the anchor bond zone.

##### 3.2.4 Design of the bonded Length

Design Load between 260 kN and 1160 kN:

The drill hole diameter is generally less than 150 mm, except for hollow stem augured anchors that are typically approximately 300 mm in diameter.

Total Anchor Length between 9 and 18 m: Because of geotechnical or geometrical requirements, few anchors for walls or for tie down structures are less than 9 m long. A minimum un-bonded length of 3 m for bar tendons and 4.5 m for strand tendons should be adopted

Ground Anchor Inclination between 10 and 45 degrees: Ground anchors are commonly installed at angles of 15 to 30 degrees below the horizontal although angles of 10 to 45 degrees

In the case of a site with no restrictions on right-of-way, a 15-degree inclination of the anchor should be assumed with a bond length of 12 m in soil or 7.5 m in rock the bond lengths at sites with more restricted right-of-way may be evaluated assuming an anchor inclination of 30 degrees and that the bond length is equal to the distance from the end of the un-bonded length to within 0.6 m of the right-of-way line

### 3.2.5 Spacing Requirements for Ground Anchors

The horizontal and vertical spacing of the ground anchors will vary depending on project specific requirements and constraints, which may include: (1) necessity for a very stiff system (i.e., closely spaced anchors) to control lateral wall movements; (2) existing underground structures that may affect the positioning and inclination of the anchors; and (3) type of vertical wall elements selected for the design.

### 3.2.6 Selection of Pre-stressing Steel Element

Table 3 : Properties of 15-mm diameter pre-stressing steel strands (ASTM A416, Grade 270 (metric 1860)).

Number of 15-mm diameter strands	Cross section area		Ultimate strength		Prestressing force					
					$0.8 f_{pu} A_{ps}$		$0.7 f_{pu} A_{ps}$		$0.6 f_{pu} A_{ps}$	
	(in. <sup>2</sup> )	(mm <sup>2</sup> )	(kips)	(kN)	(kips)	(kN)	(kips)	(kN)	(kips)	(kN)
1	0.217	140	58.6	260.7	46.9	209	41.0	182	35.2	156
3	0.651	420	175.8	782.1	140.6	626	123.1	547	105.5	469
4	0.868	560	234.4	1043	187.5	834	164.1	730	140.6	626
5	1.085	700	293.0	1304	234.4	1043	205.1	912	175.8	782
7	1.519	980	410.2	1825	328.2	1460	287.1	1277	246.1	1095
9	1.953	1260	527.4	2346	421.9	1877	369.2	1642	316.4	1408
12	2.604	1680	703.2	3128	562.6	2503	492.2	2190	421.9	1877
15	3.255	2100	879.0	3911	703.2	3128	615.3	2737	527.4	2346
19	4.123	2660	1113.4	4953	890.7	3963	779.4	3467	668.0	2972

Table 4. Guidance relationship between tendon size and trumpet opening size

Tendon type	Minimum suggested trumpet opening size (mm)	
	Class II corrosion protection	Class I corrosion protection
Number of 15-mm diameter strands		
4	102	150
7	115	165
9	127	178
11	140	191
13	153	203
17	165	216
Bar diameter (mm)		
26	64	89
32	70	95
36	76	102

### 3.3 Design of anchored reinforced pile and soldier pile wall using by deepXcav software

DeepXcav software is used for design of different types of shoring type. On this paper it was used to design for anchor reinforced pile wall and anchored soldier pile wall with timber lagging. In addition, the reinforced concrete pile design different pile spacing and level anchor an alternative, the cost should also be considered as an important factor.

#### 3.3.1 Input

The software requires the following parameters and factors to design pile wall; which are Specify the global coordinates. Specify the soil types such as, unit weight, SPT value, cohesion, friction angle and properties specify the layers, create a generalized water table. Specify the retaining wall system with excavation width & depth, pile dimension, spacing, Create a database of support members like anchor rod & grout body parameters such as length, thickness, angle of anchor installation.

#### 3.3.2 Conditions and process

The design assumption was staged construction process, all stages elasto-plastic spring analysis and un-drained condition just for the selected soil, limit equilibrium analysis based on for stage 0 and stage one Active pressure diagram and FHWA(federal highway administration apparatus pressure diagram ,(on Limit equilibrium calculations used for evaluating the total load required to stabilize a slope or excavation in stratified soils), the required to achieve a factor of safety that exceeds the target value of 1.5.The activities involved in each phase of the staged construction that are used for this research design can be stated as follows:

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Choose to perform a limit equilibrium analysis

After selecting the units, defined the following data:

The final excavation depth (D), the wall length (H). The excavation width (B).

The top of the wall elevation, Ground water elevation.

Define the basic wall type, the sections of wall

The size of the wall (width), the horizontal spacing of the wall.

Select the supports type and define properties and the height difference between the lowest support and the subgrade can also be defined, the vertical spacing of the anchor

Define surcharge

Edit soil property

### 3.3.3 Output

The outputs of the DeepXcav analysis are presented numerically incorporated with pictorial Representation. The results of the analysis include wall embedment and other safety factor, wall moment, shear ,axial displacement support reaction ,wall capacity(moment and shear) stress and pressure on wall and soil mass stress (when water flow net analysis is performed ). The different outputs of the analysis for each phase can found on the annex portion of the paper and it demonstrates some of the outputs found from the software pictorially.

## 3.4 Excel spread sheet

### 3.4.1 Input

The spread sheet requires the following parameters and factors to design pile wall; which are Specify the depth of excavation. Specify the soil types such as, unit weight, SPT value, cohesion, friction angle and properties specify the layers, create a generalized water table. Specify the retaining wall system with pile diameter, spacing, anchor rod & grout body parameters such as length, thickness, angle of anchor installation and shotcrete material properties.

### 3.4.2 Conditions and process

Spreadsheet program called “*shoring design spread sheet .xls*” is developed in this paper. This spreadsheet program has four worksheets named as “*main design free slide*”, “*depth computation free*”, “*shotcrete*”, and “*summary*”.

Empirical formulas to design anchor reinforced concrete pile wall

Evaluate site subsurface conditions and relevant properties of in situ soil and rock.

Evaluate load type acting on wall, location of critical failure surface

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Select lateral earth pressure distribution acting on back of wall for final wall height. Add appropriate water, surcharge, and seismic pressures and evaluate total lateral pressure. A staged construction analysis may be required for walls constructed in marginal soils.

Calculate horizontal ground anchor loads and wall bending moments. Adjust vertical anchor locations until an optimum wall bending moment distribution is achieved.

Evaluate required anchor inclination based on right-of-way limitations, location of appropriate anchoring strata, and location of underground structures.

Resolve each horizontal anchor load into a vertical force component and a force along the anchor.

Evaluate horizontal spacing of anchors based on wall type. Calculate individual anchor loads.

Select type of ground anchor

Evaluate vertical and lateral capacity of wall below excavation subgrade. Revise wall section if necessary

Evaluate internal and external stability of anchored system. Revise ground anchor geometry if necessary.

Estimate maximum lateral wall movements and ground surface settlements. Revise design if necessary.

Select lagging. Design wales, facing drainage systems, and connection devices.

### **3.4.3 Output**

The outputs of the spread sheet analysis are presented numerically .The results of the analysis include wall embedment and other safety factor, wall capacity (moment and shear), anchor length (bonded and unbonded) and shotcrete thickness.

## **3.5 Bills of Quantities**

In the field of geotechnical design the safety factor is not the only one important to be nowadays Designers are also challenged by reducing costs and minimizing the amount of material required. The use of optimization methods in this field is not appropriate just for minimizing costs, but also for shortening design periods and flexibility.

It is very important that bills of quantities are prepared according to a standard, widely recognized methodology. This helps avoid any ambiguities or misunderstandings and so helps avoid disputes arising through different interpretations of what has been priced

### **3.5.1 Input dates**

Standard bills of quantities formats are employed and captures all the bills in the billing and evaluation/costing of a shoring project. Such templates shall be a good guide in computation of the bill of quantities for the two different types of shoring and different level of anchor and horizontal spacing of pile. It shall also assist in bill by bill comparison of the shoring. In addition to the computation and

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generation of the bills of quantities from first principles, the following key documents were utilized in the estimation of quantities:-

Cost Estimates (Costs) estimates standard and excel;

Current material, labor and equipment market price

Online construction price;

Realistic estimates from recently tendered projects were utilized in bills that cannot be expressly quantified.

### **3.5.2 Conditions and process**

As per the technical specification and drawing Prepare take off sheet and cost breakdown detail for material, equipment and labor furthermore design fee.

### **3.5.3 out put**

Bills of Quantities comprise a list of items of work which are briefly described. The Bills also provide a measure of the extent of work and this allows the work to be priced. The work included in the item is defined in detail by the rules in the Method of Measurement. The item descriptions are therefore shorthand to allow the relevant rules of the Method to be identified. The measure may be a single item or number, dimension or weight.

## **CHAPTER FOUR**

### **4. Reinforced concrete pile wall and soldier pile wall with timber lagging Design and cost comparison**

#### **4.1 Introduction**

As per the geotechnical investigation report (Zemen head quarter project soil investigation report) prepared soil properties parameters and correlate based on the report in put data's for both excel spread sheet and DeepXcav software calculation methods in detail in the next section of the paper. moreover, the coordinate of each borehole was required using hand held GPS .the project site is characterized by flat topography average elevation of 2362m a.s.l(hand GPS reading)

#### **4.2 Design of Reinforced concrete pile wall by DeepXcav software**

This section presents the impact of parameters on optimization results, main controlling factors, configuration specifications, and savings.

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#### 4.2.1 Optimization analysis on reinforced concrete pile wall

In the optimization procedure it was established that the anchoring force function and the moment function mostly contribute to the optimization results, yet depending on the below controlling factors:

Number of wire per anchor  $N_{an}$

Embedment length,  $D$

Maximum axial distance of pile  $e_{pil}$  which is  $\leq 3.B$

Maximum percentage of longitudinal reinforcement

Drilling and concreting cost of pile

#### 4.2.2 Determination of bill of quantities

The bill of quantity for the two different shoring's used in this study the total cost of shoring wall .it should also be clearly noted that as per the design and specification .

#### 4.2.3 Determination of Quantities

Works quantities and the resultant costs were estimated for the full inclusive works, as designed and discussed herein, for the full works of both the anchored reinforced concrete wall and soldier pile wall with timber lagging. The quantities have been calculated based on final design proposals as determined from Zemen bank head quarter site investigations and studies undertaken. In determining quantities for the work items, the following key bills have been considered for purposes of overall costing and comparison:

#### 4.2.4 Bill of Quantities

A Bill of Quantities does in fact consider all costs and is transparent in relations to all costs. The full Bill of Quantities of the shoring wall, anchored reinforced pile wall and soldier pile wall are given below. The rates were derived from the current market labour, material machinery rate in addition for conventional or anchored reinforced pile wall unit rate was refer from three different local contractors ,Midrok foundation specialist PLC, TL trading P.L.C and anchor foundation specialist P.L.C. On the basis of these unit prices and outcome designs tabulated below, the total costs of the walls with esteem with the current price in the present study have been determined. A summary of these costs is presented in Table .....

Based on the optimum design obtained detail bill of quantities prepared for each of the two different pile wall walls done , in addition the whole design prepare bill of quantities and compare cost efficient.

#### 4.2.5 Analysis and comparison of costs

The unit prices (in local market) for various materials/items including labor, equipment, and other cost considered at the time of this study are as follows:

- Design and mobilization fee :150,000 Birr/Ls
- Concrete: 3520.46 Birr /m<sup>3</sup>
- Reinforcement bar: 38 Birr/kg
- Hot rolled steel : 55 birr /kg
- 5cm thick timber : 600 Birr/Pcs
- Drilling of piles: 1800 Birr /ml
- Installation of anchor :1900Birr/ml
- Testing : 800 Birr/No

The deepXcav software used in this paper is a reinforced anchored pile wall type. This design type has diam= 60cm pile with a different horizontal spacing like 0.6m,0.9,1.2m,1.5m and 1.8m.inaddition different first level anchor 3m,3.5m,3.7m,4.0m,4.5m and 5.0m. The width of the excavation is 50\*40.6m. It also has an anchor rod with different number of strands each carrying of their maximum capacity which is 270kN in total.

Table 5 :SOIL PARAMETERS

Name	g tot (kN/m <sup>3</sup> )	g dry (kN/m <sup>3</sup> )	Frict (deg)	C' (kPa)	Su (kPa)	FRp (deg)	FRcv (deg)	Eload (kPa)	Eur (kPa)	kAp NL	kPp NL	kAcv NL	kPcv NL	Vary	Spring Model	Color
Clay	16	16	32	5	150	21.1	30	20000	60000	0.47	2.12	0.33	3	True	Linear	
Rock	23	23	34	30	N/A	N/A	N/A	479000	1437000	0.28	3.54	N/A	N/A	True	Linear	
GT	23	20	45	10	N/A	N/A	N/A	30000	90000	0.17	5.83	N/A	N/A	True	Linear	

Name	Poisson v	Min Ka (clays)	Min sh (clays)	ko.NC -	nOCR -	aH.EXP (0 to 1)	aV.EXP (0 to 1)	qSkin (kPa)	qNails (kPa)	kS.nails (kN/m <sup>3</sup> )	PL (MPa)
Clay	0.45	0	5	0.5	0.5	-	-	125	83.33	4714.57	-
Rock	0.45	-	-	0.441	0.5	-	-	700	466.67	31430.45	-
GT	0.45	-	-	0.293	0.5	-	-	200	133.33	11000.66	-

#### 4.3 Design of reinforced concrete pile wall using by DeepXcav software

Define excavation capacity and all design analyses is Limit equilibrium analysis

Depth (D) = 11.5m, Wall length (H) =50 m, Excavation width (B) = 40.6m

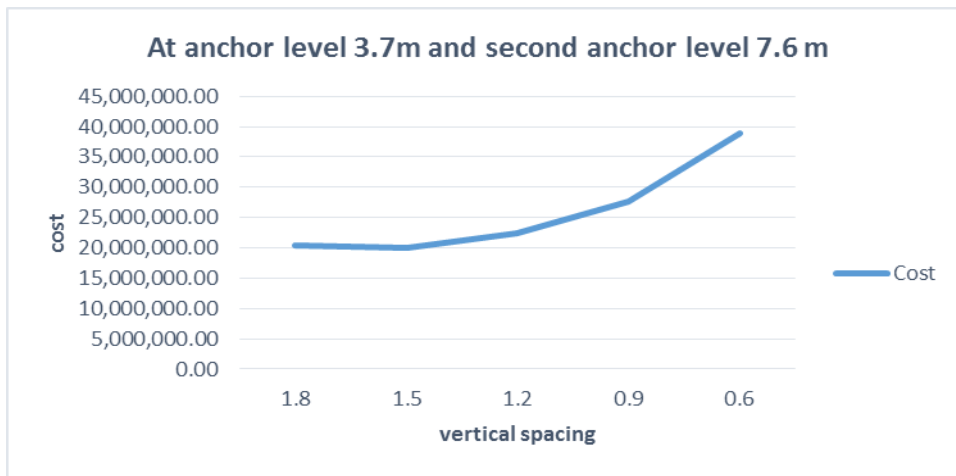
Top of the wall elevation =2362m a.s.l, Ground water elevation = 2354.4m a.s.l

Concrete  $f_c' = 25$  Mpa Rebar  $F_y = 410$ Mpa

**Table 6 at first anchor level 3.7m and second anchor level at 7.6 m**

Vertical spacing	Wall thickness	Wall moment	total bonded length		Depth of embedment	F.S	Cost
			1 <sup>st</sup> anchor level at 3.7m	2 <sup>nd</sup> anchor level at 7.6 m			
1.8	0.7	337.7	16.5	12.5	5.5	2.02	20,404,573.15
1.5	0.6	260.25	16.0	12.5	4.5	1.96	20,028,538.63
1.2	0.6	216.41	15.5	12.5	4.5	1.99	22,444,150.32
0.9	0.6	151.66	13	13	5.5	2.50	27,597,788.58
0.6	0.6	125.81	10.5	11.5	6.5	2.10	38,976,857.03

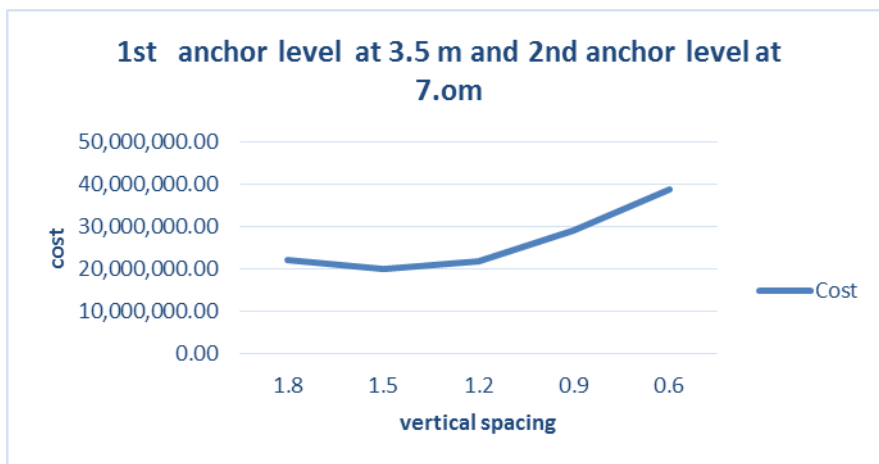
**Figure 8 graph of at first anchor level 3.7m and second anchor level at 7.6 m**



**Table 7 At first anchor level 3.5m and second anchor level at 7.0m**

Vertical spacing	Wall thickness	Wall moment	total bonded length		Depth of embedment	F.S	Cost
			1 <sup>st</sup> anchor level at 3.5m	2 <sup>nd</sup> anchor level at 7.0 m			
1.8	0.7	337.88	16.5	12.5	6.5	2.14	22,327,153.78
1.5	0.6	288.8	17.0	13.5	4.8	1.79	20,203,337.72
1.2	0.6	252.18	13.0	13.5	5.5	1.89	22,026,150.32
0.9	0.6	183.72	15.5	14.5	6.5	2.40	29,051,288.50
0.6	0.6	227.61	16.0	13.0	5.5	2.03	38,976,857.03

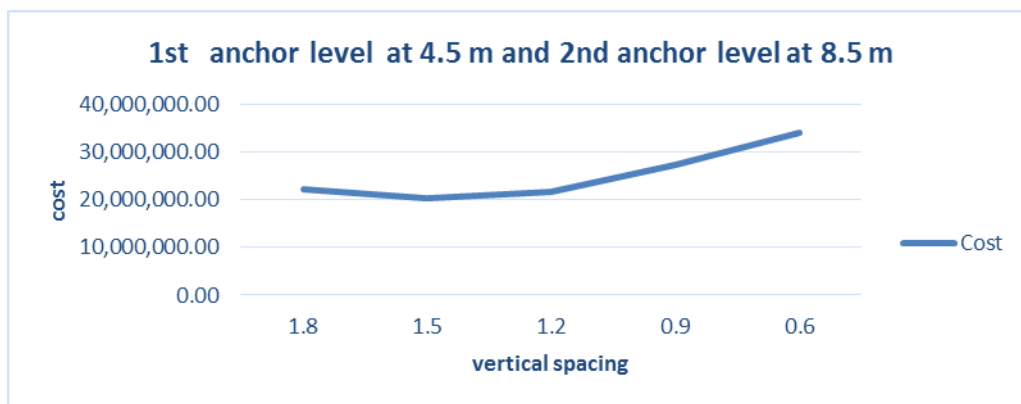
**Figure 9 1<sup>st</sup> anchor level at 3.5 m and 2<sup>nd</sup> anchor level at 7.0 m**



**Table 8 at first anchor level 4.5 m and second anchor level at 8.5 m**

Vertical spacing	Wall thickness	Wall moment	total bonded length		Depth of embedment	F.S	Cost
			1st anchor level at 3.5m	2nd anchor level at 7.0 m			
1.8	0.7	290.41	16.5	13.0	6.5	2.02	22,228,482.20
1.5	0.6	218.12	16.0	12.5	4.5	1.79	20,203,337.72
1.2	0.6	200.38	13.0	13.5	5.5	1.78	21,608,151.00
0.9	0.6	135.75	13.0	13.5	6.5	2.63	27,307,088.58
0.6	0.6	114.25	13.0	13.5	6.5	2.38	34,128,057.03

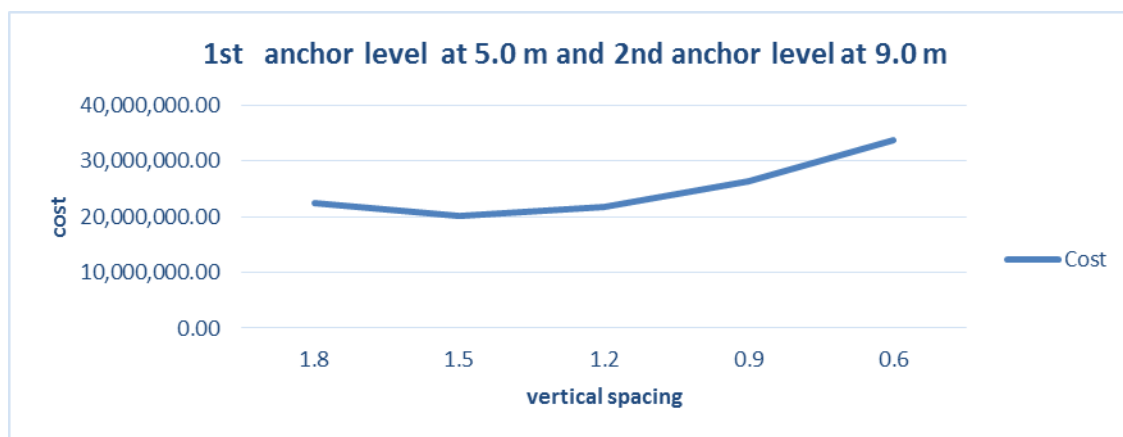
**Figure 10 1<sup>st</sup> anchor level at 4.5m and 2<sup>nd</sup> anchor level at 8.5m**



**Table 9 at first anchor level 5.0 m and second anchor level at 9.0 m**

Vertical spacing	Wall thickness	Wall moment	total bonded length		Depth of embedment	F.S	Cost
			1st anchor level at 3.5m	2nd anchor level at 7.0 m			
1.8	0.7	290.42	16.0	13.0	5.5	2.02	22,497,572.84
1.5	0.6	230.01	16.0	13.0	4.5	1.73	20,203,337.72
1.2	0.6	201.95	16.0	13.0	4.5	1.83	21,817,150.00
0.9	0.6	129.29	16.0	13.0	6.5	2.62	26,434,988.58
0.6	0.6	103.67	16.0	13.0	6.5	2.40	33,687,257.03

**Figure 11 1<sup>st</sup> anchor level at 5.0m and 2<sup>nd</sup> anchor level at 9.0m**



### 4.4 Design of Solider pile wall using by DeepXcav software

The deepXcav software used in this paper is a solider wall type. The width of the excavation is 50\*40.6m. It also has an anchor rod with three strands each carrying of their maximum capacity which is 270kN in total. Depth (D) = 11.5m, Wall length (H) =50 m, Excavation width (B) = 40.6m .Furthermore, Analysis and comparison of costs similar to the reinforced concrete pile wall methods.

Top of the wall elevation =2362m a.s.l

Ground water elevation = 2354.4m a.s.l

Concrete  $f_c' = 20$  Rebar  $F_y = 410$

Steel members  $f_y = 355$  E steel = 206000

HE= 550 cm, A = 344.3 cm<sup>2</sup>, I<sub>xx</sub> =161900 cm<sup>4</sup>

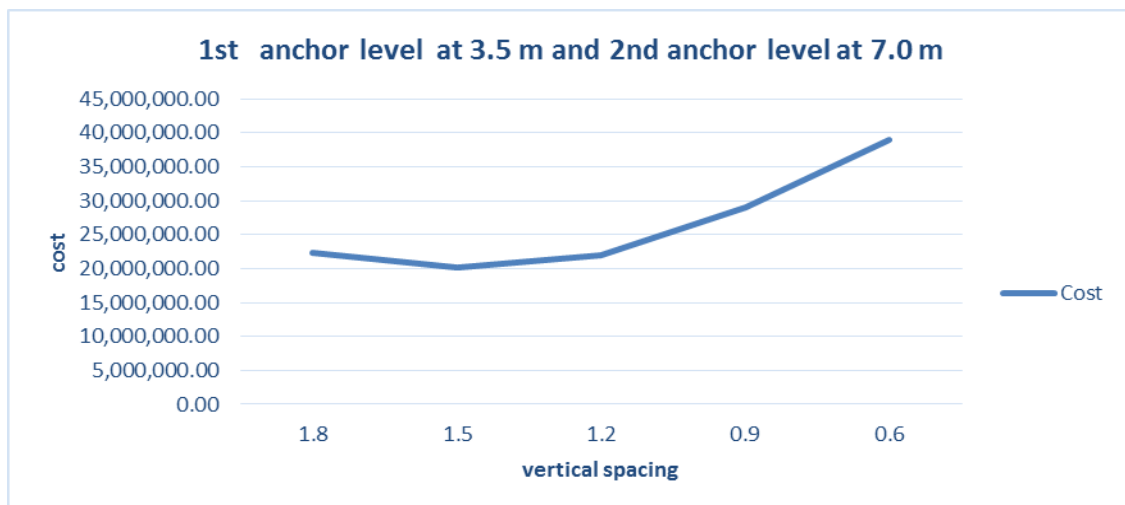
**Table 10 summary of steel structure section**

Section	W(K N/m)	A (Cm <sup>2</sup> )	D (cm)	tw (cm)	Bf (cm)	Tf (cm)	K(c m)	I <sub>xx</sub> (cm <sup>4</sup> )	S <sub>xx</sub> (cm <sup>3</sup> )	r <sub>X</sub> (cm)	I <sub>yy</sub>	S <sub>yy</sub>	r <sub>Y</sub>	r <sub>T</sub>	cW	f <sub>y</sub>
HE550	2.6	344.3	52.4	2.1	30.6	4	6.7	161900	6180	21.7	19150	1252	7.5	7.5	11190	355

**Table 11 at first anchor level 3.5m and second anchor level at 7.0m**

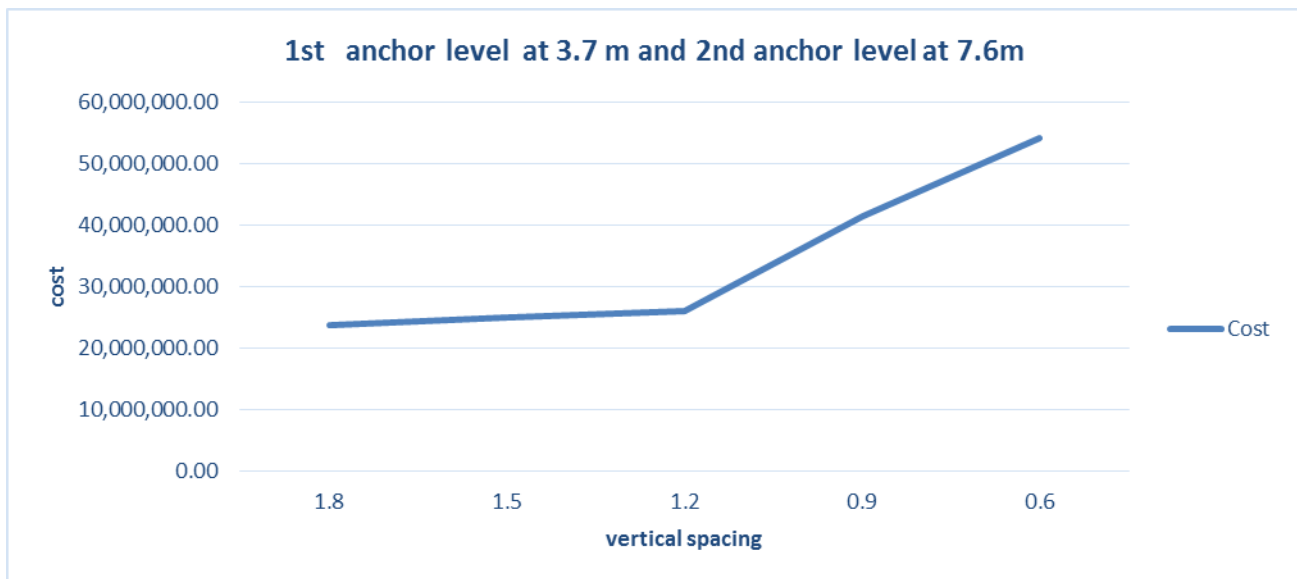
Vertical spacing	Wall moment	total bonded length		Depth of embedment	F.S	Cost
		1st anchor level at 3.5m	2nd anchor level at 7.0 m			
1.8	298.28	13.0	13.0	4.5	1.64	23,585,432.00
1.5	250.2	13.0	13.0	4.5	1.76	25,245,200.75
1.2	232.36	13.5	13.0	4.5	1.81	31,063,304.06
0.9	179.94	14.5	13.0	4.5	1.96	41,481,043.16
0.6	150.17	13.5	13.0	4.5	2.00	54150303.38

**Figure 12 graph of at first anchor level at 3.5m and 2<sup>nd</sup> anchor level at 7.0m**



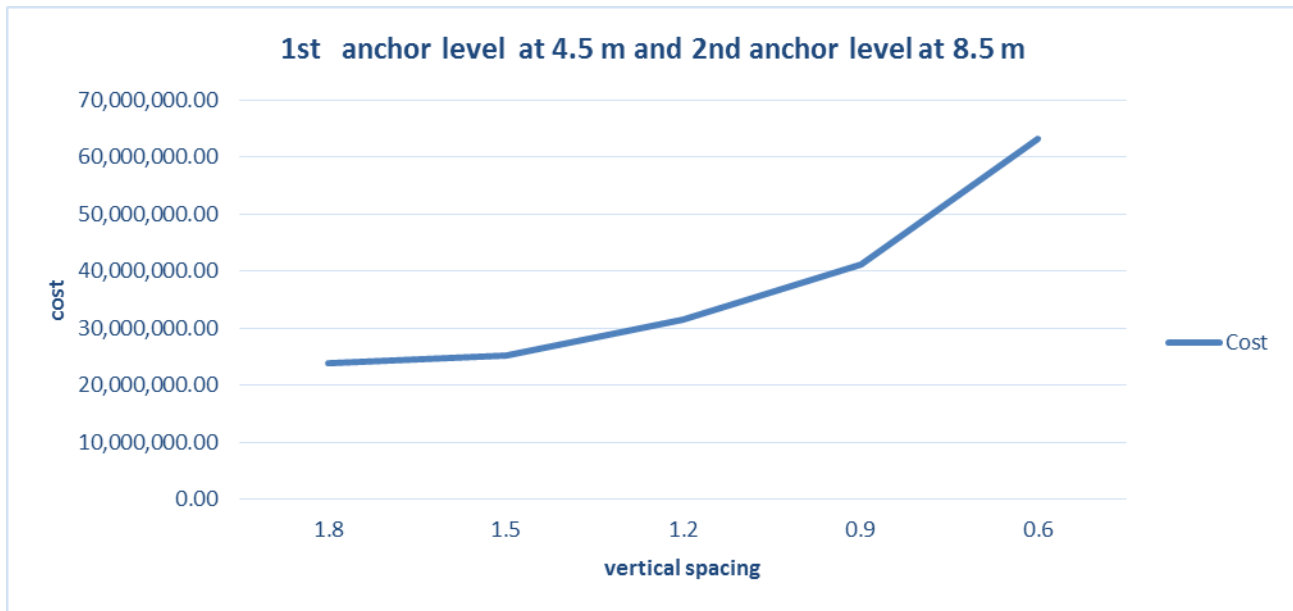
**Table 12 at first anchor level 3.7m and second anchor level at 7.6 m**

Vertical spacing	Wall moment	total bonded length		Depth of embedment	F.S	Cost
		1 <sup>st</sup> anchor level at 3.7m	2 <sup>nd</sup> anchor level at 7.6 m			
1.8	295.50	12.5	12.5	4.5	1.65	23,583,032.00
1.5	250.57	16.0	13.0	4.5	1.76	24,979,000.75
1.2	205.92	13.0	12.5	4.5	1.91	25,956,200.75
0.9	162.15	13.0	12.5	4.5	2.01	41,280,623.16
0.6	140.66	13.0	12.5	6.5	2.67	54,150,303.38

**Figure 13 1<sup>st</sup> anchor level at 3.7m and 2<sup>nd</sup> anchor level at 7.6m****Table 13 at first anchor level 4.5 m and second anchor level at 8.5 m**

Vertical spacing	Wall moment	total bonded length		Depth of embedment	F.S	Cost
		1 <sup>st</sup> anchor level at 3.5m	2 <sup>nd</sup> anchor level at 7.0 m			
1.8	308.72	13.5	12.5	4.5	1.81	23,772,432.00
1.5	258.99	13.5	12.5	4.5	1.93	25,245,200.75
1.2	166.90	15.0	14.0	4.5	2.23	31,547,304.06
0.9	127.35	13.0	13.5	6.5	2.78	41,243,883.16
0.6	127.35	14.0	13.5	6.5	2.78	63,099,903.38

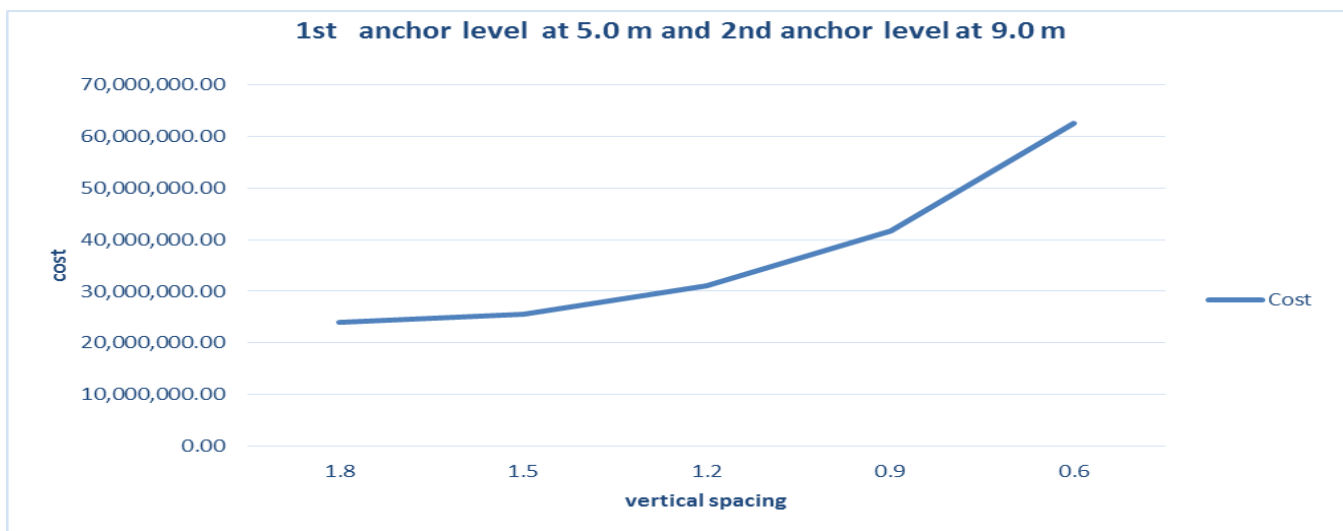
**Figure 14 graph of 1<sup>st</sup> anchor level at 4.5m and 2<sup>nd</sup> anchor level at 8.5m**



**Table 14 at first anchor level 5.0 m and second anchor level at 9.0 m**

Vertical spacing	Wall moment	total bonded length		Depth of embedment	F.S	Cost
		1st anchor level at 3.5m	2nd anchor level at 7.0 m			
1.8	304.58	15.0	12.5	4.5	1.95	23,941,832.00
1.5	257.79	15.0	12.5	4.5	2.05	25,568,600.75
1.2	203.50	15.0	12.5	4.5	2.09	31,063,304.06
0.9	163.37	15.0	12.5	4.5	2.30	41,582,683.16
0.6	117.77	15.0	14.0	4.5	2.44	62,459,703.38

**Figure 15 graph of 1<sup>st</sup> anchor level at 5.0m and 2<sup>nd</sup> anchor level at 9.0m**



## 4.5 Hand calculation

### 4.5.1 Evaluate site subsurface conditions and relevant properties of in situ soil and rock.

As per the Zemen Bank head quarter project geotechnical investigation report the proposed wall indicate the sub subsurface stratigraphy is relatively uniform .soil properties for design are shown in table 4.27 ground water was encountered in any of the boring and it is concluded that ground water levels at the site are below elevation 7.6m. The project site is characterized by flat topography with an average elevation of 2363m a.s,l (hand held GPS reading )

**Table 15:** Summary of Site Soil Stratification and Soil Properties

Average Depth	Description	Avg - C*	Avg - $\Phi^*$	Avg - Corrected SPT	Avg - unit weight $\gamma$
	Medium stiff, dark brown gravelly silty clay	38	32	8	16
1.5 - 3.6 m	Dark gray to gray, fine grained, highly weathered, fragmented to highly fractured basalt		34	17	18.5
3.6-8.5	Dense to very dense, brownish, dark grey to gray, gravelly silt SAND interlayer with highly weathered to decomposed and fragmented BASLT		45	45	23
8.5-16	Stiff to very stiff, red to reddish brown, highly plastic clayey silt	30	12	16	18.399
16 - 22.3 m	Stiff to very stiff, brownish, yellowish, whitish, grey to grey, sandy clayey silt (decomposed rock)	30	19	25	23
22.3-24.5	Stiff to very stiff, red to reddish brown, highly plastic clayey silt	34	45	23.6	18.74

\* Some of the Shear Strength Properties are derived from Correlative Relations

### 4.5.2 LOAD TYPES ACTING ON WALL

Combination using the Service Load design method, as follows:

Group I Load =  $[D + (L + I) + CF + E + B + SF]$  where D is dead load; L is live load; I is live impact load; CF is centrifugal force; E is lateral earth pressure; B is buoyancy; and SF is stream flow pressure.

Wall loads are approximated as follows:

- 
1. D: The dead load acting at the base of each soldier beam was approximated as the sum of the weight of the soldier beam, concrete backfill (if used), timber lagging, and CIP concrete facing.
  2. L and I: For conditions where traffic lanes are located within half the wall height behind the wall, AASHTO (1996) recommends that a surcharge pressure equivalent to 0.6 m of soil above the wall be included in the calculation of lateral earth pressure against the wall.
  3. E: The lateral earth pressure was approximated using the trapezoidal apparent earth pressure diagram.
  4. B, CF, and SF: These load types are not expected to be present during the construction or service life of the wall

### 4.5.3 LOCATION OF CRITICAL FAILURE SURFACE

The critical failure surface may be assumed to intersect the corner of the wall and exit at the ground surface and be sloped at  $45^\circ + \Phi'/2$  from the horizontal where  $\Phi'$  is equal to the effective stress friction angle of the soil behind the wall.

Peck, et. al. (1974) proposed a second method by expanding on Rankine's idea.

The failure plane location is calculated as in Rankine's method ( $45 + \phi/2$ ).

The anchored zone then begins a distance of 1/5 the height of the wall behind the failure plane. Rankine Failure Plane 61 degree

### 4.5.4 Select lateral earth pressure distribution acting on back of wall for final wall height.

The apparent earth pressure diagram for a two-tier anchored wall constructed in predominately cohesionless soils is shown in figure 49 where  $T_{H1}$  is the horizontal anchor load per meter of wall for the upper anchor;  $T_{H2}$  is the horizontal anchor load per meter of wall for the lower anchor; and  $P_e$  is the maximum ordinate of the apparent earth pressure diagram. It was assumed that the upper anchor is located 3.5m, 3.7m 4.0m, 4.5m and 5m below the top of the wall and the lower anchor is located 7.6 m, 7.0m 8.0m 8.5m and 9m below the top of the wall

### 4.5.5 LATERAL EARTH PRESSURE DUE TO TRAFFIC SURCHARGE

When traffic is expected to come to within a distance from the wall face equivalent to one-half the wall height, the pressure of approximately 12 kPa (AASHTO, 1996). wall should be designed for a live load surcharge

First assumption 1.5m spacing and design the first anchor level 3.7m and the second anchor level 7.6m

According to the Geotechnical Report Provided

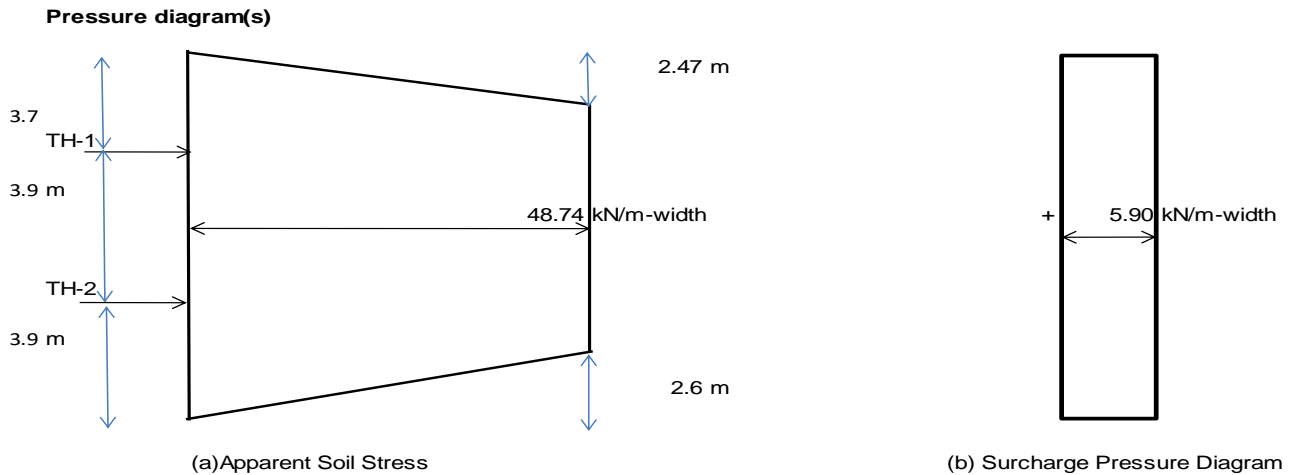


Figure 16 Pressure diagram(s)

**4.5.6 Calculate horizontal ground anchor loads and wall bending moments**

The tributary area method was used to calculate the horizontal anchor loads, TH1 and TH2, the maximum wall bending moment, Mmax, and the reaction force to be resisted by the subgrade, R.

1. The horizontal anchor loads were calculated using the tributary area method, as follows:

$$T_{H1} = \left(\frac{2}{3}H_1 + \frac{H_2}{2}\right) P_e + \left(H_1 + \frac{H_2}{2}\right) P_s \dots \dots \dots \text{(Equation 3.3)}$$

$$T_{H1} = \left(\frac{2}{3}3.7 + \frac{3.9}{2}\right) 48.74 + \left(3.7 + \frac{3.9}{2}\right) 5.9$$

**$T_{H1} = \underline{\underline{248.61KN/m}}$**

$$T_{H2} = \left(\frac{2}{3}H_2 + \frac{23}{48}H_2\right) P_e + \left(\frac{H_2}{2} + \frac{H_2}{2}\right) P_s \dots \dots \dots \text{(Equation 3.4)}$$

$$T_{H2} = \left(\frac{3.9}{2} + \frac{23}{48}3.9\right) 48.74 + \left(\frac{3.9}{2} + \frac{3.9}{2}\right) 5.9$$

**$T_{H2} = \underline{\underline{209.15KN/m}}$**

Wall bending moments were calculated for the upper anchor level (M1), between the upper and lower anchor level (M2), and between the lower anchor level and the base of the excavation (M3) using the tributary area method. The wall bending moment used for design, Mmax, is the largest of M1, M2, and M3

The value of M1 was calculated as follows:

$$M_1 = \frac{13}{54}H_1^2 P_e + P_s H_1 \frac{H_1}{2} \dots \dots \dots \text{(Equation 3.5)}$$

$$M_1 = \frac{13}{54} * 3.7^2 * 48.74 + 5.9 * 3.7 * \frac{3.7}{2}$$

$$M_1 = \underline{\underline{201.03 \text{ kN-m/m}}}$$

The maximum bending moment below the upper anchor was calculated assuming  $H_2 = H_3 = 3.9 \text{ m}$ :

$$M_{2,3} = \frac{1}{10} (H_{2,3})^2 (P_e + P_s) \dots \dots \dots \text{(Equation 3.6)}$$

$$M_{2,3} = \frac{1}{10} (3.9)^2 (48.74 + 5.9)$$

$$M_{2,3} = \underline{\underline{83.11 \text{ kN-m/m}}}$$

The wall bending moment used for design is  $M_{\max} = \underline{\underline{201.03 \text{ kN-m/m}}}$ .

The reaction force to be resisted by the subgrade is assumed to act at the base of the excavation and was calculated using the tributary area method as follows:

$$R = \left( \frac{3H_3}{16} \right) P_e + \left( \frac{H_3}{2} \right) P_s \dots \dots \dots \text{(Equation 3.7)}$$

$$R = \left( \frac{3 \times 3.9}{16} \right) 48.74 + \left( \frac{3.9}{2} \right) 5.9$$

$$R = \underline{\underline{47.15 \text{ kN/m}}}$$

#### 4.5.7 TRIAL DESIGN ASSUMPTIONS

Initial designs were developed for a reinforced concrete with bar anchors and for wall with strand anchors. The inclination of all anchors was assumed to be  $30^\circ$  and the wall center-to-center spacing was assumed to be 1.5 m. A cross section view of the initial design for the wall including the bar anchors. The wall design including the strand anchors is the same as that shown in figure -7, except that the minimum un-bonded length of the lowermost anchor is greater than that for the bar anchor configuration. A discussion of the un-bonded and bond lengths for the strand and bar designs is provided subsequently.

#### 4.5.8 ANCHOR DESIGN LOAD

Upper anchor: The anchor design load ( $DL_1$ ) was calculated as follows:

$$(DL_1) = \frac{TH_1 (\text{spacing})}{\cos \theta} \dots \dots \dots \text{(Equation 3.8)}$$

$$(DL_1) = \frac{248.61 (1.5)}{\cos 30^\circ}$$

$$(DL_1) = \underline{430.61 \text{ kN}}$$

Lower anchor: The anchor design load (DL2) was calculated as follows

$$(DL_2) = \frac{TH^2 (\text{spacing})}{\cos \theta} \dots \dots \dots (\text{Equation 3.9})$$

$$(DL_2) = \frac{209.15 (1.5)}{\cos 30^\circ}$$

$$(DL_2) = \underline{362.25 \text{ kN}}$$

The maximum calculated anchor design load is 430.61 kN.

#### 4.5.9 DESIGN OF THE UNBONDED LENGTH

Peck, et al. (1974) proposed a second method by expanding on Rankine's idea. The failure plane location is calculated as in Rankine's method ( $45 + \phi/2$ ). The anchored zone then begins a distance of 1/5 the height of the wall behind the failure plane.

Table 16 : unbounded length

Rankine Failure Plane	61 deg		
	Length in RAW* (m)	Transition (1/5 x H) (m)	Total Unbonded Length (m)
Layer -1 Anchor	7.96	2.3	10.26
Layer -2 Anchor	3.98	2.3	6.28
* Rankine Active Wedge			

#### 4.5.10 ANCHOR CAPACITY

The anchor bond zones will be formed in the Sand and Silt Medium dense (11-30) SPT range (for different Elevation). Assuming that the load transfer rate is controlled by the medium dense silty sand layer, a load transfer rate of 100 kN/m was selected from (table 3)

$$\text{Maximum bond length} = \frac{430.61 \text{ kN} * 2}{100 \text{ kN/m}}$$

$$\text{Maximum bond length} = \underline{8.61 \text{ m}}$$

$$\text{Maximum bond length} = \frac{362.25 \text{ kNm} * 2}{100 \text{ kN/m}}$$

---

Maximum bond length = 7.245m

#### 4.5.11 EXTERNAL STABILITY

The external stability of the anchored wall was evaluated using a slope stability analysis program. A target factor of safety of 1.3 was selected. Wall and subsurface input parameter values used are the same as those used for the stability analysis to evaluate the anchor un-bonded lengths.

#### 4.5.12 SELECTION OF TENDON

Anchor Capacity DIN 4125 for Active (Normal) Earth Pressure

Maximum allowable anchor forces

Normal earth pressure 1\*130 KN

$$\text{No. of Strand Anchor for first layer} = \frac{T1}{130} = \frac{431.61}{130} = 4$$

$$\text{No. of Strand Anchor for second layer} = \frac{T1}{130} = \frac{362.25}{130} = 3$$

#### 4.5.13 Shear Force Distribution

For such an indeterminate System and Top-Down Construction/Excavation approach, it is important to evaluate the shear force at each stage of excavation.

Table 17: shear force distribution

First Excavation (m)	Sign	Shear Force
0	+	0
3.7	+	120.23
3.7	+	128.38
7.6	+	181.95
7.6	+	27.19
11.5	+	99.54

Therefore, the Maximum Shear Force per Meter Width of the Wall is  $Q = \underline{\underline{181.95 \text{ kN/m}}}$

#### 4.5.14 SELECTION OF TENDON

The ground at the site has been classified as aggressive and therefore a Class I (double protection) encapsulated tendon was selected. Dimensions are calculated for both bar and strand tendons assuming a maximum test load of 1.33 DL.

15 mm, Grade 270 4-strand pre-stressing tendon may also be selected. The allowable tensile capacity of the tendon is 626 kN (see table 4). The minimum estimated trumpet opening is 150 mm for a Class I corrosion protection system (see table 5).

#### 4.5.15 LATERAL CAPACITY OF EMBEDDED LENGTH

The pile must be sufficiently embedded to develop passive resistance to carry the lateral load resulting from the reaction force to be resisted by the subgrade,  $R$ , and the active pressure acting over the soldier beam width,  $b$ , (i.e., 0.6 m) along the embedded soldier beam length. A factor of safety of 1.5 is required.

The lateral load,  $R_{Load}$ , is calculated as follows:

Table 18 :Embedment Depth (D) calculation

Toe Depth (m)	Wedge Resistance (single Pile) (kN/m)	Flow Resistance (kN/m)	Rankine Continous (kN/m)	Minimum Wang-Reese Passive Resistance (KN/m)	Total Passive Force (kN)	Total Active Force (kN)	Factor of Safety
0.0	0.0	0.0	0.0	0.0	0.0	70.72077	0.0
0.5	15.2	60.9	40.5	15.2	3.8	112.32812	0.0
1.0	39.4	121.8	81.0	39.4	19.7	155.70599	0.1
1.5	72.7	182.8	121.5	72.7	54.5	200.85439	0.3
2.0	115.1	243.7	162.0	115.1	115.1	247.77332	0.5
2.5	166.6	304.6	202.5	166.6	208.3	296.46277	0.7
3.0	227.2	365.5	243.0	227.2	340.8	346.92275	1.0
3.5	296.9	426.4	283.5	283.5	496.1	399.15325	1.2
4.0	375.7	487.3	324.0	324.0	648.0	453.15427	1.4
<b>4.5</b>	<b>463.5</b>	<b>548.3</b>	<b>364.5</b>	<b>364.5</b>	<b>820.1</b>	<b>508.92583</b>	<b>1.6</b>
5.0	560.4	609.2	405.0	405.0	1012.5	566.46791	1.8
5.5	666.4	670.1	445.5	445.5	1225.1	625.78051	2.0
6.0	781.5	731.0	486.0	486.0	1458.0	686.86364	2.1
6.5	905.7	791.9	526.5	526.5	1711.1	749.71729	2.3
7.0	1039.0	852.8	567.0	567.0	1984.5	814.34147	2.4
7.5	1181.4	913.8	607.5	607.5	2278.1	880.73618	2.6
8.0	1332.8	974.7	648.0	648.0	2592.0	948.90141	2.7
8.5	1493.3	1035.6	688.5	688.5	2926.1	1018.8372	2.9
9.0	1662.9	1096.5	729.0	729.0	3280.5	1090.5435	3.0
9.5	1841.6	1157.4	769.5	769.5	3655.1	1164.0203	3.1
10.0	2029.4	1218.3	810.0	810.0	4050.0	1239.2676	3.3

Hence, Depth of Embedment Below Bottom Excavation is (D in m)

**4.50 m**

#### 4.6 Design by Excel spread sheet

Lateral Earth Pressure due to Soil

#Trail -1 vertical spacing 1.8m and 3.5m first anchor level

soil property summary						
Site Information						
Site Area:		=				
Depth of final Excavation (H)		=	11.5		m	
Side of Design		=	Free Shoring			
Table 1: Summary of Site Soil Stratification and Soil Properties						
Average Depth	Description	Avg - C*	Avg - $\phi^*$	Avg - Corrected SPT	Avg - unit weight $\gamma$	
	Medium stiff, dark brown gravelly silty clay	38	32	8	18	
1.5 - 3.6 m	Dark gray to gray, fine grained, highly weathered, fragmented to highly fractured basalt		34	17	18.5	
3.6-8.5	Dense to very dense, brownish, dark grey to gray, gravelly silt SAND interlayer with highly weathered to decomposed and fragmented BASLT		45	45	23	
8.5-16	Stiff to very stiff, red to reddish brown, highly plastic clayey silt	30	12	16	18.399	
16 - 22.3 m	Stiff to very stiff, brownish, yellowish, whitish, grey to grey, sandy clayey silt (decomposed rock)	30	19	25	23	
22.3-24.5	Stiff to very stiff, red to reddish brown, highly plastic clayey silt	34	45	23.6	18.74	
* Some of the Shear Strength Properties are Derived From Correlative Relations						

Lateral Earth Pressure due to Soil								
Depth (M)	Description of Soil	$k_a$	$\gamma$	$\sigma_w$	$\sigma_v$	$\sigma_h$	$\sigma_{hf}/m\text{-width}^*$	
0		0.31	16			0	-42.13	0.00
1	Medium stiff, dark brown gravelly silty clay	0.31	16			16	-37.21	0.00
2		0.31	16			32	-32.30	0.00
3		0.28	18.5			51	-26.13	0.00
3	Dark gray to gray, fine grained, highly weathered, fragmented to highly fractured basalt	0.28	18.5			51	15.69	20.40
4		0.28	18.5			69	20.92	27.20
4		0.17	19.2			69	13.18	17.13
5	Dense to very dense, brownish, dark grey to gray, gravelly silt SAND interlayer with highly weathered to decomposed and fragmented BASLT	0.17	19.2			88	16.47	21.41
6		0.17	19.2			107	19.77	25.69
7		0.17	19.2			127	23.06	29.98
8		0.17	19.2	39	185	26.35	34.26	
9		0.17	19.2	44	209	29.65	38.54	
9	Stiff to very stiff, red to reddish brown, highly plastic clayey silt	0.66	18.99	44	209	88.56	115.13	
10		0.66	18.99	49	233	104.23	135.50	
11		0.66	18.99	54	257	119.90	155.87	
12		0.66	18.99	59	281	135.57	176.24	
13		0.66	18.99	64	305	151.24	196.61	
14		0.66	18.99	69	329	166.91	216.98	
15		0.66	18.99	74	353	182.57	237.35	
16		0.66	18.99	78	376	198.24	257.72	
16	Stiff to very stiff, brownish, yellowish, whitish, grey to grey, sandy clayey silt (decomposed rock)	0.66	18.74	78	376	198.24	257.72	
17		0.51	18.74	83	400	160.75	208.97	
18		0.51	18.74	88	424	172.78	224.61	
19		0.51	18.74	93	447	184.81	240.25	
20		0.51	18.74	98	471	196.84	255.89	
21		0.51	18.74	103	495	208.87	271.53	
22		0.51	18.74	108	518	220.90	287.17	
22	Stiff to very stiff, red to reddish brown, highly plastic clayey silt	0.17	18.74	108	518	64.07	83.29	
23		0.17	18.74	113	542	68.13	88.56	
24		0.17	18.74	118	566	72.18	93.84	
25		0.17	18.74	123	589	76.24	99.11	
26		0.17	18.74	128	613	80.30	104.39	
Total Load to Bottom Exc. (P Total-KN/m-width)		=	437.0635			KN/m-mwidth		

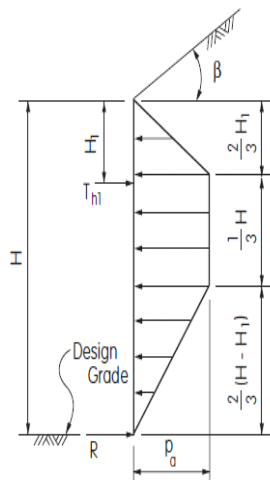
**Approximate - Apparent Lateral Earth Pressure Diagram for Excavation in Stratified Soil**

For walls with a single Level of Anchors:

$$P_a = P_{total} / (2/3) * H$$

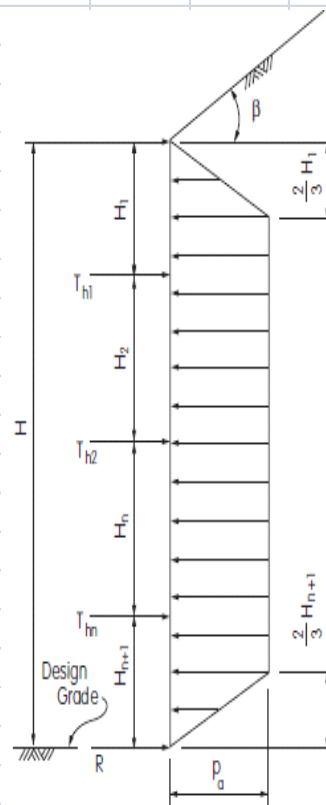
For Walls with multiple level of anchors:

$$P_a = P_{total} / (H - (1/3)H_1 - (1/3)H_{n+1})$$



Note:  $H_1 \leq \frac{2}{3} H$

a) Wall with a single level of anchors



b) Wall with multiple levels of anchors

where

- $P_a$  maximum ordinate of apparent pressure diagram
- $P_{total}$  Total lateral load required to be applied to the wall face to provide a factor of safety equal to 1.3 for the retained soil mass when stability is analysed using an appropriate limit equilibrium method of analysis, except that use factor of safety greater than 1.44  $P_a$
- $H$  wall design height
- $H_1$  distance from ground surface at the top of wall to the upper most level anchor.
- $H_{n+1}$  Distance from the design grade at the bottom of a wall to lowermost level of anchor
- $T_{hi}$  Horizontal Component of Design Force in anchor level i
- $R$  Design Reaction force at the design grade at bottom of wall to be resisted embedded portion of the wall

Initial Design Proposal - Location of Anchors						
Number of Anchor Layer	=	2				
Level of Anchor Layer-1 from NGL	=	3.5	m			
Level of Anchor Layer-2 from NGL	=	3.5	m			
Proposed Spacing of Pile	=	1.8	m	<	1.8 m	Ok!
Proposed Diameter of Pile	=	0.6	m			
Proposed Diameter of Anchor Hole	=	0.13	m			

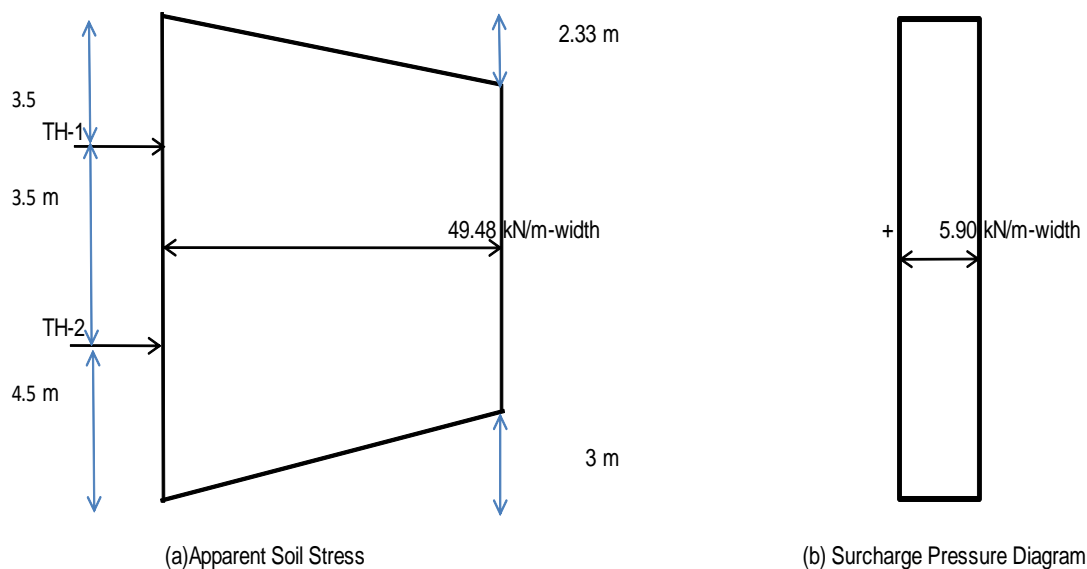
Ordinate of Apparent Pressure diagram - Soil						
		$P_a$	49.48	KN/m-m width		

Surcharge Pressure ( $P_s$ )						
Type of Surcharge*	=	Traffic Load				When traffic is expected to come to within a distance from the wall face equivalent to one-half the wall height, the pressure of approximately 12 kPa (AASHTO, 1996).wall should be designed for a live load surcharge
Live Load Surcharge Pressure Assumed	=	12.00	kPa			
According to AASHTO 1996	=					
Factored Surcharge Load	=	5.90	kN/m-mwidth			

**Water Pressure**

According to the Geotechnical Report Provided

**Pressure diagram(s)**



### Calculation of Ground Anchor Loads from Apparent Lateral Earth Pressure Diagram

*Ground anchor loads for flexible anchored wall applications can be estimated from apparent earth pressure envelopes. Methods commonly used include the tributary area method and the hinge method which were developed to enable hand calculations to be made for statically indeterminate systems. Both methods, when used with appropriate apparent earth pressure diagrams, have provided reasonable estimates of ground anchor loads and wall bending moments for anchored systems constructed in competent soils. (Ground Anchors and Anchored Structures)*

In this design tributary Area Method is Employed

Anchor Load

TH-1	=	202.04 KN/m	From Apparent Soil Pressure
	=	30.97 KN/m	From Surcharge Load
TH-1/m-width		233.01 KN/m	
TH-2	=	193.28 KN/m	From Apparent Soil Pressure
	=	23.60 KN/m	From Surcharge Load
TH-2/m-width		216.87 KN/m	
R	=	41.75 KN/m	From Apparent Soil Pressure
	=	13.27 KN/m	From Surcharge Load
R/m-width		55.02 KN/m	

<b>Bending Moment - Tributary Area Method [Ground Anchors and Anchored Structures]</b>			
The maximum Bending Moment is the Larger of			
$M_1 = \frac{13}{54} H_1^2 p_e + p_s H_1 \frac{H_1}{2}$			
$M_{2,3} = \frac{1}{10} (H_{2,3})^2 (p_e + p_s)$			
Accordingly,			
$M_1$	=	182.05 kNm/m	
$M_{2,3}$	=	112.14 kNm/m	
Therefore, the design moment per meter width of wall is:			
$M$	=	182.05 kNm/m	

<b>Shear Force Distribution</b>			
For such an indeterminate System and Top-Down Construction/Excavation approach, it is important to evaluate the shear force at each stage of excavation			
First Excavation	Sign	Shear Force	
0 m	+	0	kN/m
3.5 m	+	115.45	kN/m
3.5 m	-	117.56	kN/m
7 m	+	171.07	kN/m
7 m	-	45.81	kN/m
11.5 m	+	102.63	kN/m
Therefore, the Maximum Shear Force Per Meter Width of the Wall is			
$Q$	=	171.07 kN/m	

**Anchor Design Load**Orientation ( $\theta$ ) = 30 deg

*The the practical minimum angle is 15° below horizontal, with angles of 15-30° being the most common, to facilitate flow of grout mix and to enable the whole grout body to be filled effectively.*

Upper Anchor Load (T1)

T1 = 484.30 kN

Lower Anchor Load (T1)

T2 = 450.76 kN

Anchor Capacity DIN 4125 for Active( Normal) Earth Pressure

Maximum allowable anchor forces					
Anchor type	Steel quality (N/mm <sup>2</sup> )	Steel diameter (mm)	Allowable anchor force acc. DIN 4125 Normal earth pressure		Elastic stretch per kN and m of free length (mm/kNxm)
			(kN)	At rest (kN)	
Strand anchor	St 1570/ 1770	2 x 0,6"	251	330	0,018315
		3 x 0,6"	377	496	0,012210
		4 x 0,6"	502	661	0,009158
		5 x 0,6"	628	826	0,007326
		6 x 0,6"	754	992	0,006105
		7 x 0,6"	879	1 157	0,005233
		8 x 0,6"	1 005	1 300	0,004579
		9 x 0,6"	1 130	-	0,004070
		10 x 0,6"	1 256	-	0,003663
		11 x 0,6"	1 300	-	0,003330
Single bar anchor	St 835/ 1030	32	384	473	0,00604
		36	485	599	0,00477
	St 1080/ 1230	26,5	340	388	0,00880
		32	496	563	0,00604
		36	628	723	0,00477

Accordingly,

No. of Strand Anchor for first layer 4

No. of Strand Anchor for second layer 4

<b>Anchor Length</b>						
<b>Length of Unbonded and Bonded Strand Anchors</b>						
Peck, et. al. (1974) proposed a second method by expanding on Rankine's idea.						
The failure plane location is calculated as in Rankine's method ( $45 + \phi/2$ ).						
The anchored zone then begins a distance of 1/5 the height of the wall behind the failure plane.						
<b>Unbonded Length</b>						
	Rankine Failure Plane		61 deg	Conservatively		
			Length in RAW* (m)	Transition (1/5 x H) (m)	Total Unbonded Length (m)	
	Layer -1 Anchor		8.16	2.3	10.46	
	Layer -2 Anchor		4.59	2.3	6.89	
	* Rankine Active Wedge					
<b>Bonded Length</b>						
According to FHWA-IF-99-015 [Ground Anchors and Anchored Structures], for small diameter anchors Rock Anchors, the Ultimate Capacity of Grout Body is Given						
			τ <sub>u</sub> (kN/m)			
	Dense to very dense		100			
	Dense to very dense		100			
	Required Bond Length Using F.S = 2,					
	Anchor Layer -1	=	9.69	m	>	4.5 m OK!
	Anchor Layer -2	=	9.02	m	>	4.5 m OK!
The filling grout pressure must at least be 10 bars to achieve this capacity						
<b>Total Anchor Length = Unbonded Length + Bonded Length</b>						
			Required Length (m)	Proposed Length (m)		
	Total Length of Anchor Layer-1 [m]	=	20.15	<b>21</b>		
	Total Length of Anchor Layer-2 [m]	=	15.91	<b>16</b>		

Toe Depth (m)	Wedge Resistance (single Pile) (kN/m)	Flow Resistance (kN/m)	Rankine Continous (kN/m)	Minimum Wang-Reese Passive Resistance (KN/m)	Total Passive Force (kN)	Total Active Force (kN)	Factor of Safety
0.0	0.0	0.0	0.0	0.0	0.0	99.038479	0.0
0.5	15.2	60.9	48.6	15.2	3.8	140.64583	0.0
1.0	39.4	121.8	97.2	39.4	19.7	184.0237	0.1
1.5	72.7	182.8	145.8	72.7	54.5	229.1721	0.2
2.0	115.1	243.7	194.4	115.1	115.1	276.09103	0.4
2.5	166.6	304.6	243.0	166.6	208.3	324.78048	0.6
3.0	227.2	365.5	291.6	227.2	340.8	375.24046	0.9
3.5	296.9	426.4	340.2	296.9	519.6	427.47096	1.2
<b>4.0</b>	<b>375.7</b>	<b>487.3</b>	<b>388.8</b>	<b>375.7</b>	<b>751.3</b>	<b>481.47198</b>	<b>1.6</b>
4.5	463.5	548.3	437.4	437.4	984.2	537.24354	1.8
4.8	510.8	578.7	461.7	461.7	1096.5	565.79326	1.9
5.0	560.4	609.2	486.0	486.0	1215.0	594.78562	2.0
5.5	666.4	670.1	534.6	534.6	1470.2	654.09822	2.2
6.0	781.5	731.0	583.2	583.2	1749.6	715.18135	2.4
7.0	1039.0	852.8	680.4	680.4	2381.4	842.65918	2.8
7.5	1181.4	913.8	729.0	729.0	2733.8	909.05389	3.0
8.0	1332.8	974.7	777.6	777.6	3110.4	977.21912	3.2
8.5	1493.3	1035.6	826.2	826.2	3511.4	1047.1549	3.4
9.0	1662.9	1096.5	874.8	874.8	3936.6	1118.8612	3.5
9.5	1841.6	1157.4	923.4	923.4	4386.2	1192.338	3.7
10.0	2029.4	1218.3	972.0	972.0	4860.0	1267.5853	3.8

Hence, Depth of Embedment Below Bottom Excavation is (D in m)

**4.00 m**

The remaining shoring design using by spread sheet Design different level of anchor and different vertical spacing of reinforced concrete pile wall summarize as follow

**Table 19** :Summary of different level of anchor and vertical pile spacing

No. Anchors	Proposed Spacing of 9ile	Level of Anchor Layer-1	Level of Anchor Layer-2	M <sub>1</sub>	M <sub>2,3</sub>	Maximum Moment Force	Maximum Shear Force	TH1	TH2	T1	T2	1st level Un-boned length	1st level boned length	2nd level Un-boned length	2nd level boned length	1st level No strand	2nd level No strand	Depth of Embedment	total Pile Length	Remark
2.0	0.6	5.0	4.0	366.0	87.1	366.0	217.7	300.3	174.5	208.1	120.9	8.9	5.0	4.9	2.4	2.0	1.0	13.0	24.5	
2.0	0.9	5.0	4.0	366.0	87.1	366.0	217.7	300.3	174.5	312.1	181.3	8.9	6.2	4.9	3.6	3.0	2.0	7.5	19.0	
2.0	1.2	5.0	4.0	366.0	87.1	366.0	217.7	300.3	174.5	416.1	241.8	8.9	8.3	4.9	4.8	4.0	2.0	5.3	16.8	
2.0	1.5	5.0	4.0	366.0	87.1	366.0	217.7	300.3	174.5	520.1	302.2	8.9	10.4	4.9	6.0	5.0	3.0	4.3	15.8	
2.0	1.8	5.0	4.0	366.0	87.1	366.0	217.7	300.3	174.5	624.2	362.6	8.9	12.5	4.9	7.3	5.0	3.0	4.0	15.5	
2.0	0.6	4.0	4.0	234.3	87.1	234.3	191.2	262.0	200.7	181.5	139.0	10.0	5.0	5.9	2.8	2.0	2.0	13.0	24.5	
2.0	0.9	4.0	4.0	234.3	87.1	234.3	191.2	262.0	200.7	272.3	208.6	10.0	5.5	5.9	4.2	3.0	2.0	7.5	19.0	
2.0	1.2	4.0	4.0	234.3	87.1	234.3	191.2	262.0	200.7	363.1	278.1	10.0	7.3	5.9	5.6	3.0	3.0	5.5	17.0	
2.0	1.5	4.0	4.0	234.3	87.1	234.3	191.2	262.0	200.7	453.8	347.6	10.0	9.1	5.9	7.0	4.0	3.0	4.5	16.0	
2.0	1.8	4.0	4.0	234.3	87.1	234.3	191.2	262.0	200.7	544.6	417.1	10.0	10.9	5.9	8.3	5.0	4.0	4.0	15.5	
2.0	0.6	3.5	3.5	182.05	112.1	182.1	171.1	233.0	216.9	161.4	150.3	10.5	3.2	6.9	3.0	2.0	2.0	13.0	24.5	
2.0	0.9	3.5	3.5	182.05	112.1	182.1	171.1	233.0	216.9	242.2	225.4	10.5	5.0	6.9	4.5	2.0	2.0	7.5	19.0	
2.0	1.2	3.5	3.5	182.05	112.1	182.1	171.1	233.0	216.9	322.9	300.5	10.5	6.5	6.9	6.0	3.0	3.0	5.5	17.0	
2.0	1.5	3.5	3.5	182.05	112.1	296.5	171.1	233.0	216.9	403.59	375.6	10.5	8.1	6.9	7.5	4.0	3.0	4.5	16.0	
2.0	1.8	3.5	3.5	182.05	112.1	182.1	171.1	233.0	216.9	484.3	450.8	10.5	9.7	6.9	9.0	4.0	4.0	4.0	15.5	
2.0	0.6	4.5	4.0	296.5	87.1	296.5	204.5	281.2	187.6	194.8	130.0	9.4	5.0	5.4	2.6	2.0	1.0	13.0	24.5	
2.0	0.9	4.5	4.0	296.5	87.1	296.5	204.5	281.2	187.6	292.2	194.9	9.4	5.8	5.4	3.9	3.0	2.0	7.5	19.0	
2.0	1.2	4.5	4.0	296.5	87.1	296.5	204.5	281.2	187.6	389.6	259.9	9.4	7.8	5.4	5.2	3.0	2.0	5.5	17.0	
2.0	1.5	4.5	4.0	296.5	87.1	296.5	204.5	281.2	187.6	487.0	324.9	9.4	9.7	5.4	6.5	4.0	3.0	4.3	15.8	
2.0	1.8	4.5	4.0	296.5	87.1	296.5	204.5	281.2	187.6	584.4	389.9	9.4	11.7	5.4	7.8	5.0	3.0	4.0	15.5	
2.0	0.6	3.5	3.5	135.8	170.4	170.4	149.9	203.1	233.6	140.7	161.9	11.0	5.0	7.9	3.2	2.0	2.0	13.0	24.5	
2.0	0.9	3.5	3.5	135.8	170.4	170.4	149.9	203.1	233.6	211.0	242.8	11.0	5.0	7.9	4.9	2.0	2.0	7.5	19.0	
2.0	1.2	3.5	3.5	135.8	170.4	135.8	149.9	203.1	233.6	281.4	323.7	11.0	5.6	7.9	6.5	3.0	3.0	5.8	17.3	
2.0	1.5	3.5	3.5	135.8	170.4	170.4	149.9	203.1	233.6	351.7	404.7	11.0	7.0	7.9	8.1	3.0	4.0	4.8	16.3	

2.0	1.8	3.5	3.5	135.8	170.4	170.4	149.9	203.1	233.6	422.0	485.6	11.0	8.4	7.9	9.7	4.0	4.0	4.3	15.8
2.0	0.6	3.7	3.9	201.1	83.1	201.1	182.0	248.6	209.2	172.2	144.9	10.3	5.0	6.3	2.9	2.0	2.0	13.0	24.5
2.0	0.9	3.7	3.9	201.1	83.1	201.1	182.0	248.6	209.2	258.4	217.4	10.3	5.2	6.3	4.4	2.0	2.0	7.5	19.0
2.0	1.2	3.7	3.9	201.1	83.1	201.1	182.0	248.6	209.2	344.5	289.8	10.3	6.9	6.3	5.8	3.0	3.0	5.5	17.0
2.0	1.5	3.7	3.9	201.1	83.1	201.1	182.0	248.6	209.2	430.7	362.3	10.3	8.6	6.3	7.3	4.0	3.0	5.5	17.0
2.0	1.8	3.7	3.9	201.1	83.1	201.1	182.0	248.6	209.2	516.7	434.7	10.3	10.3	6.3	8.7	4.0	4.0	4.0	15.5
2.0	0.6	3	3.5	133.75	138.45	138.45	157.52	213.57	230.2	147.96	159.49	10.97	5.0	7.4	3.19	2	2	13	24.5
2.0	0.9	3	3.5	133.75	138.45	138.45	157.52	213.57	230.2	221.95	239.23	10.97	5.0	7.4	7.78	2	2	7.5	19
2.0	1.2	3	3.5	133.75	138.45	133.75	157.52	213.57	230.2	295.93	318.98	10.97	5.92	7.4	6.38	3	3	5.5	17
2.0	1.5	3	3.5	133.75	138.45	138.45	157.52	213.57	230.2	369.91	398.72	10.97	7.4	7.4	7.97	3	4	4.75	16.25
2.0	1.8	3	3.5	133.75	138.45	138.45	157.52	213.57	230.2	443.89	478.47	10.97	8.88	7.4	9.57	4	4	4.25	15.75

**Design Compare among deepXcav. Hand calculation and excel spread sheet at anchor level 3.7 m and 7.6m**

### DeepXcav design

Vertical spacing	Wall moment	total bonded length		Depth of embedment	F.S
		1st anchor level at 3.7m	2nd anchor level at 7.6 m		
1.5	260.25	13.5	12.5	4.5	1.96

### Hand calculation

Vertical spacing	Wall moment	total bonded length		Depth of embedment	F.S
		1st anchor level at 3.7m	2nd anchor level at 7.6 m		
1.5	201.1	16	13	4.5	1.6

### Excel spread sheet

Vertical spacing	Wall moment	total bonded length		Depth of embedment	F.S
		1st anchor level at 3.7m	2nd anchor level at 7.6 m		
1.5	201.1	16	13	4.5	1.6

#### 4.7 SHOT CRETE DESIGN

This is a technique in which cement, aggregate, and water are batched and mixed together prior to being delivered into a pump and conveyed through a hose to a nozzle where it is pneumatically projected onto a surface. Compressed air is introduced to the material flow at the nozzle in order to project the material toward the substrate. Wet shotcrete normally incorporates admixtures and may also include fibers

Concrete grade =30

Reinforced bar grade =400

Total wall depth = 11.5m use 1m width strip for design

Wall width (effective span) 2.0m

Wall thickness = 200mm

Effective wall thickness = 164mm

#### Loading

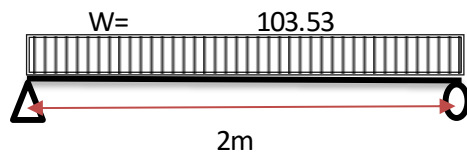
Surcharge =12KN/m

Earth pressure at GWL, P1 =27.2 KN/m

Earth pressure at dredge line, P1= 155.87 KN/m

Avg.lateral earth pressure = 91.53 KN/m

Total load due to surcharge and earth pressure= 103.53 KN/m



$$\text{Maximum moment} = \frac{wl^2}{8} = 29.12$$

$$\rho = 0.8 \frac{f_{cd}}{f_{yd}} \left( \frac{0.0035 E_s}{0.035 + f_{yd}} \right) = 0.002$$

$$A_s = \rho b d$$

$$A_s = 0.002 * 1000 * 200$$

$$A_s = 554.98 \text{mm}^2$$

$$S = a_s / A_s * 1000$$

$$S = 205 \text{ mm}$$

Use  $\Phi$  12 c/c 200

For Vertical bars use minimum requirements -  $\Phi$  8 c/c 200

## 4.8 Summary

The design done by the DeepXcav software, Hand calculation methods and excel spread sheet for the two different shoring systems; i.e. Reinforced concrete pile wall and soldier pile wall. Design vertical pile spacing of 1.8m, 1.5m, 1.2m, 0.9m and 0.6m at the first anchor level 3.5m, 3.7m, 4.0m and 5.0m for selection of optimum design.

### Reinforced concrete pile wall

The design is considered excavation stages i.e

- The first stage of construction assumption for design was installed a reinforced concrete pile wall into the ground
- Second stage of construction assumption at the first anchor level cantilever excavation depth
- Third stage of construction assumption: - installed by 30degree using the maximum anchor load tieback at the level of first anchor level
- The fourth stage of a construction progress was assumed the second stage of excavation below the lowest support level (before the lowest support is installed )
- The fifth stage of a construction progress was assumed excavate up to the anchor the 2<sup>nd</sup> strand by 30degree at the level of the 2<sup>nd</sup> anchor level
- Final excavation the remaining excavation

Select the optimum design according to safe design and cost efficient as per the standard vertical pile spacing 1.5m at the first anchor level 3.7m and 2<sup>nd</sup> anchor level 3.9m

Design using by maximum anchor load = 248.61KN/m

Maximum bending moment of pile = 201.03 KN/m

Maximum shear force per meter =181.95 KN/m

Angle of anchor orientation =30degree

Anchor design =430.61KN for first level anchor

Anchor design =362.25KN for second level anchor

The critical failure surface may be assumed to intersect the corner of the wall and exit at the ground surface and be sloped at  $45^\circ + \phi'/2$  from the horizontal where  $\phi'$  is equal to the effective stress friction angle of the soil behind the wall At 61 degree

First layer anchor number of anchor =4, second layer anchor number of anchor =3

The length of unbounded length at first anchor =10.26 m and the length of second anchor length =6.26m

1<sup>st</sup> anchor Bonded length= 8.61 m and 2<sup>nd</sup> bonded length =7.25m

Calculations were performed using the DeepXcav software, hand calculation and excel spreadsheet presented. Based on these calculations, embedment depth 1.93 m is required to achieve a factor of safety that exceeds the target value of 1.5.the embedment length is 4.5m.

### **Solider pile wall**

Design of solider pile wall the same procedure from reinforced concrete pile wall. The first stage of construction assumption for design was installed a reinforced concrete pile wall and define excavation stage The above mentioned **HE 550** pile wall installed length and diameter of pile

Design using by maximum anchor load = 249.61KN/m

Maximum bending moment of pile = 250.27 KN/m

Maximum shear force per meter =217.7 3KN/m

Angle of anchor orientation =30degree

Anchor design =538.47KN for first and second level anchor

First layer anchor number of anchor =4, second layer anchor number of anchor =4

The length of unbounded length at first anchor =10.0m and the length of second anchor length =11 m

1<sup>st</sup> anchor Bonded length= 10 m and 2<sup>nd</sup> bonded length =7.4m

Calculations were performed using the DeepXcav software and excel spreadsheet presented. Based on these calculations, embedment depth of 1.765 m is required to achieve a factor of safety that exceeds the target value of 1.5.the embedment length is 4.5m

Both hand calculation and excel spreadsheet results almost the same design result but design by deepXcav slightly different from the other.

Table 20 Total summary of total cost

total summary				
	1 <sup>st</sup> anchor level	reinforced concrete pile wall Total Amount	soldier pile wall total amount	difference in %
1.8m spacing with two anchor	3.5	22,327,153.78	23,585,432.00	6%
	3.7	20,404,573.15	23,583,032.00	16%
	4	22,228,482.84	23,772,432.00	7%
	5	22,497,572.84	23,941,832.00	6%
1.5m spacing with two anchor	3.5	20,203,337.72	25,245,200.75	25%
	3.7	20,028,538.63	24,979,000.75	25%
	4	20,203,337.72	25,245,200.75	25%
	5	20,203,337.72	25,568,600.75	27%
1.2m spacing with two anchor	3.5	22,026,150.32	31,063,304.06	41%
	3.7	22,444,150.32	25,956,200.75	16%
	4.5	21,608,150.00	31,547,304.06	46%
	5	21,817,150.00	31,063,304.06	42%
0.9m spacing with two anchor	3.5	29,051,288.50	41,481,043.16	43%
	3.7	27,597,788.58	41,280,623.16	50%
	4	27,307,088.58	41,243,883.16	51%
	5	26,434,988.58	41,582,683.16	57%
0.6m spacing with two anchor	3.5	38,976,857.03	54150303.38	39%
	3.7	38,976,857.03	54150303.38	39%
	4	34,128,057.03	63099903.38	85%
	5	33,687,257.03	62459703.38	85%

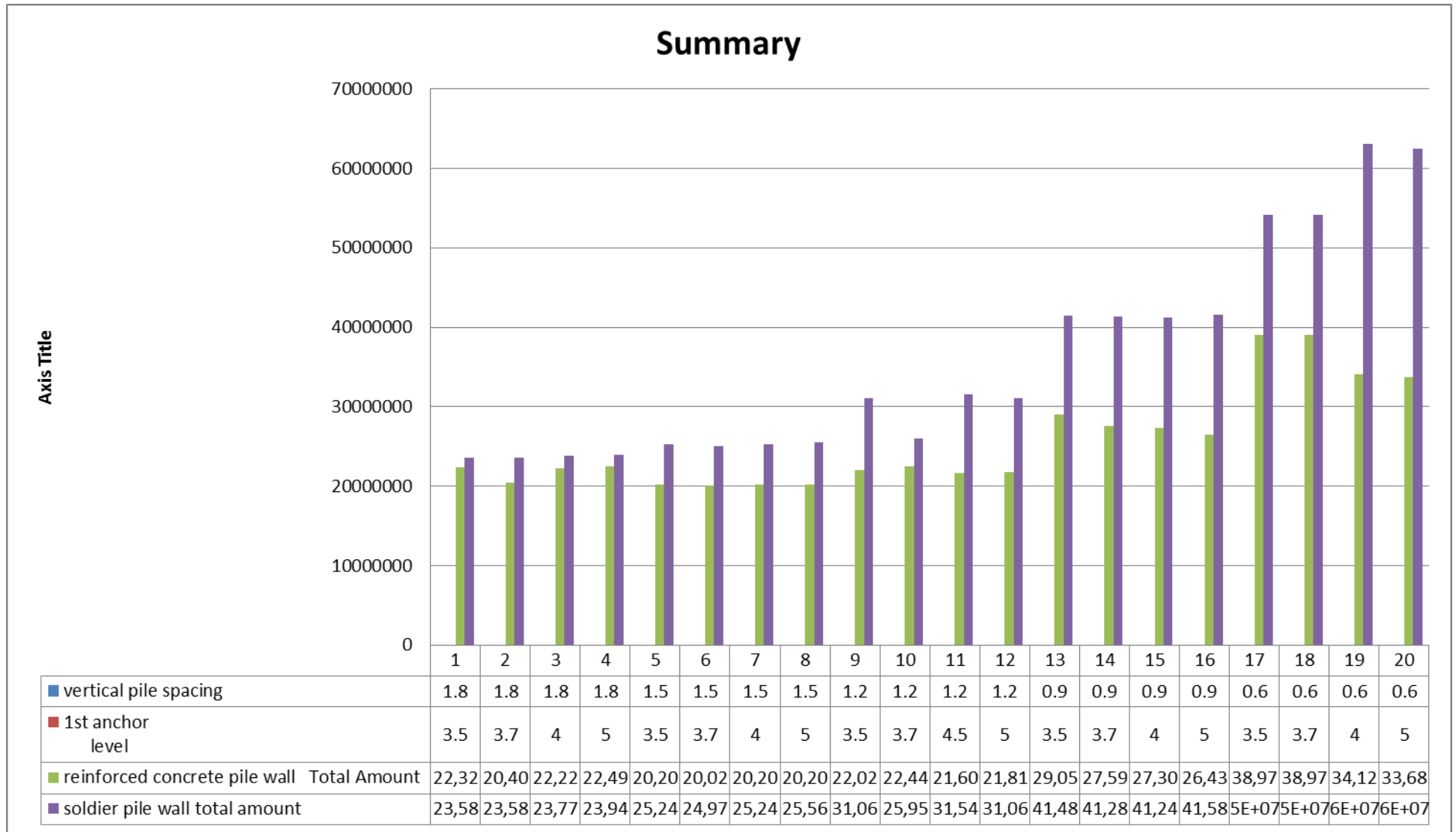


Figure 17 cost comparison between different levels of anchor with different spacing

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

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It can be concluded between different levels of anchor and vertical pile spacing design and prepare bill of quantities 3.7 m the first anchor level and 3.9 m the second anchor level 1.5m vertical spacing is the most preferable than the other. It can be concluded that from the analysis, the total cost of the soldier pile wall with timber lagging is more expensive than the cost of an anchored reinforced concrete wall.

Table 21 summary of the two types of shoring

Shoring type	Total amount
Reinforced concrete pile wall	20,199,818.17
Soldier pile wall with timber lagging	24,979,000.75

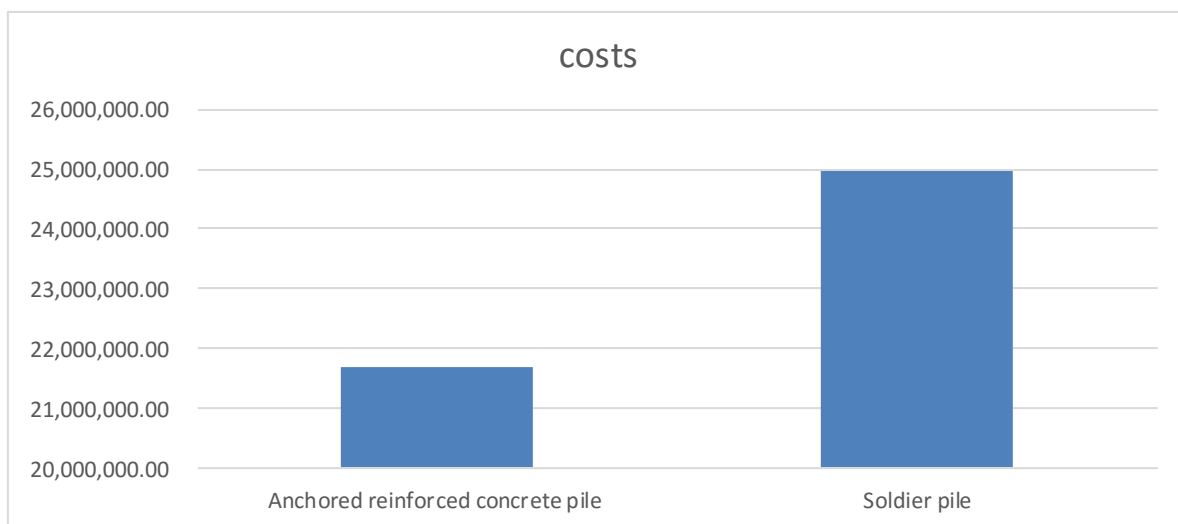


Figure 18 comparison of the two different types of shoring

## CHAPTER FIVE

### 5. conclusions and recommendations

#### 5.1 conclusions

To study the cost effectiveness of the two types of shoring system: reinforced concrete wall and soldier pile wall designed for a vertical spacing of 1.8m, 1.5 m, 1.2m, 0.9m and 0.6m moreover, the first anchor level 3.5m, 3.7m, 4.0m and 5.0m using by DeepXcav software, excel spread sheet and hand calculation .Based on the design obtained bill of quantities prepared for each of two types of reinforced concrete pile wall and soldier pile wall done and select the optimum design and cost efficient .

#### Reinforced concrete pile wall and soldier pile wall result

- At 1.8m vertical spacing soldier pile wall cost higher than the reinforced concrete pile wall by 6-16%
- At 1.5m vertical spacing soldier pile wall cost higher than the reinforced concrete pile wall by 25-40%
- At 1.2m vertical spacing soldier pile wall cost higher than the reinforced concrete pile wall by 15-42%
- At 0.9m vertical spacing soldier pile wall cost higher than the reinforced concrete pile wall by 43-53%
- At 0.6m vertical spacing soldier pile wall cost higher than the reinforced concrete pile wall by 39-85%

Cost comparison of using anchored reinforced concrete pile wall and soldier pile with timber lagging showed that in terms of material and construction cost, use of anchored reinforced concrete pile wall is cheaper than soldier pile with timber lagging pile wall.

The anchored reinforced concrete pile wall chosen for the local projects than the soldier pile with timber lagging wall because soldier pile wall

- They cannot be used in high water table conditions without extensive dewatering.
- They are Poor backfilling and associated ground losses can result in significant surface settlements.
- They are not as stiff as other retaining systems because only the flange of a soldier pile is embedded beneath sub-grade; it is very difficult to control basal soil movements.

In summary it can therefore be concluded that:-

- In our country anchored reinforced concrete pile walls are chosen due to its material availability and construction costs;
- Soldier pile wall design and construction constitute over 6-85 % of the costs of design and construction of reinforced concrete pile wall.
- At first anchor level at 3.7m, the second anchor level at 7.6m from the top level of the ground and the vertical pile spacing is 1.5m soldier pile wall design and construction constitute over 25% of the cost of design and construction of reinforced concrete pile wall.
- In general, other than the during the installation the pile will deviate relatively easily during driving and the pile will corrode, anchored reinforced concrete pile is preferable to a soldier pile wall in terms of durability and costs;

### **5.2 Recommendations**

- Further studies should be undertaken to compare the construction cost and benefit for the two shoring systems based on construction period
- There is need to carry out further research on performance and financial implications of having change shoring material or wall material properties and supporting system material properties
- Further studies should be analyses for soil arching effect by finite element analysis
- Deep excavation and the supporting system have area left to be further researches like Ground movements throughout excavation result in damage to existing structure located nearby.

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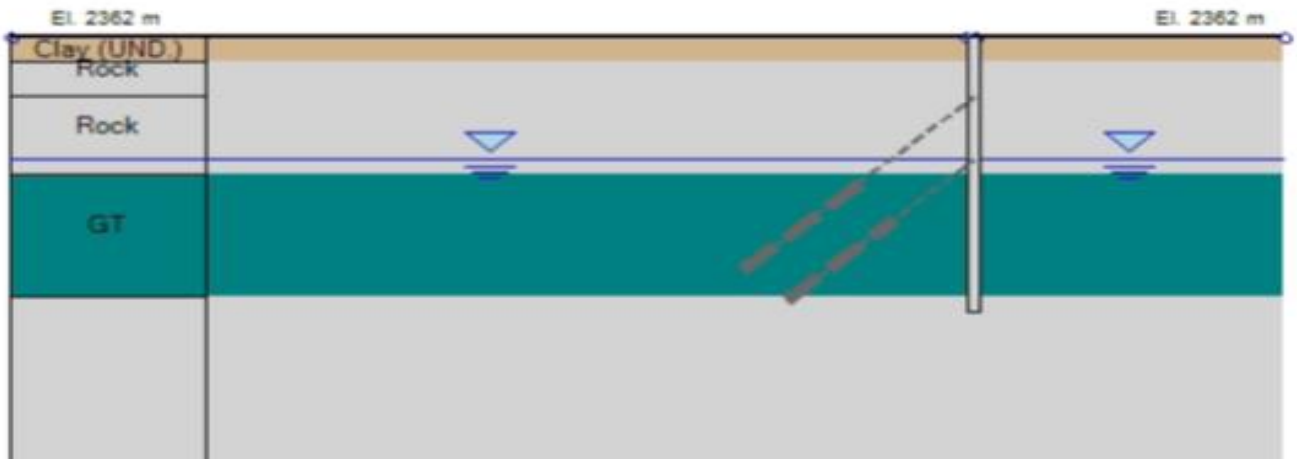
# ANNEX I

## Design assumption of Construction procedure sketch

### EXCAVATION STAGES SKETCHES

The first stage of construction

Figure 19 installed a reinforced concrete pile wall for 1.5 m spacing and 1<sup>ST</sup> anchor level 3.7m



Second stage of construction

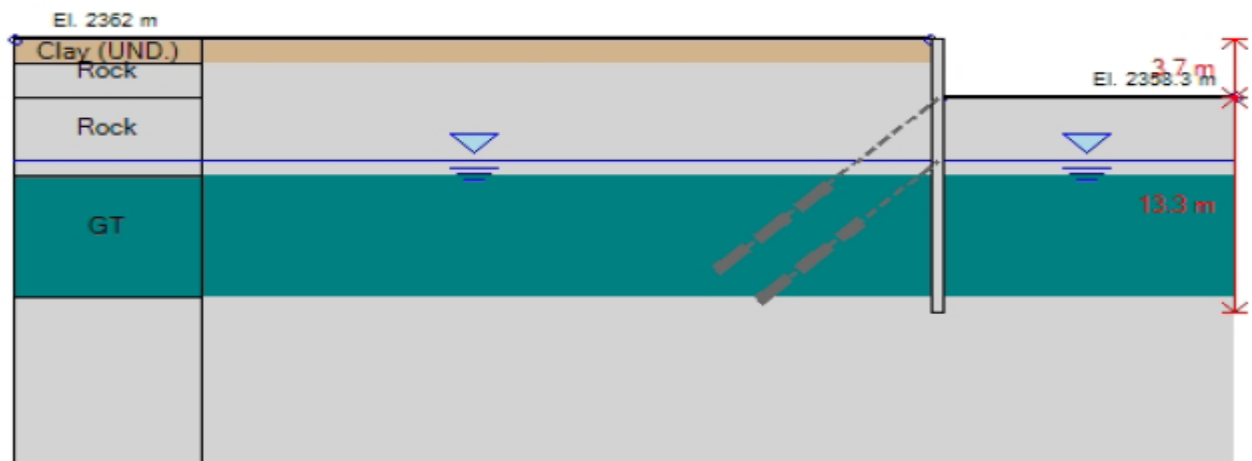


Figure 20 3.7m cantilever excavation depth for stages for 1.5 m spacing and 1<sup>ST</sup> anchor level 3.7m

Third stage of construction

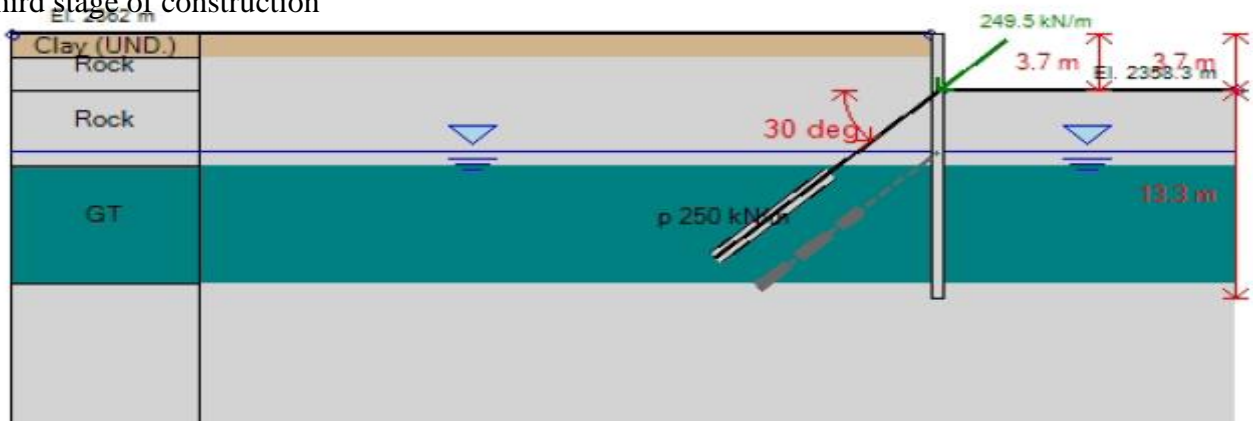


Figure 21 1<sup>st</sup> level anchor installation for 1.5 m spacing and 1<sup>ST</sup> anchor level 3.7m

The fourth stage of a construction progress

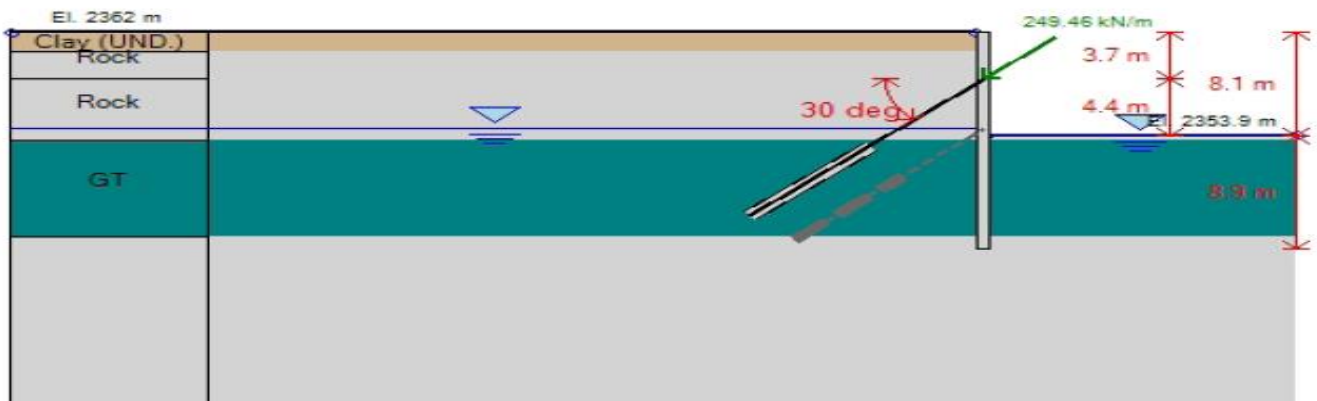


Figure 22 the next 3.9m excavation for 1.5 m spacing and 1<sup>ST</sup> anchor level 3.7m

The fifth stage of a construction progress

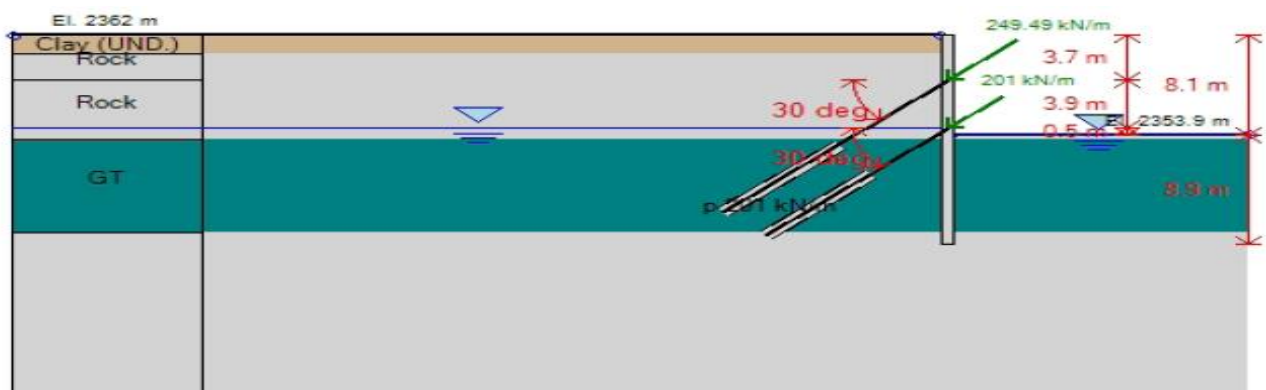


Figure 23 2<sup>nd</sup> level anchor installation for 1.5 m spacing and 1<sup>ST</sup> anchor level 3.7m

Final excavation the remaining 3.9 m at the level 2350.5m a.s.l

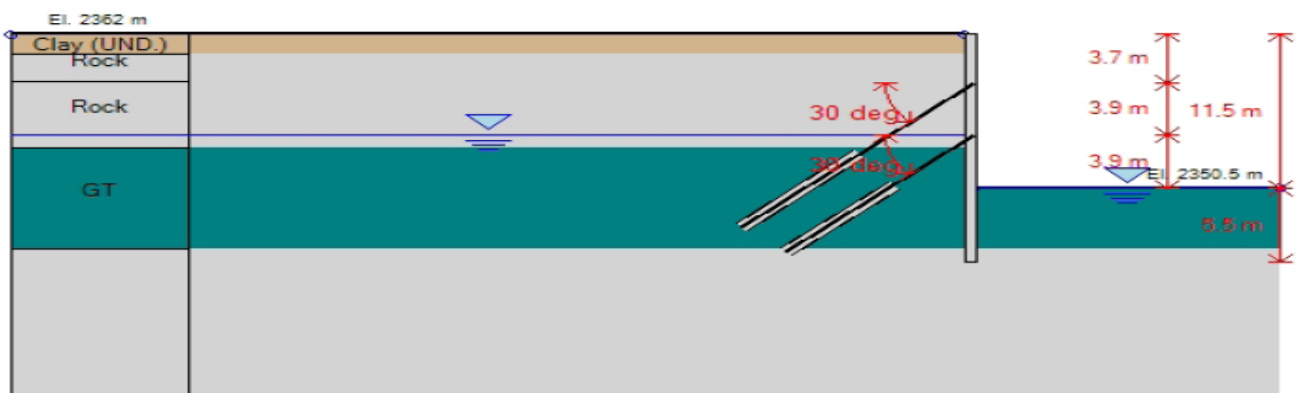


Figure 24 the final 3.9m excavation for 1.5 m spacing and 1<sup>ST</sup> anchor level 3.7m



The fourth stage of a construction progress

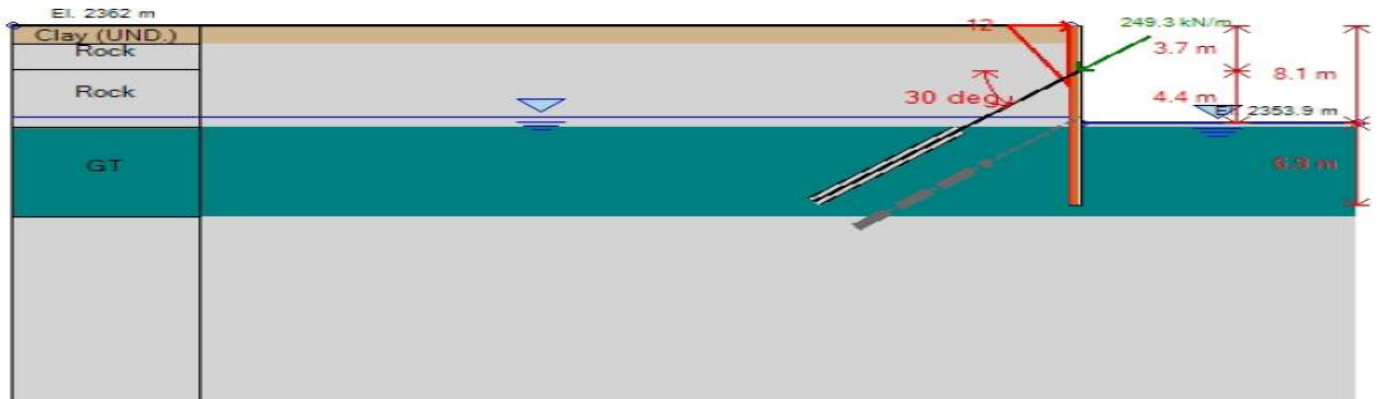


Figure 28 the second stage excavation for 3.7m and 1.5m pile spacing

The fifth stage of a construction progress was assumed excavate up to 8.1m and anchor the 2<sup>nd</sup> strand 195.2KN/m by 30degree at the level of 2353.9m a.s.l

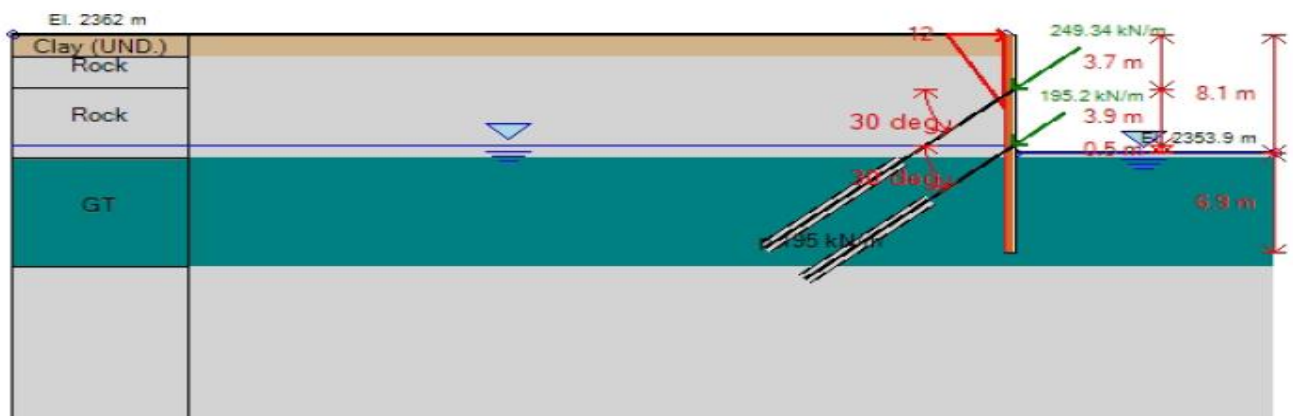


Figure 29 the second anchor installation for 3.7m and 1.5m pile spacing

Final excavation the remaining 3.9 m at the level 2350.5m a.s.l

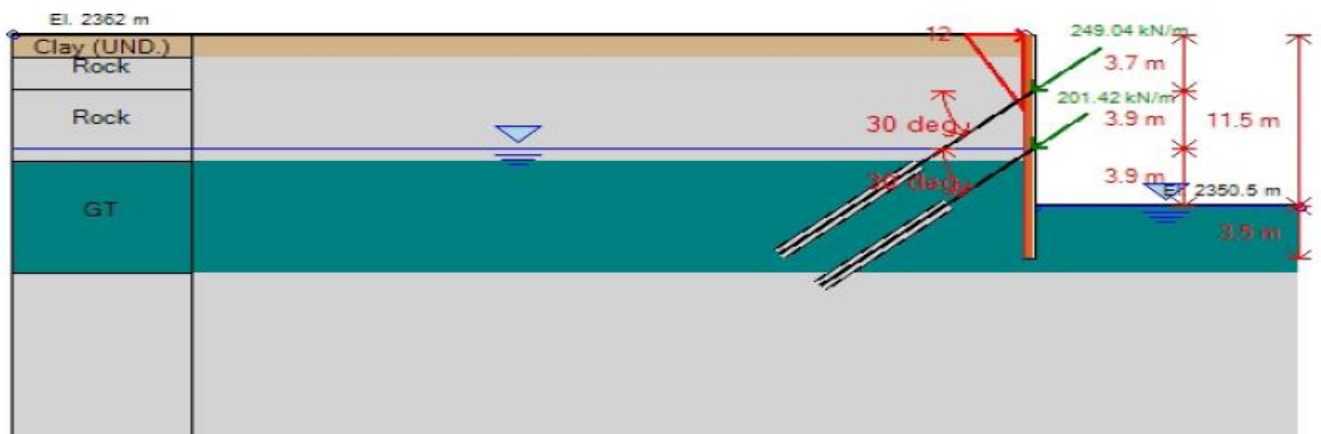


Figure 30 final excavations for 3.7m and 1.5m pile spacing

## **ANNEX II**

Design reinforced concrete pile wall and soldier pile wall with timber lagging

**Design reinforced concrete**

#Trial -1 vertical pile spacing 1.8m and 3.7m first anchor level

Horizontal wall spacing: 1.8, Wall thickness = 0.7m

Depth of embedment = 5.5m

D = 70 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

Z = 2358.3 m, L<sub>free</sub> = 10.5m, L<sub>fix</sub> = 12 m, R<sub>fix</sub> = 50 %

Z = 2354.4 m, L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Table 22: Summary Vs design section for 1.8 m pile spacing and 3.7m first anchor level

Reinforced concrete pile	Wall moment	Wall shear	Wall displace	Max support (reaction KN/m)	Critical sport check	Embedment wall FS	Comment
		187.61	142.5	0.72	249.5	0.939	2.023

Reinforced concrete pile	Calculation result		Wall displacement	Settlement	Wall moment (KN-m/m)	Wall moment (KN-m)
	Calculation successful		0.72	0.43	187.61	337.7
	Wall shear (KN/m)	Wall shear (KN)	STR combined wall ratio	STR moment wall ratio	STR shear wall ratio	Wall concrete SerV stress ratio FIC
	142.5	256.5	0.949	0.949	0.969	N/A

Reinforced concrete pile	Wall reinforcement Stress ratio FS	Max support Reaction (KN/m)	Max support Reaction (KN)	Critical Support check	STR support Ratio	Support Geotech Capacity ratio (P)	Fs Basal
	N/A	249.5	508.73	0.939	0.611	0.939	3.377

Reinforced concrete	Toe FS Passive	Toe Fs Rotation	Toe Fs Length	Z cut (paratie)	Fs mobilized Passive	FS true/active True/active	Hydraulic Heave FS
		10.496	3.433	3.135	N/A	2.026	1.777

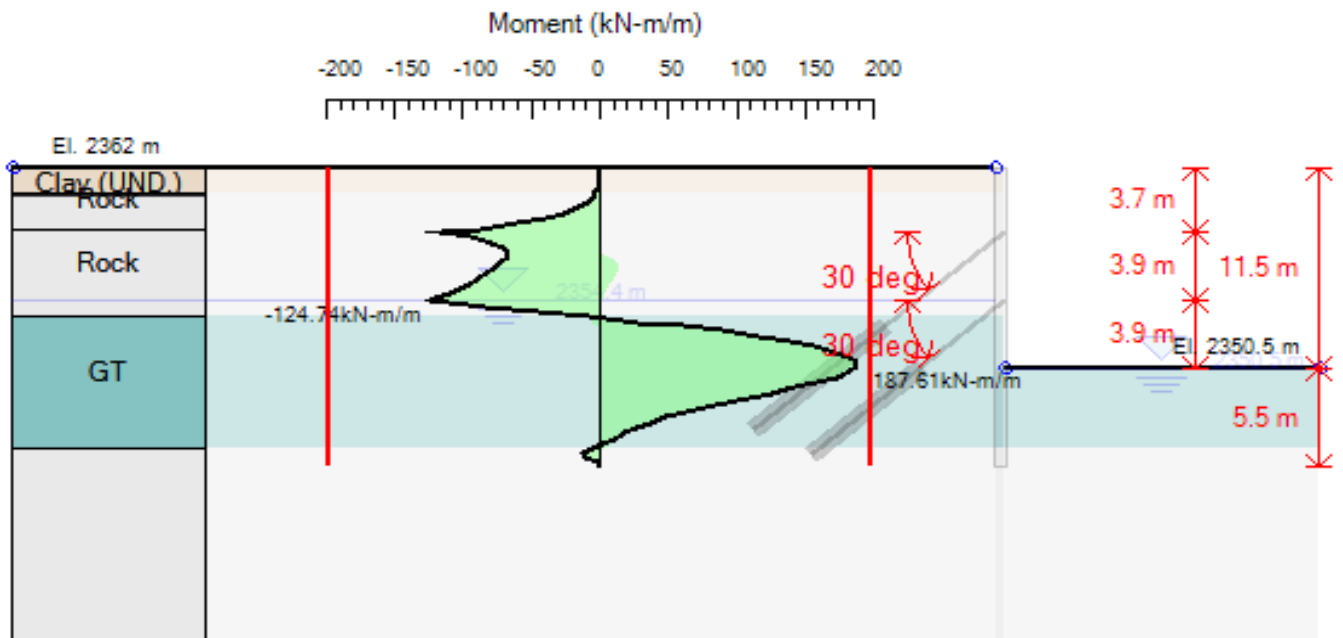


Figure- 31 wall bending moment and moment capacity 1.8m and 3.7m first anchor level

#Trail -2 vertical pile spacing 1.5m and 3.7m first anchor level

Horizontal wall spacing: 1.5, Pile diameter = 0.6m

Depth of embedment =4.5m

Pile Section and dimensions

D = 60 cm, A = 2827.43 cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level support type and length

Z = 2358.3 m, L<sub>free</sub> = 10.5 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Second level support type and length

Z = 2354.4 m, , L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Table 23: Summary Vs design section for 1.5m pile spacing and 3.7m first anchor level

Reinforced concrete pile	Wall moment	Wall shear	Wall displace	Max support (reaction KN/m)	Critical sport check	Embedment wall FS	Comment
		173.5	138.5	0.95	249.5	0.963	1.963
Reinforced concrete	Calculation result			Wall displacement	Settlement	Wall moment (KN-m/m)	Wall moment (KN-m)
	Calculation successful			0.95	0.56	173.5	260.25

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Wall shear (KN/m)	Wall shear(KN)	STR combined wall ratio	STR moment wall ratio	STR shear wall ratio	Wall concrete SerV stress ratio FIC	
	138.5	207.75	0.915	0.915	0.942	N/A	
Reinforced concrete pile	Wall reinforcement Stress ratio FS	Max support Reaction (KN/m)	Max support Reaction (KN)	Critical Support check	STR support Ratio	Support Geotech Capacity ratio (P)	Fs Basal
	N/A	249.5	512.95	0.963	0.616	0.963	3.377

Reinforced concrete pile	Toe FS Passive	Toe Fs Rotation	Toe Fs Length	Z cut (paratie)	Fs mobilized Passive	FS true/active True/active	Hydraulic Heave FS
	10.496	3.432	3.135	N/A	1.974	1.807	1.498

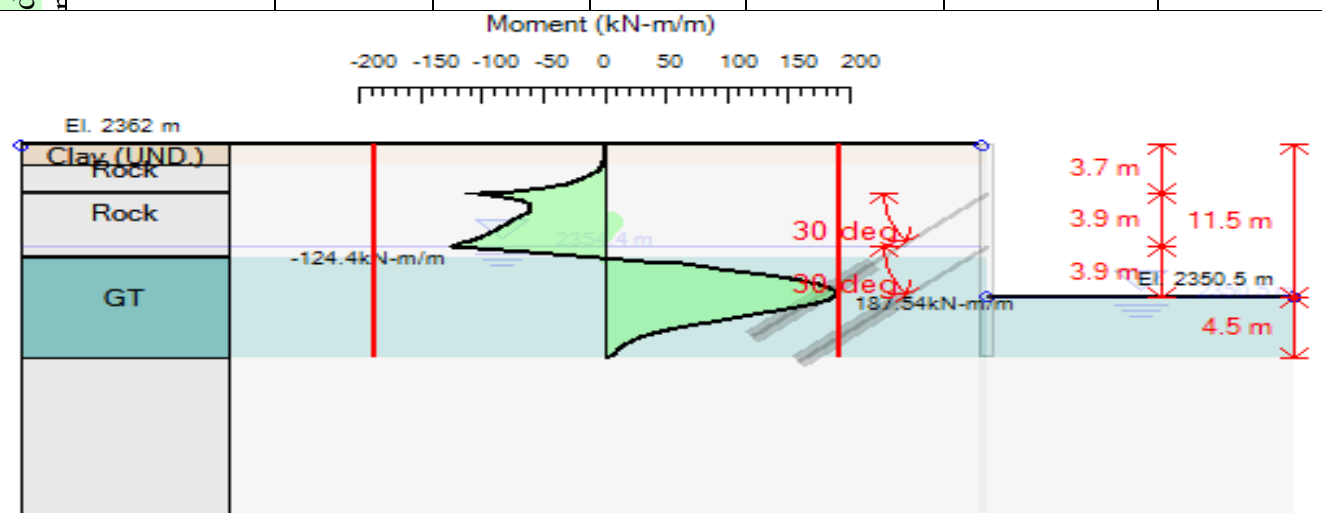


Figure 32 wall bending moment and moment capacity 1.5m and 3.7m first anchor level

#Trial -3 vertical pile spacing 1.2m and 3.7m first anchor level

Horizontal wall spacing: 1.2, Wall thickness = 0.6m

Depth of embedment =4.5m

Pile Section and dimensions

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level support type and length

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Z = 2358.3 m, Lfree = 10 m, Lfix = 11 m, Rfix = 50 %

Second level support type and length

Z = 2354.4 m ,Lfree = 7 m, Lfix = 11 m, Rfix = 50 %

**Table 24: Summary Vs design section for 1.2m pile spacing and 3.7m first anchor level**

Reinforced concrete pile	Wall moment	Wall shear	Wall displace	Max support (reaction KN/m)	Critical sport check	Embedment wall FS	Comment
	180.34	140.49	0.95	249.5	0.963	1.993	Calculation successful

Extended summaries

Reinforced concrete	Calculation result		Wall displacemen t	Settlement	Wall moment (KN-m/m)	Wall moment (KN-m)
		Calculation successful		0.82	0.49	180.34
Reinforced pile	Wall shear (KN/m)	Wall shear(KN)	STR combined wall ratio	STR moment wall ratio	STR shear wall ratio	Wall concrete SerV stress ratio FIC
	149.49	168.59	0.761	0.761	0.765	N/A

Reinforced concrete pile	Wall reinforcement Stress ratio FS	Max support Reaction (KN/m)	Max support Reaction (KN)	Critical Support check	STR support Ratio	Support Geotech Capacity ratio (P)	Fs Basal
	N/A	249.5	510.52	0.963	0.613	0.963	3.377
Reinforced concrete	Toe FS Passive	Toe Fs Rotation	Toe Fs Length	Z cut (paratie)	Fs mobilized Passive	FS true/active True/active	Hydraulic Heave FS
	10.496	3.432	3.135	N/A	1.974	1.792	1.498

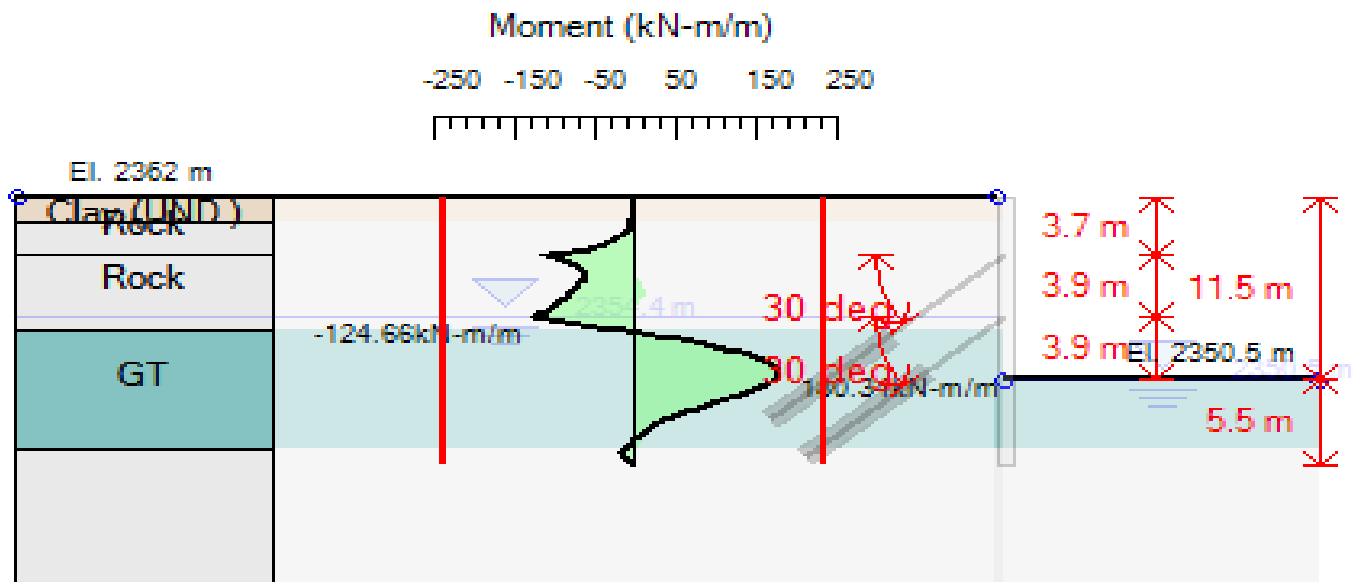


Figure 33: wall bending moment and moment capacity for 1.2m spacing and 3.7m first anchor level

#Trail -4 vertical pile spacing 0.9 m and 3.7m first anchor level

Top of the wall elevation =2362m a.s.l, Ground water elevation = 2354.4m a.s.l

Horizontal wall spacing: 0.9, Wall thickness = 0.6m

Embedment depth =5.5m

Pile Section and dimensions

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

Z = 2358.3 m, L<sub>free</sub> = 8 m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2354.4 m, L<sub>free</sub> = 8 m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Table 25: Summary Vs design section 0.9 m pile spacing and 3.7m first anchor level

Reinforced concrete pile	Wall moment	Wall shear	Wall displace	Max support (reaction KN/m)	Critical sport check	Embedment wall FS	Comment
		168.51	136.56	0.56	249.5	0.856	2.541

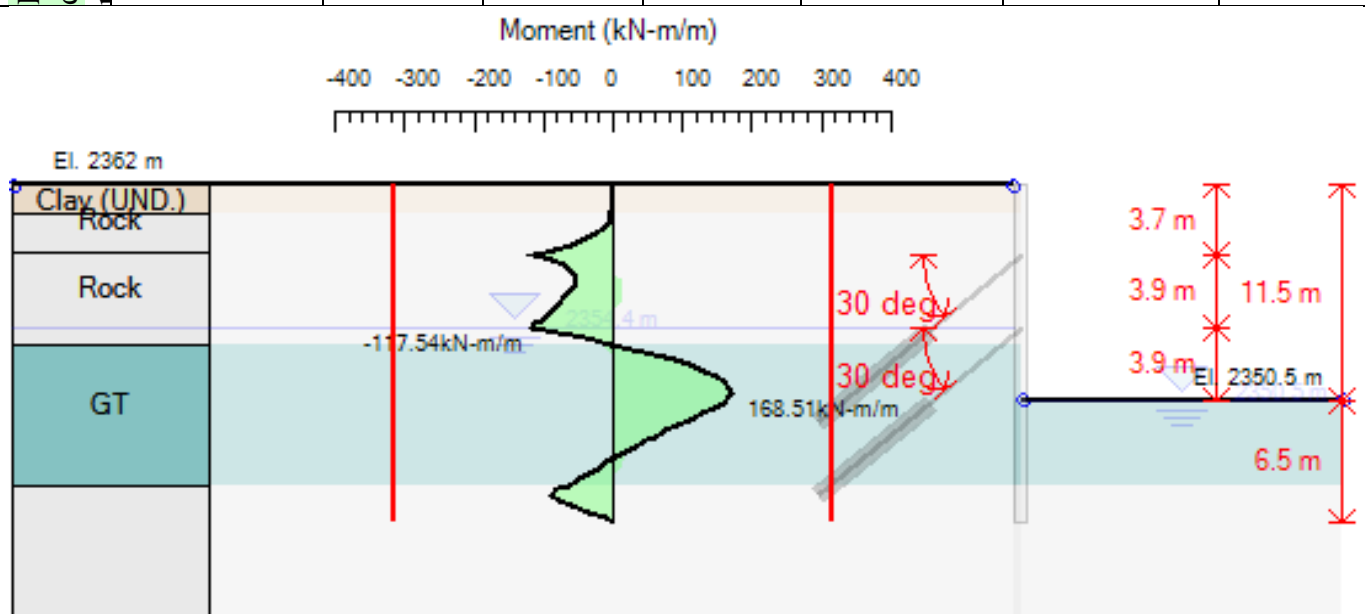
## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

### Extended summary

Reinforced concrete pile	Calculation result		Wall displacement	Settlement	Wall moment (KN-m/m)	Wall moment (KN-m)
	Calculation successful		0.56	0.33	168.51	151.66
	Wall shear (KN/m)	Wall shear(KN)	STR combined	STR moment	STR shear	Wall concrete SerV
			wall ratio	wall ratio	wall ratio	stress ratio FIC
	136.56	122.9	0.533	0.533	0.557	N/A

Reinforced concrete pile	Wall reinforcement Stress ratio FS	Max support Reaction (KN/m)	Max support Reaction (KN)	Critical Support check	STR support Ratio	Support Capacity (P)	Geotech ratio	Fs Basal
	N/A	249.5	504.02	0.856	0.605	0.856		3.334

Reinforced concrete pile	Toe FS Passive	Toe Fs Rotation	Toe Fs Length	Z cut (paratie)	Fs mobilized Passive	FS true/active True/active	Hydraulic Heave FS
	41.395	9.158	8.273	N/A	2.541	1.605	1.59



**Figure 34: wall bending moment and moment capacity for 0.9 m and 3.7m first anchor level**

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

# **Trail 5** vertical pile spacing 0.6 m and 3.7m first anchor level

Define excavation capacity

Horizontal wall spacing: 0.6, Wall thickness = 0.6m

Embedment length =6.5m

Pile Section and dimensions

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>Top</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

Z = 2358.3 m, L<sub>free</sub> = 5 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2354.4 m, L<sub>free</sub> = 6 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Table 26: Summary Vs design section 0.6 m pile spacing and 3.7m first anchor level

Reinforced concrete pile	Wall moment	Wall shear	Wall displace	Max support (reaction KN/m)	Critical sport check	Embedment wall FS	Comment
		209.68	148.67	0.55	249.5	0.93	2.104

Reinforced concrete pile	Calculation result		Wall displacement	Settlement	Wall moment (KN-m/m)	Wall moment (KN-m)
	Calculation successful		0.55	0.34	209.68	125.81
	Wall shear (KN/m)	Wall shear(KN)	STR combined	STR moment	STR shear	Wall concrete SerV
			wall ratio	wall ratio	wall ratio	stress ratio FIC
	148.67	89.2	0.442	0.442	0.405	N/A

Reinforced concrete pile	Wall reinforcement Stress ratio FS	Max support Reaction (KN/m)	Max support Reaction (KN)	Critical Support check	STR support Ratio	Support Geotech Capacity ratio (P)	Fs Basal
	N/A	249.5	506.1	0.93	0.608	0.93	3.377
Reinforced concrete pile	Toe FS Passive	Toe Fs Rotation	Toe Fs Length	Z cut (paratie)	Fs mobilized Passive	FS true/active True/active	Hydraulic Heave FS
	10.496	3.432	3.135	N/A	2.104	1.736	1.498

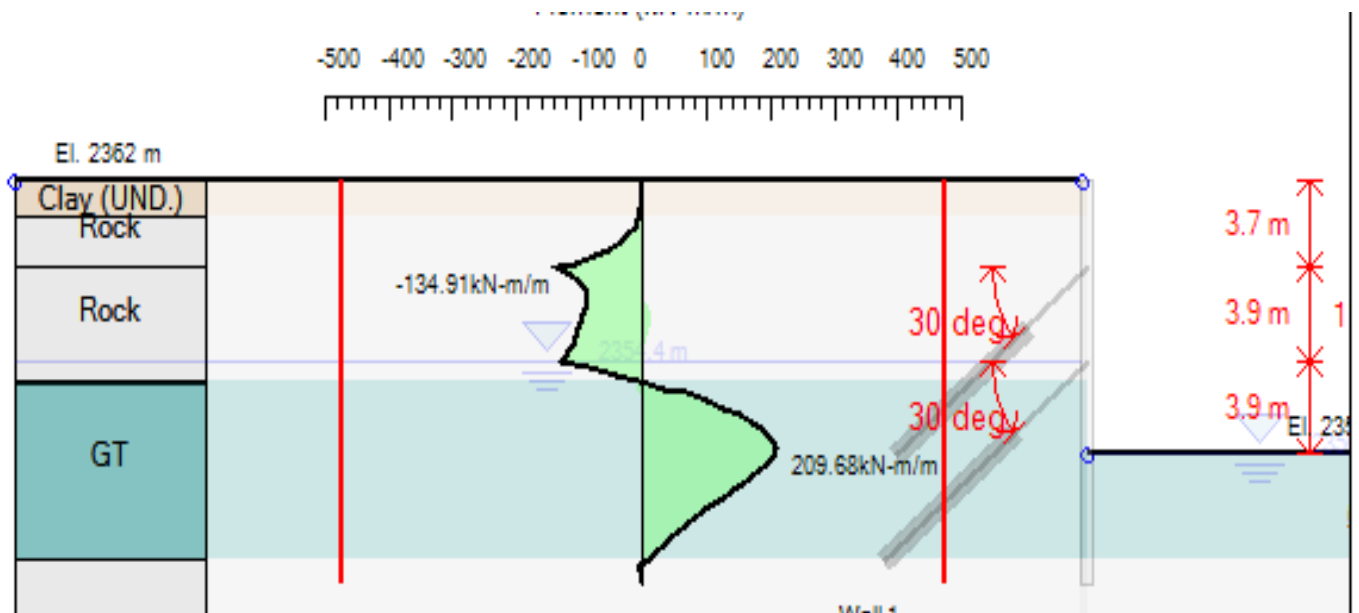


Figure 35: wall bending moment and moment capacity for 0.6 m and 3.7m first anchor level

#Trail -6 vertical pile spacing 1.8 m and 3.5m first anchor level

Horizontal wall spacing: 1.8m .Wall thickness = 0.6m

Embedment length =6.5m

Pile Section and dimensions

$D = 70 \text{ cm}$ ,  $A = 3848.45 \text{ cm}^2$ ,  $I_{xx} = 1178588.11 \text{ cm}^4$

Bar #D10 Longitudinal reinforcement

Top reinforcement:  $N = 14 \text{ bars } \#D24 = A_{sTop} 63.34 \text{ cm}^2$ ,  $C_{top} = 7.62 \text{ cm}$

Shear reinforcements =  $A_s 0.785 \text{ cm}^2$ ,  $sV = 20 \text{ cm}$

First level Support type and length

$Z = 2358.5 \text{ m}$ ,  $L_{free} = 10.5 \text{ m}$ ,  $L_{fix} = 12 \text{ m}$ ,  $R_{fix} = 50 \%$

Second level Support type and length

$Z = 2355 \text{ m}$ ,  $S = 2.35 \text{ m}$ ,  $L_{free} = 7.4 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$

Table 27: Summary Vs design section 0.6 m pile spacing and 3.7m first anchor level

reinforced concrete pile	Wall Moment	Wall Shear	Wall Displacement	Max Support	Critical Support	Embedment Comments	Comments
	207.71	143.54	0.84	232.1	0.931	2.143	Calculation successful

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
reinforced concrete pile	Calculation successful	0.84	0.53	207.71	373.88

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
reinforced concrete pile	143.54	258.37	0.895	0.895	0.973	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
reinforced	N/A	232.1	506.71	0.931	0.608	0.931	3.334

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
reinforced	10.375	3.737	3.37	N/A	2.143	1.757	1.592

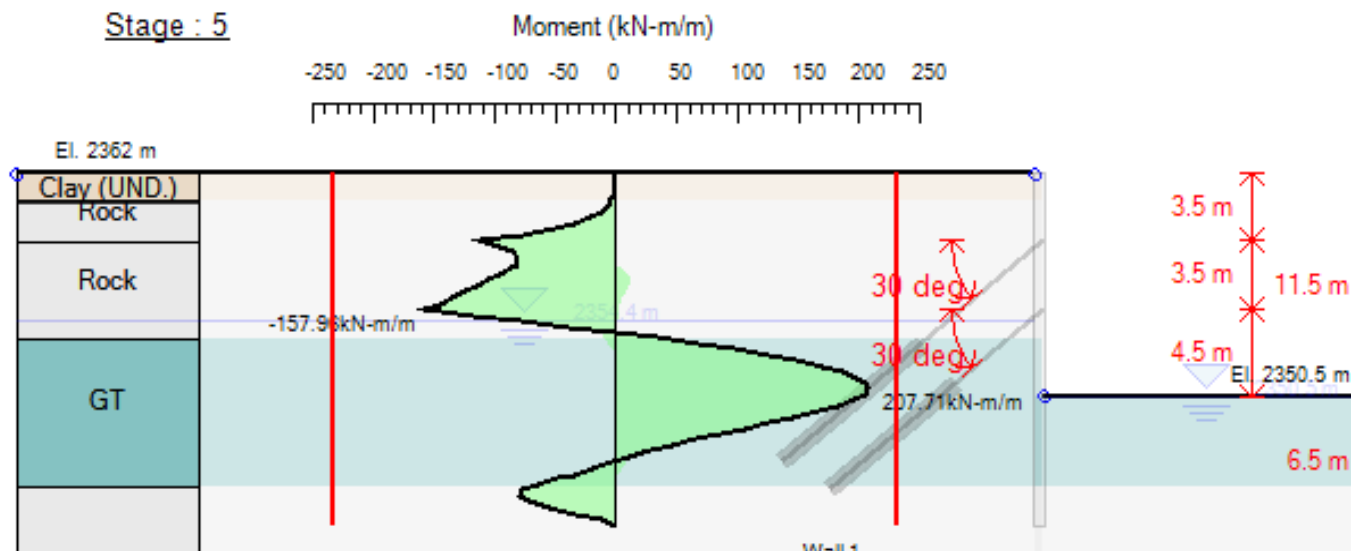


Figure 36: wall bending moment and moment capacity for 1.8 m and 3.5m first anchor level

#Trail 7 vertical pile spacing **1.5 m** and 3.5m first anchor level

Horizontal wall spacing: 1.5m .Wall thickness = 0.6m

Embedment length =4.8m

Pile Section and dimensions

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Z = 2358.3 m, L<sub>free</sub> = 11 m, L<sub>fix</sub> = 12 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2354.4 m, L<sub>free</sub> = 7.9 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Table 28: Summary Vs design section for 1.5 m pile spacing and 3.5m first anchor level

Reinforced concrete pile	Wall moment	Wall shear	Wall displace	Max support (reaction KN/m)	Critical sport check	Embedment wall FS	Comment
	208.8	142.41	1.25	249.5	0.882	1.79	Calculation successful

Reinforced concrete pile	Wall reinforcement Stress ratio FS	Max support Reaction (KN/m)	Max support Reaction (KN)	Critical Support check	STR support Ratio	Support Geotech Capacity ratio (P)	Fs Basal
	N/A	249.5	514.42	0.882	0.618	0.882	3.341
Reinforced concrete pile	Toe FS Passive	Toe Fs Rotation	Toe Fs Length	Z cut (paratie)	Fs mobilized Passive	FS true/active True/active	Hydraulic Heave FS
	8.233	2.927	2.474	N/A	1.79	1.834	1.353

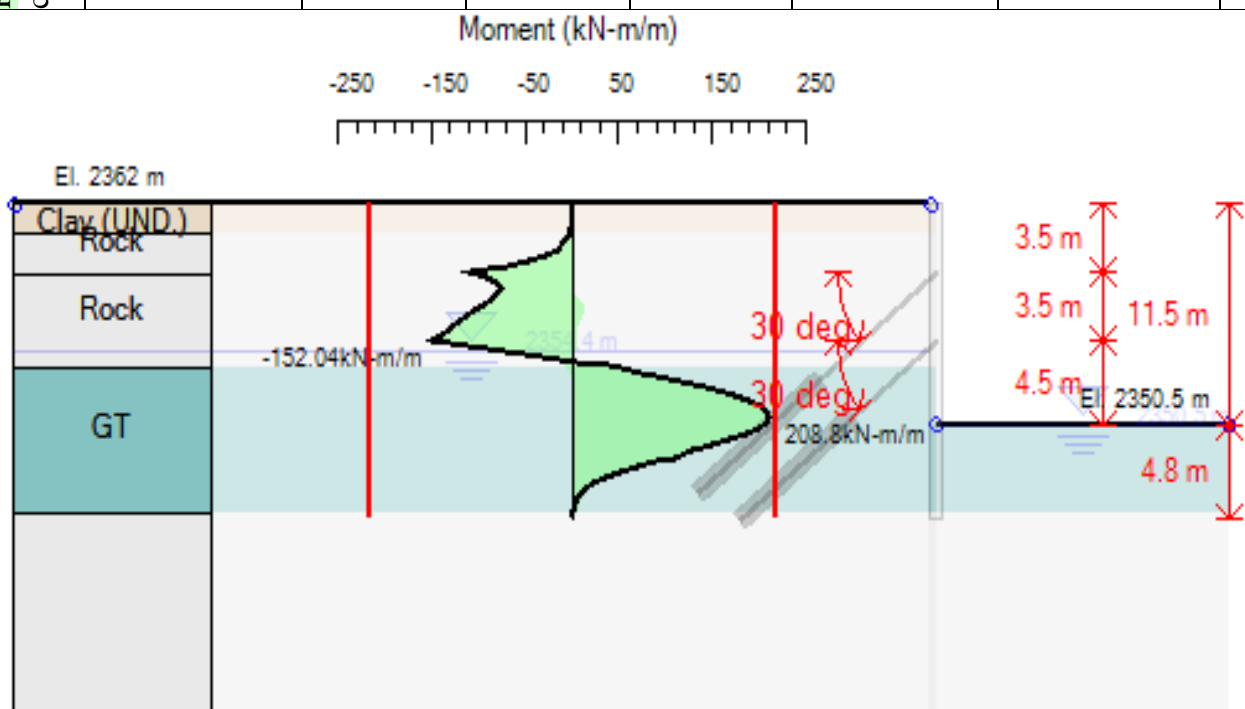


Figure 37: wall bending moment and moment capacity for 1.5 m and 3.5m first anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

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#Trail 8 m vertical pile spacing 1.2 and 3.5m first anchor level

Horizontal wall spacing: 1.2m, Wall thickness = 0.6m

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

Embedment length=5.5m

First level Support type and length

Z = 2358.3 m, L<sub>free</sub> = 8 m, L<sub>fix</sub> = 10m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2354.4 m, L<sub>free</sub> = 9 m, L<sub>fix</sub> = 9 m, R<sub>fix</sub> = 50 %

Table 29: analysis and checking summary for 1.2 m pile spacing and 3.5m first anchor level

### Summary vs Design Section

reinforced concrete	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
reinforced concrete	210.15	151.55	1.07	298.8	0.693	1.895	Calculation

### Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
reinforced concrete pile	Calculation successful		1.07	0.69	210.15	252.18

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
reinforced	N/A	298.8	520.92	0.693	0.625	0.693	3.377

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
reinforced	13.143	3.369	3.135	N/A	1.895	1.74	1.498

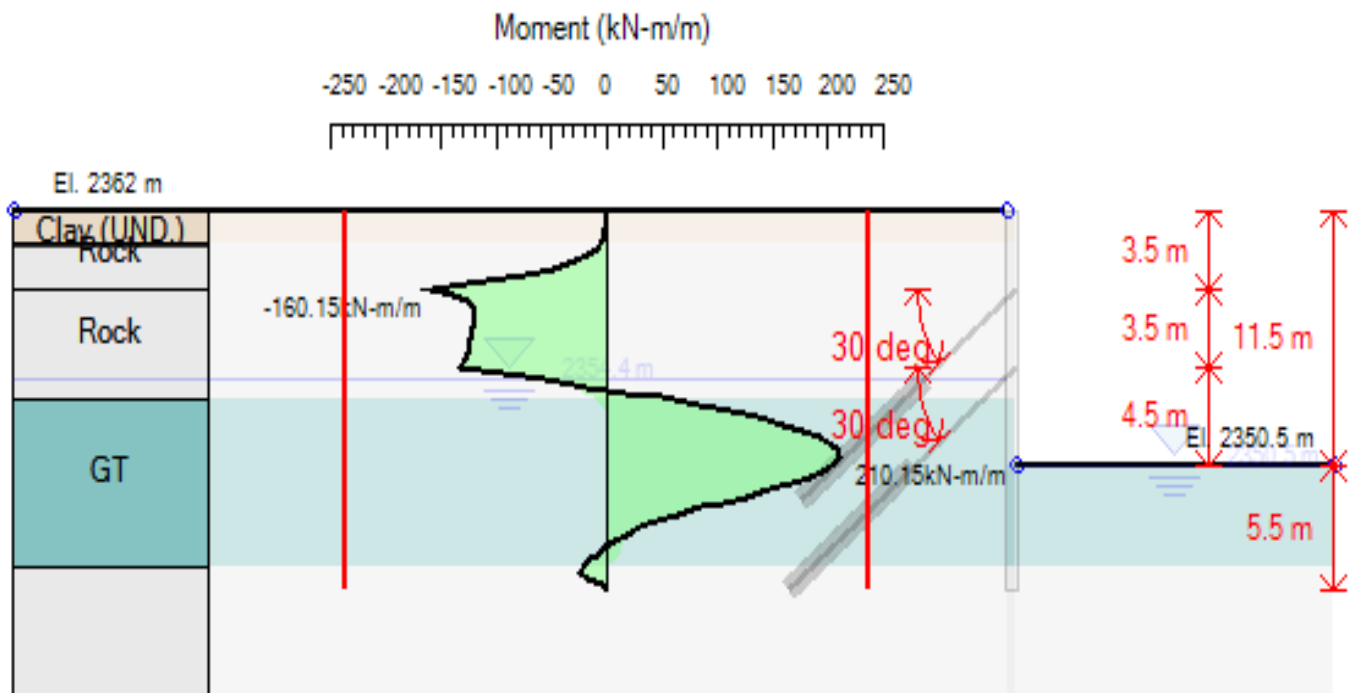


Figure 38: wall bending moment and moment capacity for 1.2 and 3.5m first anchor level

#Trail -9 vertical pile spacing 0.9 m and 3.5m first anchor level

Horizontal wall spacing: 0.9m, Wall thickness = 0.6m

$D = 60 \text{ cm}$ ,  $A = 2827.43 \text{ cm}^2$ ,  $I_{xx} = 636172.51 \text{ cm}^4$

Bar #D10 Longitudinal reinforcement

Top reinforcement:  $N = 14 \text{ bars } \#D24 = A_{sTop} 63.34 \text{ cm}^2$ ,  $C_{top} = 7.62 \text{ cm}$

Shear reinforcements =  $A_s 0.785 \text{ cm}^2$ ,  $s_V = 20 \text{ cm}$

Embedment length = 6.5m

First level Support type and length

$Z = 2358.3 \text{ m}$ ,  $L_{free} = 10 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$

Second level Support type and length

$Z = 2354.4 \text{ m}$ ,  $L_{free} = 9 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$

Table 30: analysis and checking summary for 0.9 m pile spacing and 3.5m first anchor level

### Summary vs Design Section

Reinforced	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced	183.72	132.85	0.64	249.5	0.917	2.476	Calculation

### Extended Summary

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Reinforced concrete pile	Calculation successful	0.64	0.39	183.72	165.35

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Reinforced concrete pile	132.85	119.56	0.582	0.582	0.542	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Reinforced concrete pile	N/A	249.5	499.73	0.917	0.6	0.917	3.334

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced concrete pile	25.872	8.901	6.067	N/A	2.476	1.626	1.59

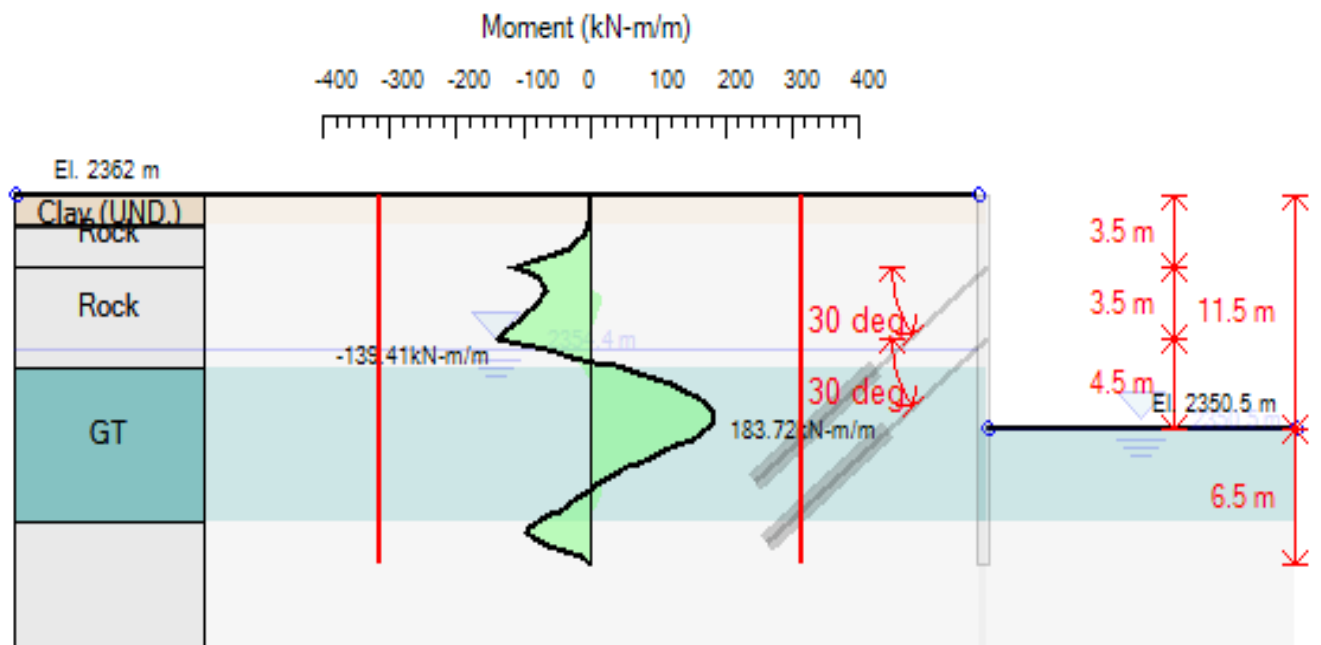


Figure 39: wall bending moment and moment capacity for 0.9 m and 3.5m first anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

#Trail- 10 vertical pile spacing 0.6 m and 3.5m first anchor level

Horizontal wall spacing: 0.6m, Wall thickness = 0.6m

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

Embedment length =5.5m

First level Support type and length

Z = 2358.3 m, L<sub>free</sub> = 10.5 m, L<sub>fix</sub> = 11m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2354.4 m, L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Table 31: analysis and checking summary for 0.6 m pile spacing and 3.5m first anchor level

### Summary vs Design Section

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displaceme	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced concrete pile	227.61	148.66	0.62	235.4	0.963	2.035	Calculation successful

### Extended Summary

	Calcaiaon Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Reinforced concrete pile	Calculation successful	0.62	0.39	227.61	136.57

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Reinforced concrete pile	N/A	235.4	503.09	0.963	0.604	0.963	3.377

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced concrete pile	10.522	3.343	3.135	N/A	2.035	1.754	1.498

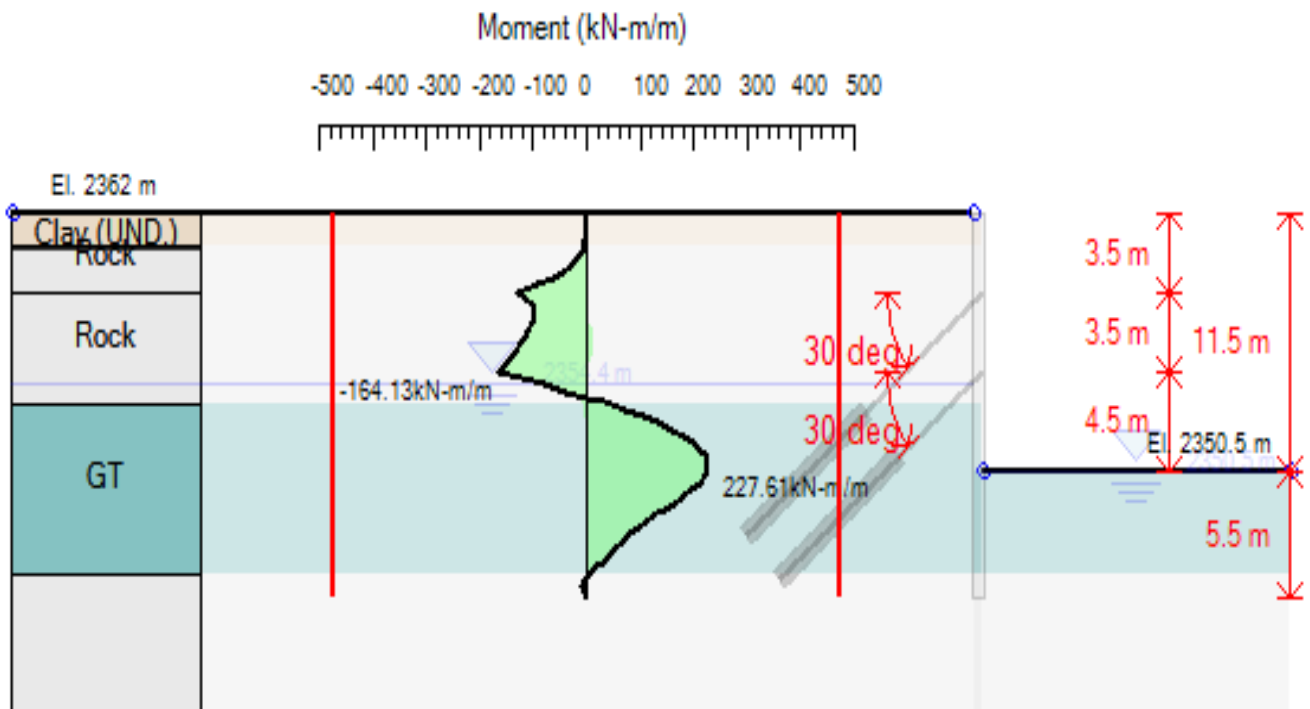


Figure 40: wall bending moment and moment capacity for 0.6 m and 3.5m first anchor level

**#Trail 11 vertical pile spacing 1.8 m and 4.5 m first anchor level**

Horizontal wall spacing: 1.8 m, Wall thickness = 0.7m

Select the support type and define properties

Embedment length = 6.5m

Pile Section and dimensions

$D = 60 \text{ cm}$ ,  $A = 2827.43 \text{ cm}^2$ ,  $I_{xx} = 636172.51 \text{ cm}^4$

Bar #D10 Longitudinal reinforcement

Top reinforcement:  $N = 14 \text{ bars \#D24} = A_{sTop} 63.34 \text{ cm}^2$ ,  $C_{top} = 7.62 \text{ cm}$

Shear reinforcements =  $A_s 0.785 \text{ cm}^2$ ,  $s_V = 20 \text{ cm}$

First level Support type and length

$Z = 2357.5 \text{ m}$ ,  $L_{free} = 10.5 \text{ m}$ ,  $L_{fix} = 12 \text{ m}$ ,  $R_{fix} = 50 \%$

Second level Support type and length,

$Z = 2353.5 \text{ m}$ ,  $L_{free} = 7.4 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$

Table 32: analysis and checking summary for 1.8 m pile spacing and 4.5 m first anchor level

Summary vs Design Section

Reinforced concrete pile	Wall Moment (kN-m/m)	Wall Shear (kN/m)	Displacement (cm)	Max Support Reaction	Critical Support Check	Embedment Wall FS	Comments
Reinforced	161.34	137.7	0.59	262.6	0.882	2.021	Calculation

Extended Summary

	Calculation Result		Wall (cm)	Settlement (cm)	Wall Moment (kN-m/m)	Wall Moment (kN-m)
Reinforced concrete pile	Calculation successful		0.59	0.34	161.34	290.41

	Wall Shear (kN/m)	Wall Shear (kN)	STR Combined Wall Ratio	STR Moment Wall Ratio	STR Shear Wall Ratio	Wall Concrete Stress Ratio FIC
Reinforced concrete pile	137.7	247.86	0.816	0.816	0.936	N/A

	Max Support Reaction	Max Support Reaction (kN)	Critical Support Check	STR Support Ratio	Support Geotech Capacity Ratio	FS Basal
Reinforced concrete pile	N/A	262.6	0.882	0.609	0.882	3.377

	Toe FS Passive	Toe FS Rotation	Toe FS Length	Zcut (Paratie)	FS Mobilized Passive	FS True/Active	Hydraulic Heave FS
Reinforced concrete pile	15.294	3.501	3.135	N/A	2.021	1.792	1.5

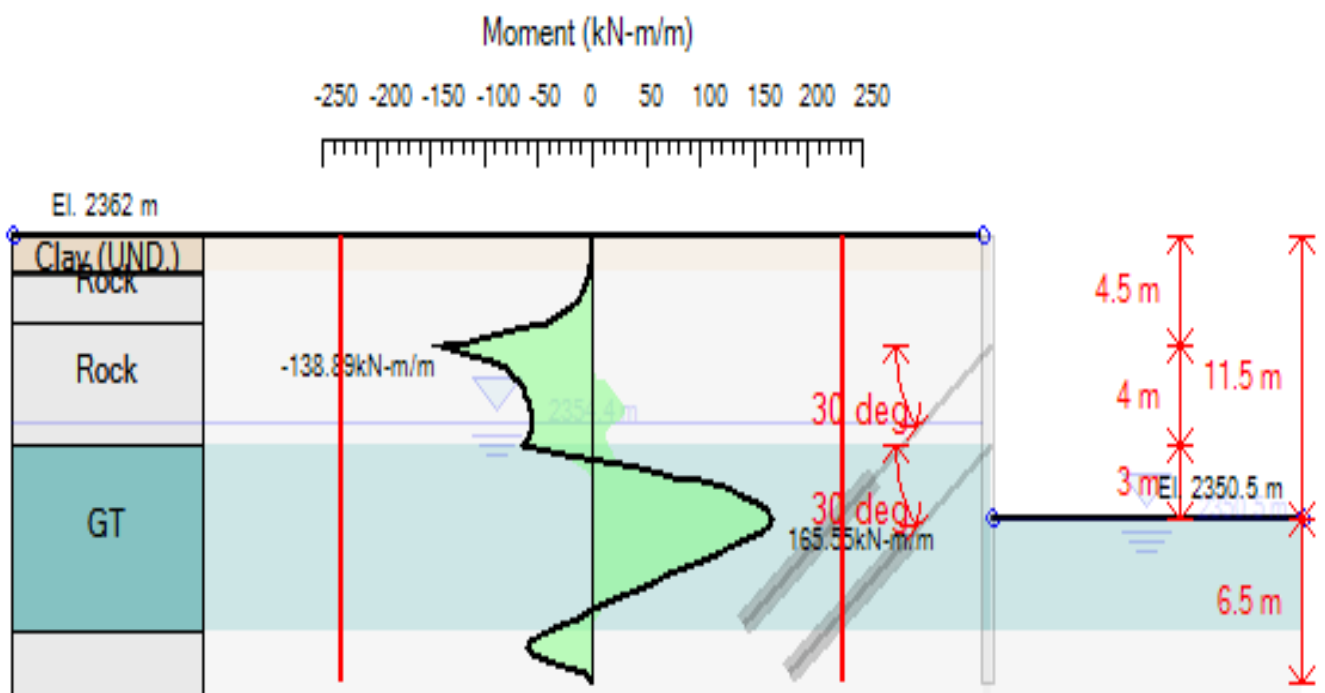


Figure 41: wall bending moment and moment capacity for 1.8 m and 4.5 m first anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

#Trail 12 vertical pile spacing 1.5 m and 4.5 m first anchor level

Horizontal wall spacing: 1.5 m, Wall thickness = 0.6m

Embedment length =4.5m

Section dimensions

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

Z = 2357.5m, L<sub>free</sub> = 10.5m, L<sub>fix</sub> = 11 m

Second level Support type and length

Z = 2353.5m, L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 10 m

Table 33: analysis and checking summary for 1.5 m pile spacing and 4.5 m first anchor level

### Summary vs Design Section

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displacement	Max Support Reaction	Critical Support Check	Embedment Wall FS	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced concrete pile	145.41	137.44	0.7	249.5	0.963	1.794	Calculation successful

### Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment	
			(cm)	(cm)	(kN-m/m)	(kN-m)	
Reinforced concrete pile	Calculation successful		0.7	0.4	145.41	218.12	
	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete	
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC	
Reinforced concrete pile	137.44	206.16	0.703	0.703	0.881	N/A	
	Wall Reinforcement	Max Support	Max Support	Critical	STR Support	Support Geotech	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Reinforced concrete pile	N/A	249.5	513.04	0.963	0.616	0.963	3.34
	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced concrete pile	10.306	3.05	2.739	N/A	1.794	1.776	1.598

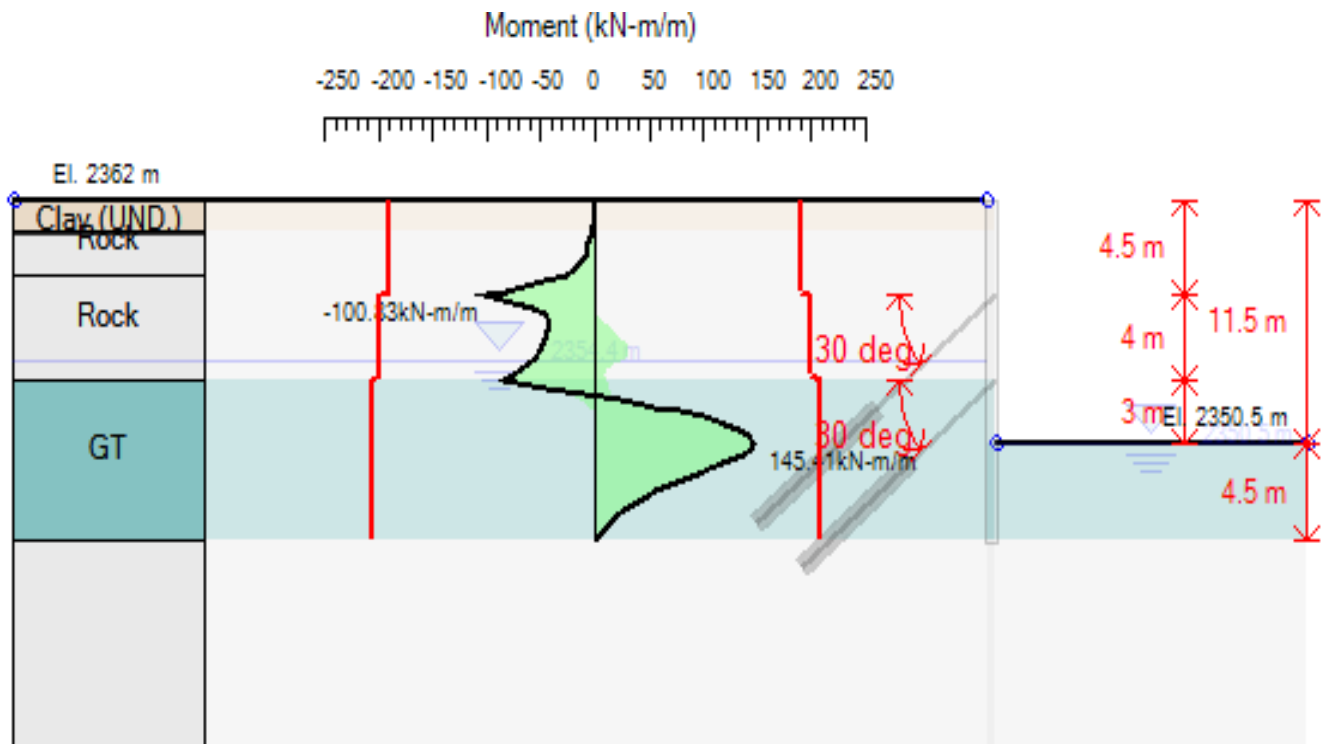


Figure 42: wall bending moment and moment capacity for 1.5 m and 4.5 m first anchor level

#trail 13 Vertical pile spacing 1.2 m and 4.5 m first anchor level

Horizontal wall spacing: 1.2 m, Wall thickness = 0.6m

Embedment length=4.5m

$D = 60 \text{ cm}$ ,  $A = 2827.43 \text{ cm}^2$ ,  $I_{xx} = 636172.51 \text{ cm}^4$

Bar #D10 Longitudinal reinforcement

Top reinforcement:  $N = 14 \text{ bars } \#D24 = A_{sTop} 63.34 \text{ cm}^2$ ,  $C_{top} = 7.62 \text{ cm}$

Shear reinforcements =  $A_s 0.785 \text{ cm}^2$ ,  $sV = 20 \text{ cm}$

First level Support type and length

$Z = 2357.5 \text{ m}$ ,  $L_{free} = 8.0 \text{ m}$ ,  $L_{fix} = 10 \text{ m}$ ,  $R_{fix} = 50 \%$

Second level Support type and length

$Z = 2353.5 \text{ m}$ ,  $L_{free} = 8.0 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Table 34 analysis and checking summary for 1.2 m pile spacing and 4.5 m first anchor level

### Summary vs Design Section

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displaceme	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced concrete pile	166.98	151.25	0.81	298.8	0.996	1.787	Calculation successful

### Extended Summary

	Calcaiaon Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Reinforced concrete pile	Calculation successful	0.81	0.75	166.98	200.38

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Reinforced concrete pile	151.25	181.5	0.706	0.706	0.823	N/A

	Wall Reinforcement	Max Support	Max Support	Critical	STR Support	Support Geotech	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Reinforced concrete pile	N/A	298.8	525.03	0.996	0.63	0.996	3.34

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced	10.306	3.077	2.739	N/A	1.787	1.59	1.598

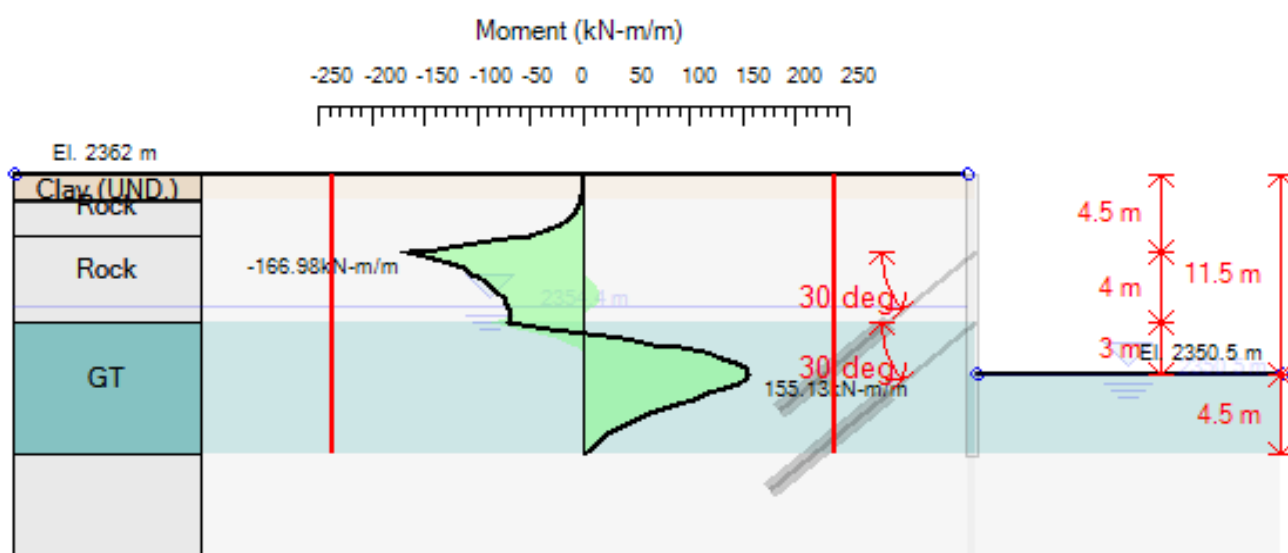


Figure 43: wall bending moment and moment capacity 1.2 m and 4.5 m first anchor level

**#Trail 14** Vertical pile spacing 0.9 m and 4.5 m first anchor level

Horizontal wall spacing: 0.9 m, Wall thickness = 0.6m

Embedment length =6.5m

Pile Section and dimensions

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

Z = 2357.5m, L<sub>free</sub> = 8.0m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2353.5m, L<sub>free</sub> = 8.0 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Table 35: analysis and checking summary for 0.9 m pile spacing and 4.5 m first anchor level

Summary vs Design Section

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displacement	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced concrete pile	150.83	131.48	0.48	283.5	0.963	2.632	Calculation successful

Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
Reinforced concrete pile	Calculation successful		0.48	0.28	150.83	135.75

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Reinforced concrete pile	131.48	118.33	0.477	0.477	0.537	N/A

	Wall Reinforcement	Max Support	Max Support	Critical	STR Support	Support Geotech	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Reinforced concrete pile	N/A	283.5	503.17	0.963	0.604	0.963	3.334

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced concrete pile	25.917	9.619	8.273	N/A	2.632	1.595	1.59

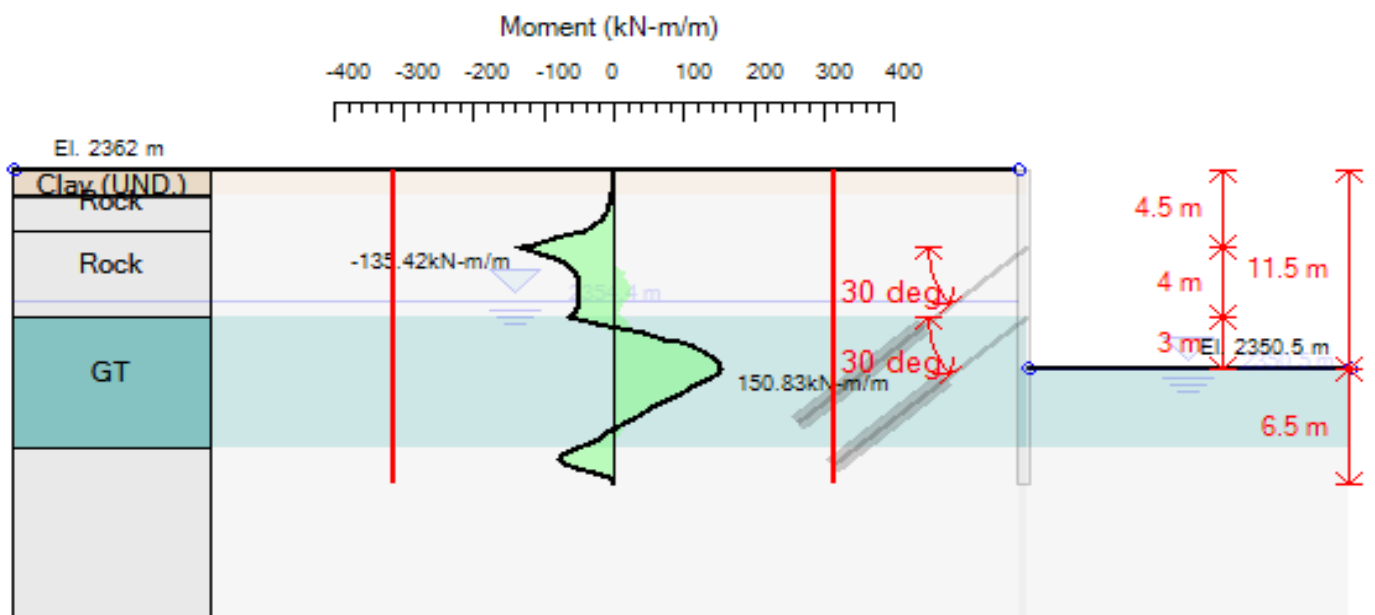


Figure 44: wall bending moment and moment capacity for 0.6 m and 4.5 m first anchor level

**#Trail 15 vertical pile spacing 0.6 m and 4.5 m first anchor level**

Horizontal wall spacing: 0.6 m, Wall thickness = 0.6m

Embedment length = 6.5

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

X = 0.6 m, Z = 2357.5m, L<sub>free</sub> = 8.0m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2353.5m, L<sub>free</sub> = 8.0 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Table 36: analysis and checking summary for 0.6 m pile spacing and 4.5 m first anchor level

**Extended Summary**

	Calcuaiion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.49	0.3	190.42	114.25

**Summary vs Design Section**

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displaceme	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced concrete pile	190.42	145.19	0.49	285.12	0.963	2.384	Calculation successful

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	145.19	87.11	0.402	0.402	0.395	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	285.12	507.85	0.963	0.61	0.963	3.334

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	10.388	3.973	3.957	N/A	2.384	1.704	1.59

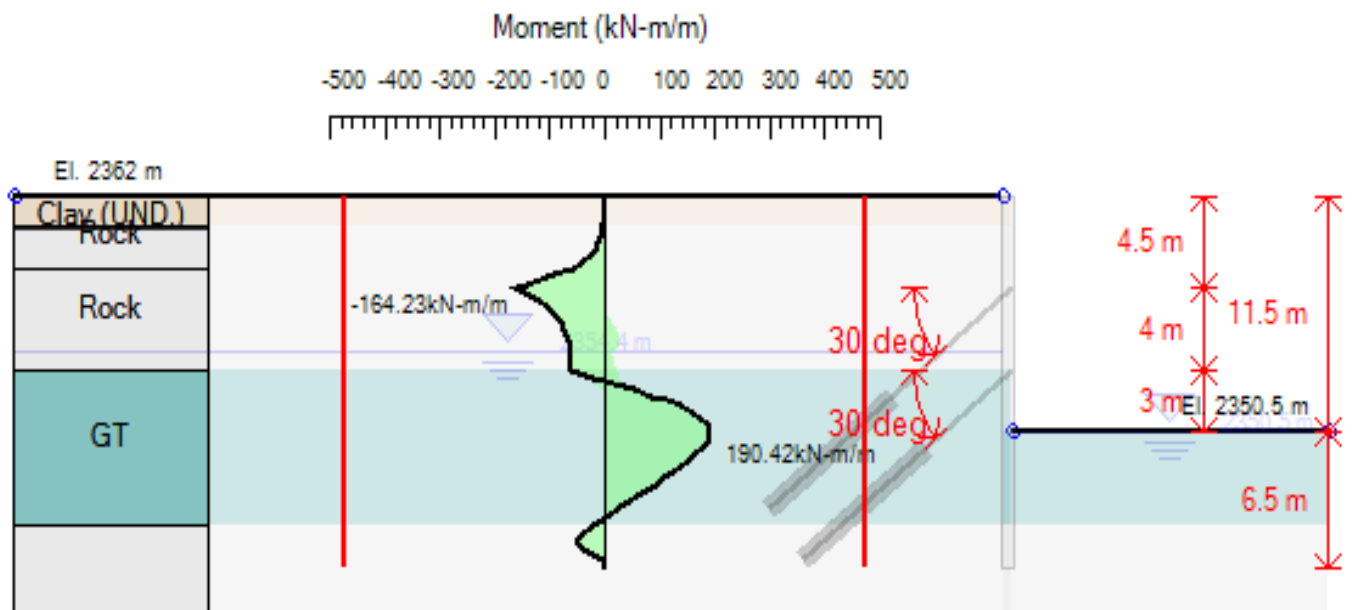


Figure 45: wall bending moment and moment capacity for 0.6 m and 4.5 m first anchor level

#Trail -16 Vertical pile spacing 1.8 m and 5.0 m first anchor level

Horizontal wall spacing: 1.8 m, Wall thickness = 0.7m

Embedment length =5.5m

$D = 70 \text{ cm}$ ,  $A = 2827.43 \text{ cm}^2$ ,  $I_{xx} = 636172.51 \text{ cm}^4$

Bar #D10 Longitudinal reinforcement

Top reinforcement:  $N = 14 \text{ bars } \#D24 = A_{sTop} 63.34 \text{ cm}^2$ ,  $C_{top} = 7.62 \text{ cm}$

Shear reinforcements =  $A_s 0.785 \text{ cm}^2$ ,  $s_v = 20 \text{ cm}$

First level Support type and length

$Z = 2357.0 \text{ m}$ ,  $L_{free} = 10.5 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$

Second level Support type and length

$Z = 2353 \text{ m}$ ,  $L_{free} = 7.4 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$



Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

**#Trail 17 Vertical pile spacing 1.5 m and 5.0 m first anchor level**

Horizontal wall spacing: 1.5 m, Wall thickness = 0.6m

Embedment length=4.5m

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

Z = 2357.0m, L<sub>free</sub> = 10.5m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2353m, L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Table 38 analysis and checking summary for 1.5 m pile spacing and 5.0 m first anchor level

Summary vs Design Section							
Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displacement	Max Support Reaction	Critical Support Check	Embedment Wall FS	Comments
	(kN-m/m)	(kN/m)	(cm)				
Reinforced concrete pile	153.34	137.64	0.79	249.5	0.963	1.736	Calculation successful

Extended Summary					
	Calculation Result	Wall (cm)	Settlement (cm)	Wall Moment (kN-m/m)	Wall Moment (kN-m)
Reinforced concrete pile	Calculation successful	0.79	0.45	153.34	230.01

	Wall Shear (kN/m)	Wall Shear (kN)	STR Combined Wall Ratio	STR Moment Wall Ratio	STR Shear Wall Ratio	Wall Concrete Stress Ratio FIC
Reinforced concrete pile	137.64	206.46	0.809	0.809	0.936	N/A

	Wall Reinforcement Service	Max Support Reaction	Max Support Reaction (kN)	Critical Support Check	STR Support Ratio	Support Geotech Capacity Ratio	FS Basal
Reinforced concrete pile	N/A	249.5	512.14	0.963	0.615	0.963	3.34

	Toe FS Passive	Toe FS Rotation	Toe FS Length	Zcut (Paratie)	FS Mobilized Passive	FS True/Active	Hydraulic Heave FS
Reinforced concrete pile	9.853	2.958	2.739	N/A	1.736	1.827	1.598

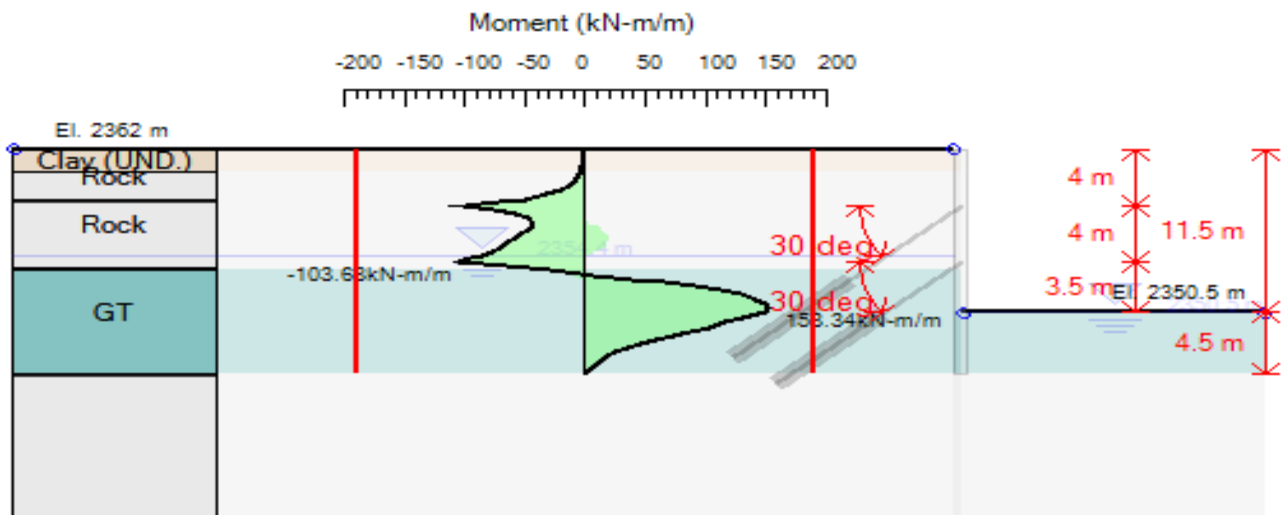


Figure 47: wall bending moment and moment capacity for 1.5 m and 5.0 m first anchor level

**#Trail 18 vertical pile spacing 1.2 m and 5.0 m first anchor level**

Horizontal wall spacing: 1.2 m, Wall thickness = 0.6m

Embedment length = 4.5m

$D = 60 \text{ cm}$ ,  $A = 2827.43 \text{ cm}^2$ ,  $I_{xx} = 636172.51 \text{ cm}^4$

Bar #D10 Longitudinal reinforcement

Top reinforcement:  $N = 14 \text{ bars } \#D24 = A_{sTop} 63.34 \text{ cm}^2$ ,  $C_{top} = 7.62 \text{ cm}$

Shear reinforcements =  $A_s 0.785 \text{ cm}^2$ ,  $sV = 20 \text{ cm}$

First level Support type and length

$Z = 2357.0 \text{ m}$ ,  $L_{free} = 10.5 \text{ m}$ ,  $L_{fix} = 11 \text{ m}$ ,  $R_{fix} = 50 \%$

Second level Support type and length

$Z = 2353 \text{ m}$ ,  $L_{free} = 7.4 \text{ m}$ ,  $L_{fix} = 10 \text{ m}$ ,  $R_{fix} = 50 \%$

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Table 39: analysis and checking summary for 1.2 m pile spacing and 5.0 m first anchor level

### Summary vs Design Section

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displaceme	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced	168.29	153.11	1.06	298.8	0.996	1.832	Calculation

### Extended Summary

	Calculaion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Reinforced concrete pile	Calculation successful	1.06	0.77	168.29	201.95

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Reinforced concrete pile	153.11	183.73	0.711	0.711	0.833	N/A

	wall Reinforcement	Max Support	Max Support	Critical	STR Support	Support Geotech	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Reinforced concrete pile	N/A	298.8	525.81	0.996	0.631	0.996	3.34

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced	10.331	3.183	2.739	N/A	1.832	1.614	1.598

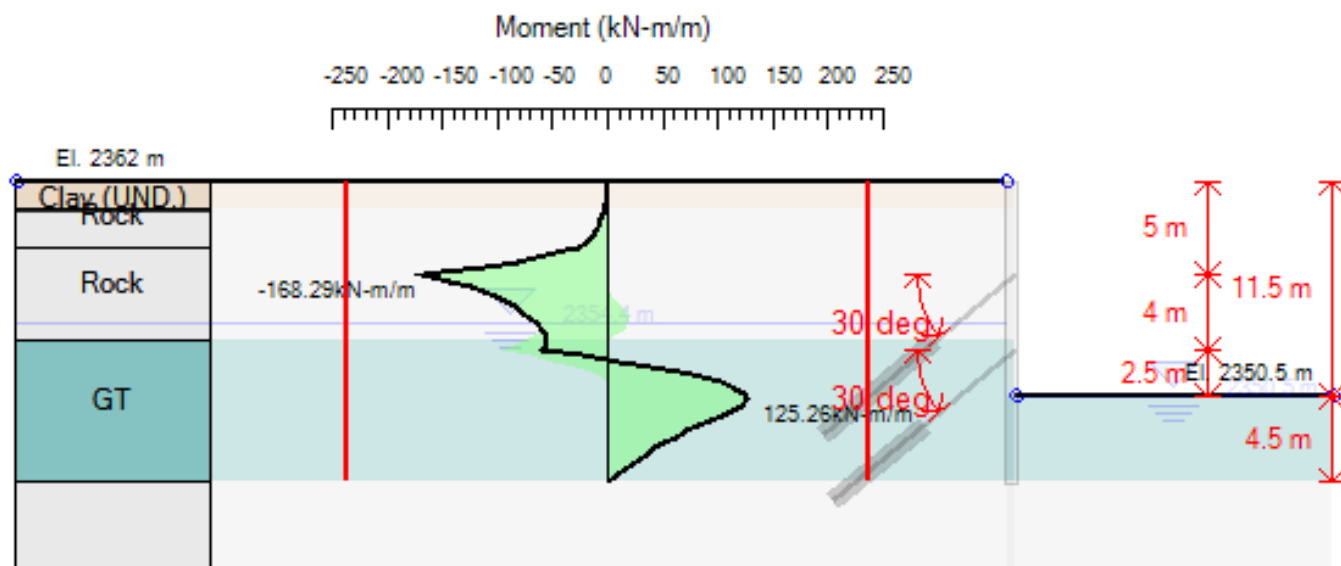


Figure 48: wall bending moment and moment capacity for 1.2 m and 5.0 m first anchor level

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

**#Trail-19 Vertical pile spacing 0.9 m and 5.0 m first anchor level**

Horizontal wall spacing: 0.9 m, Wall thickness = 0.6m

Embedment depth= 6.5m

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>sTop</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

Z = 2357.0m, L<sub>free</sub> = 10.5m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2353m, , L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 10 m, R<sub>fix</sub> = 50 %

Table 40: analysis and checking summary for 0.9 m pile spacing and 5.0 m first anchor level

**Summary vs Design Section**

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displaceme	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced	143.66	134.43	0.43	302.4	0.963	2.627	Calculation

**Extended Summary**

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Reinforced concrete pile	Calculation successful	0.43	0.24	143.66	129.29

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Reinforced concrete pile	134.43	120.99	0.455	0.455	0.549	N/A

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced	25.959	9.921	8.273	N/A	2.627	1.597	1.59

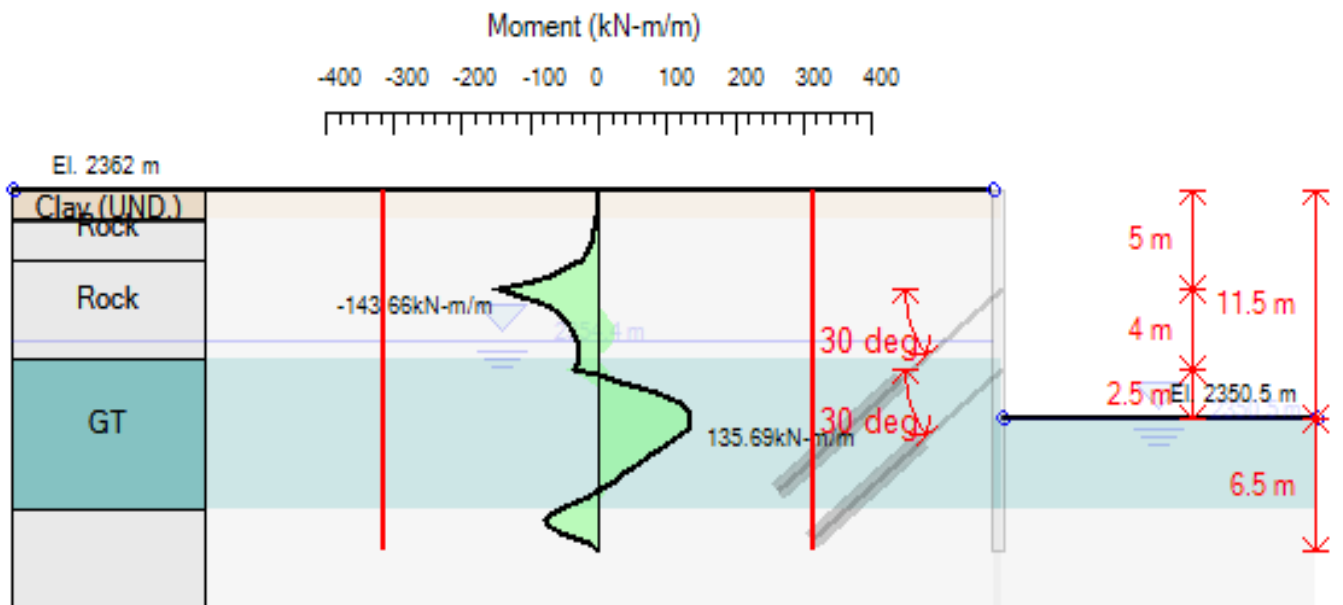


Figure 49: wall bending moment and moment capacity for 0.9 m and 5.0 m first anchor level

**#Trail 20 vertical pile spacing 0.6 m and 5.0 m first anchor level**

Horizontal wall spacing: 0.6 m, Wall thickness = 0.6m

Embedment length =6.5m

D = 60 cm, A = 2827.43cm<sup>2</sup>, I<sub>xx</sub> = 636172.51 cm<sup>4</sup>

Bar #D10 Longitudinal reinforcement

Top reinforcement: N = 14 bars #D24 = A<sub>Top</sub> 63.34 cm<sup>2</sup>, C<sub>top</sub> = 7.62 cm

Shear reinforcements = A<sub>s</sub> 0.785 cm<sup>2</sup>, s<sub>V</sub> = 20 cm

First level Support type and length

Z = 2357.0m, L<sub>free</sub> = 10.5m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2353m, L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Table 41: analysis and checking summary for 0.6 m pile spacing and 5.0 m first anchor level

**Summary vs Design Section**

Reinforced concrete pile	Wall Moment	Wall Shear	Wall Displaceme	Max Support	CriticalSupport	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Reinforced	172.79	143.27	0.43	300.65	0.963	2.404	Calculation

Extended Summary

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Reinforced concrete pile	Calculation successful	0.43	0.26	172.79	103.67

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Reinforced concrete pile	143.27	85.96	0.365	0.365	0.39	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Reinforced	N/A	300.65	509.04	0.963	0.611	0.963	3.334

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Reinforced	10.406	4.072	3.957	N/A	2.404	1.696	1.59

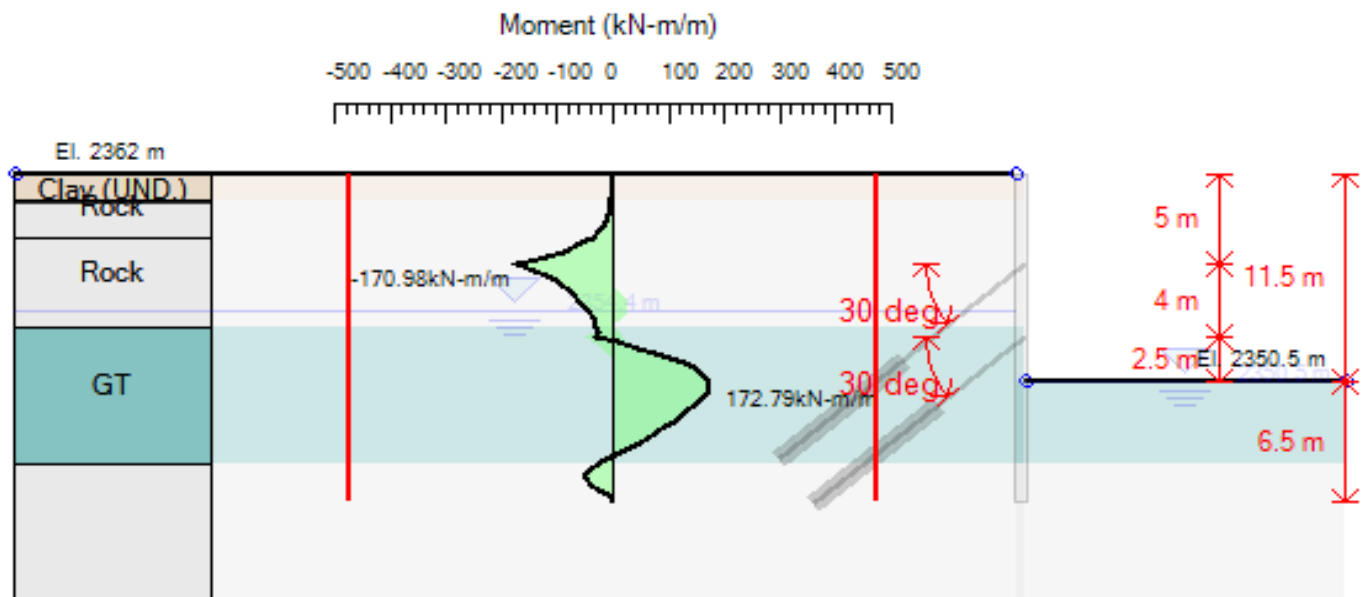


Figure 50: wall bending moment and moment capacity for 0.6 m and 5.0 m first anchor level

**Design of Solider pile wall using by DeepXcav software**

#Trail- 1 vertical spacing 1.8m and 3.5m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.8 m

Table 42: Material property

Section	W (KN /m)	A (Cm2)	D (cm)	tw (cm )	bf (cm)	Tf (c m)	K(cm )	Ixx (cm4)	Sxx (cm3 )	rX (cm)	Iyy	Syy	rY	rT	cW	fy
HE550	2.6	344.3	52.4	2.1	30.6	4	6.7	16190	6180	21.7	19150	1252	7.5	7.5	11190	355

Wall type: Soldier pile and timber lagging

Hor. wall spacing: 1.8 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2358.5 m, Lfree = 8 m, Lfix = 10 m, Rfix = 50 %

Second level Support type and length

Z = 2354.4 m , Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 43: analysis and checking summary for 1.8m and 3.5m anchor level

**Summary vs Design Section**

Soldier pile	Wall (kN-m/m)	Wall Shear (kN/m)	Wall (cm)	Max Support Reaction	Critical Support Check	Embedment Wall FS	Comments
Soldier pile	165.71	144.67	0.67	249.36	0.995	1.645	Calculation

**Extended Summary**

	Calculaion Result	Wall (cm)	Settlement (cm)	Wall Moment (kN-m/m)	Wall Moment (kN-m)
Soldier pile	Calculation successful	0.67	0.65	165.71	298.28

	Wall Stress Ratio FIS	Max Support Reaction	Max Support Reaction (kN)	Critical Support Check	STR Support Ratio	Support Capacity Ratio	FS Basal
Soldier pile	N/A	249.36	539.03	0.995	0.647	0.995	3.342

	Toe FS Passive	Toe FS Rotation	Toe FS Length	Zcut (Paratie)	FS Mobilized Passive	FS True/Active	Hydraulic Heave FS
Soldier pile	5.717	5.242	2.333	N/A	1.645	1.919	1.601

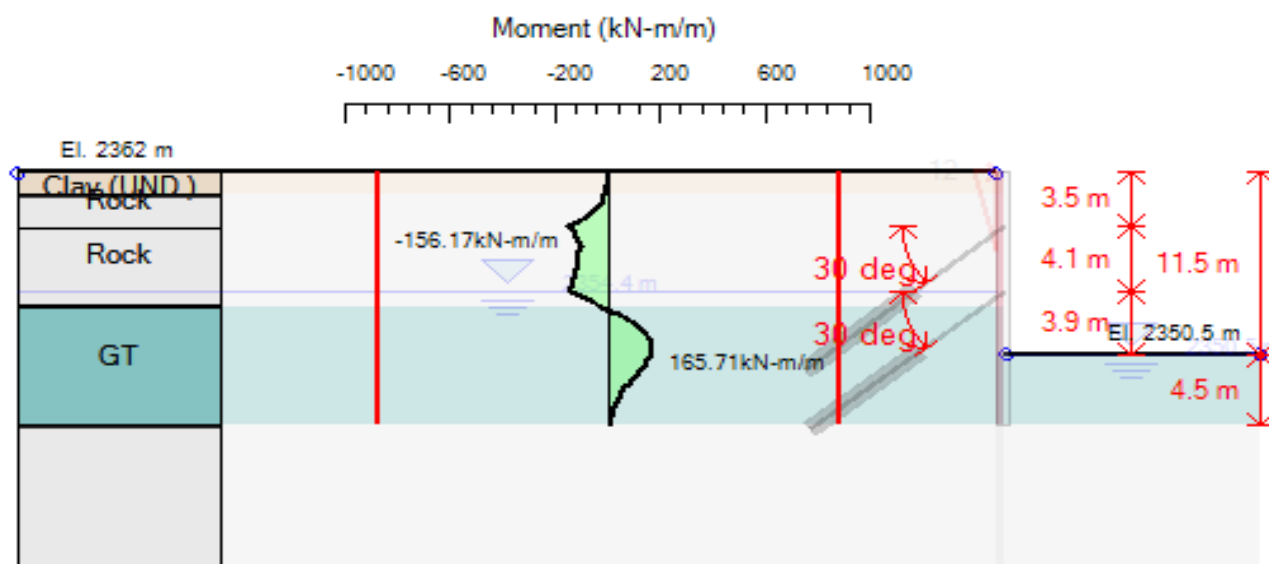


Figure 51: wall bending moment and moment capacity for 1.8m and 3.5m anchor level

**#Trail- 2** vertical spacing 1.5m and 3.5m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.5 m

Hor. wall spacing: 1.5 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2358.5 m, Lfree = 8 m, Lfix = 10 m, Rfix = 50 %

Second level Support type and length

Z = 2354.4 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 44: analysis and checking summary for 1.5m and 3.5m anchor level

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	166.8	144.39	0.54	249.32	0.991	1.757	Calculation

**Extended Summary**

	Calculaion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.54	0.54	166.8	250.2

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	144.39	216.58	0.099	0.158	0.175	N/A

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.32	538.53	0.991	0.647	0.991	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	6.874	5.7	2.739	N/A	1.757	1.855	1.601

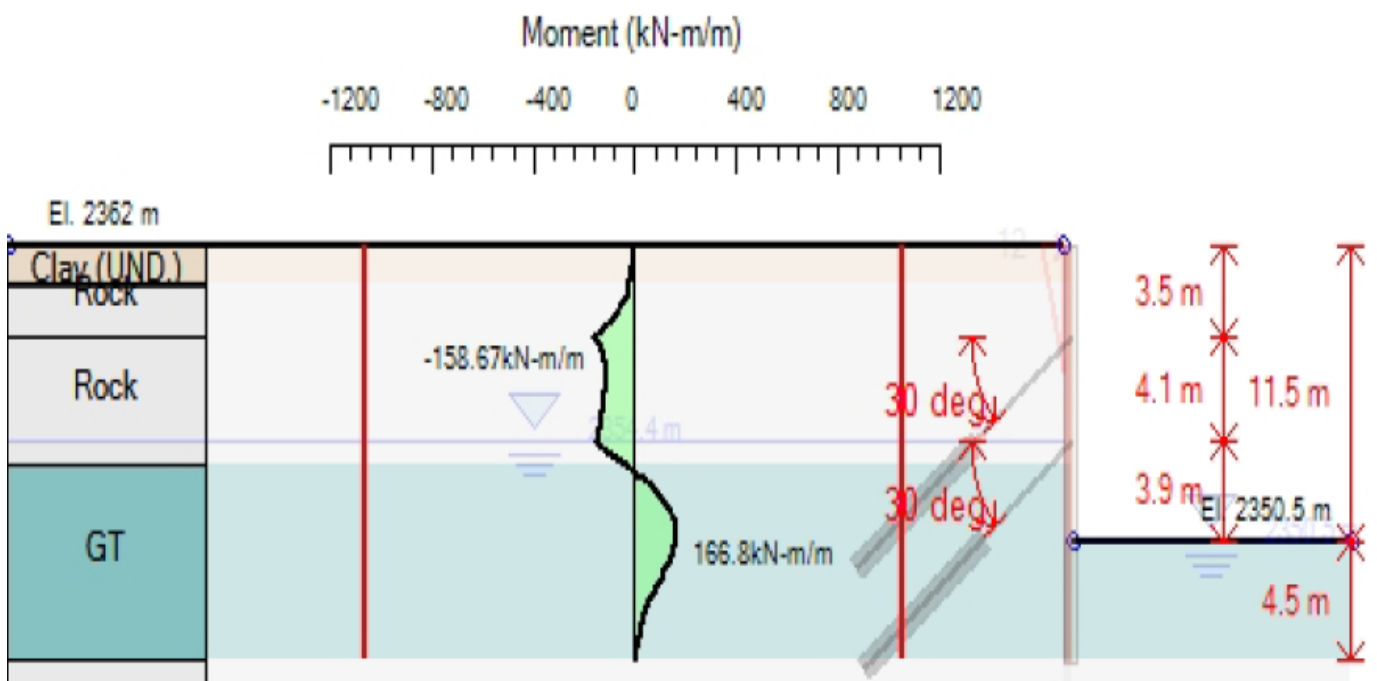


Figure 52: wall bending moment and moment capacity for 1.5m and 3.5m anchor level

#Trail- 3 vertical spacing 1.2m and 3.5m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.2 m

Hor. wall spacing: 1.2 Wall thickness = 0.57

Embedment length = 4.5m

HE= 550 cm, A = 344.3 cm<sup>2</sup>, I<sub>xx</sub> = 161900 cm<sup>4</sup>

First level Support type and length

Z = 2358.5 m, L<sub>free</sub> = 8 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Second level Support type and length

Z = 2355 m, L<sub>free</sub> = 7.4 m, L<sub>fix</sub> = 11 m, R<sub>fix</sub> = 50 %

Table 45: analysis and checking summary for 1.2m and 3.5m anchor level

Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	193.63	144.67	0.5	249.22	0.983	1.801	Calculation

Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful		0.5	0.45	193.63	232.36

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	144.67	173.6	0.092	0.147	0.14	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.22	538.32	0.983	0.646	0.983	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	7.916	5.855	3.316	N/A	1.801	1.805	1.601

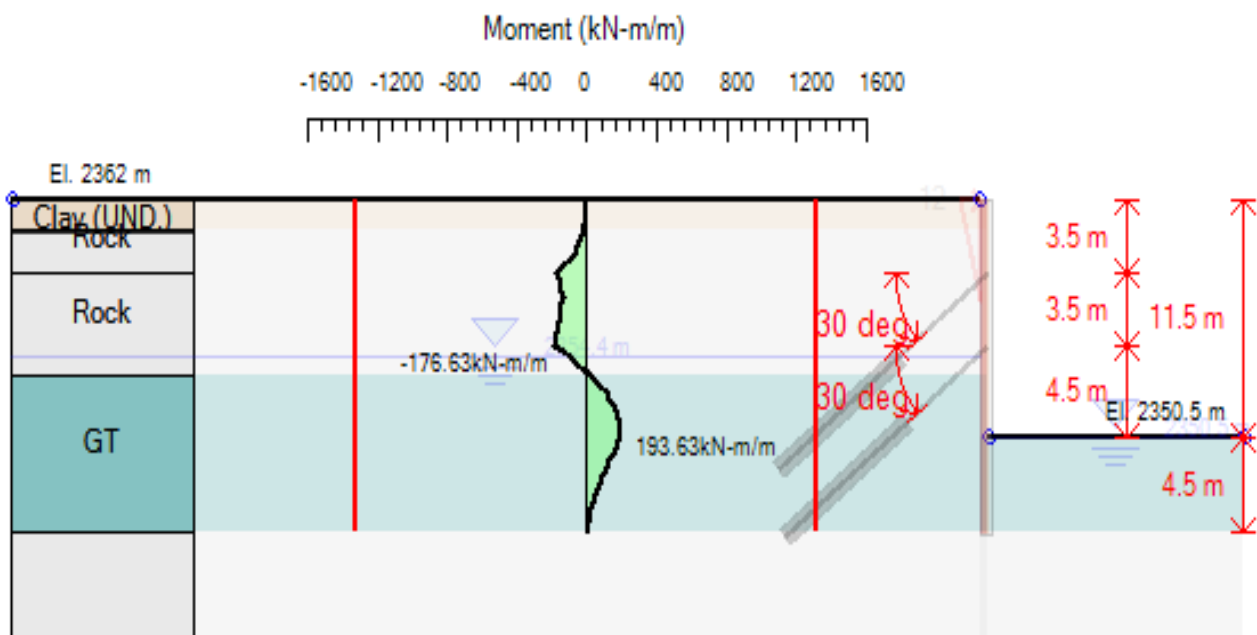


Figure 53: wall bending moment and moment capacity for 1.2m and 3.5m anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

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#Trail- 4 vertical spacing 0.9 m and 3.5m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.9m

Hor. wall spacing: 0.9 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2358.5 m, , Lfree = 9 m, Lfix = 11 m, Rfix = 50 %

Second level Support type and length

Z = 2355 m, Lfree = 7.4 m, Lfix = 11 m, Rfix = 50 %

Table 46: analysis and checking summary for 0.9 and 3.5m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	199.93	145.87	0.41	249.17	0.98	1.963	Calculation

### Extended Summary

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.41	0.35	199.93	179.94

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	145.87	131.28	0.071	0.114	0.106	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.17	538.21	0.98	0.646	0.98	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	10.576	6.534	3.316	N/A	1.963	1.695	1.601

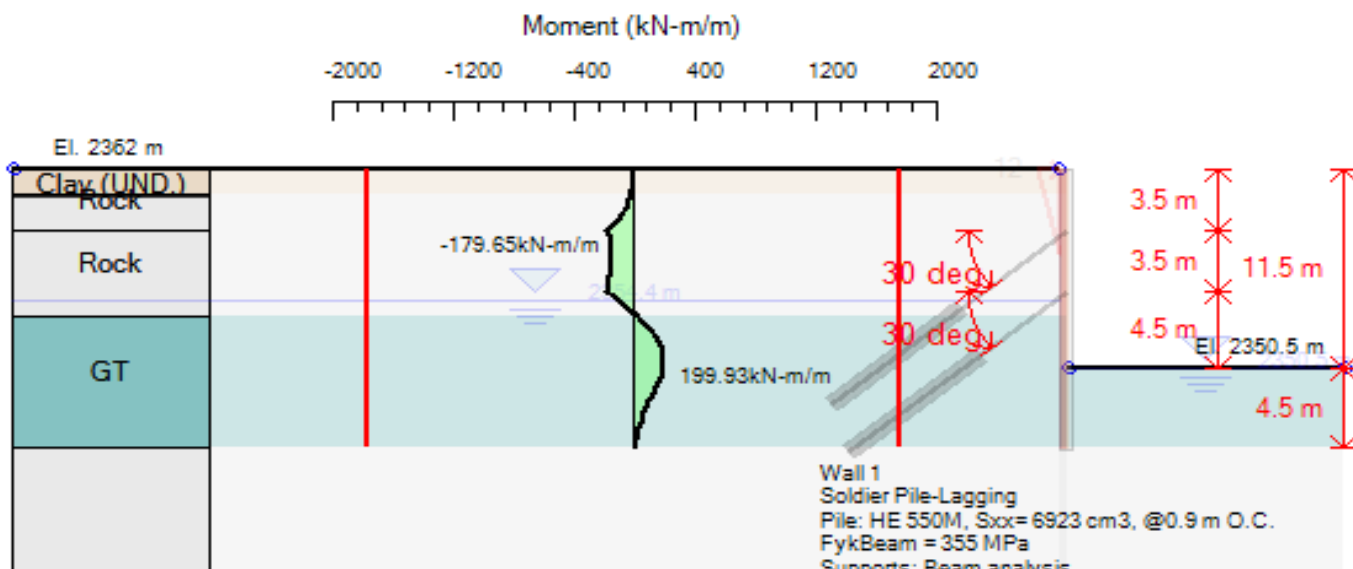


Figure 54: wall bending moment and moment capacity for 1.2m and 3.5m anchor level

#Trail- 5 vertical spacing 0.6 m and 3.5m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.6m

Hor. wall spacing: 0.6 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2358.5 m, Lfree = 8 m, Lfix = 11 m, Rfix = 50 %

Second level Support type and length

Z = 2355 m, Lfree = 7.4 m, Lfix = 11 m, Rfix = 50 %

Table 47: analysis and checking summary for 0.9m and 3.5m anchor level

Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	250.28	157.57	0.37	249.1	0.981	2.6	Calculation

Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful		0.37	0.25	250.28	150.17
	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	157.57	94.54	0.059	0.095	0.076	N/A

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.1	538.06	0.981	0.646	0.981	3.331
	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	32.921	10.256	6.067	N/A	2.6	1.523	1.584

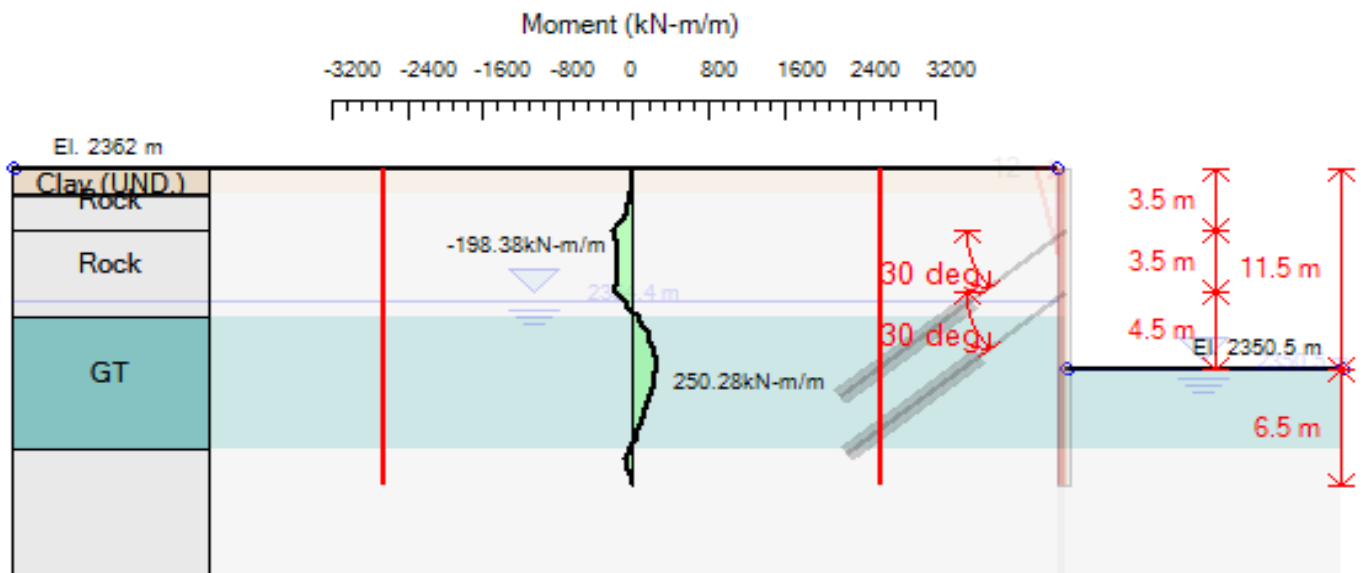


Figure 55: wall bending moment and moment capacity for 0.6 m and 3.5m anchor level

#Trail- 6 vertical spacing 1.8 m and 3.7m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.8 m

Hor. wall spacing: 1.8 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2354.4 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Second level Support type and length

Z = 2354.4 m, Lfree = 7.4 m, Lfix = 10 m

Table 48: analysis and checking summary for 1.8m and 3.7m anchor level

Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	164.2	145.37	0.75	249.38	0.993	1.653	Calculation

Extended Summary

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.75	0.67	164.2	295.56

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	145.37	261.67	0.117	0.187	0.211	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.38	538.66	0.993	0.647	0.993	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	5.722	5.235	2.333	N/A	1.653	1.915	1.601

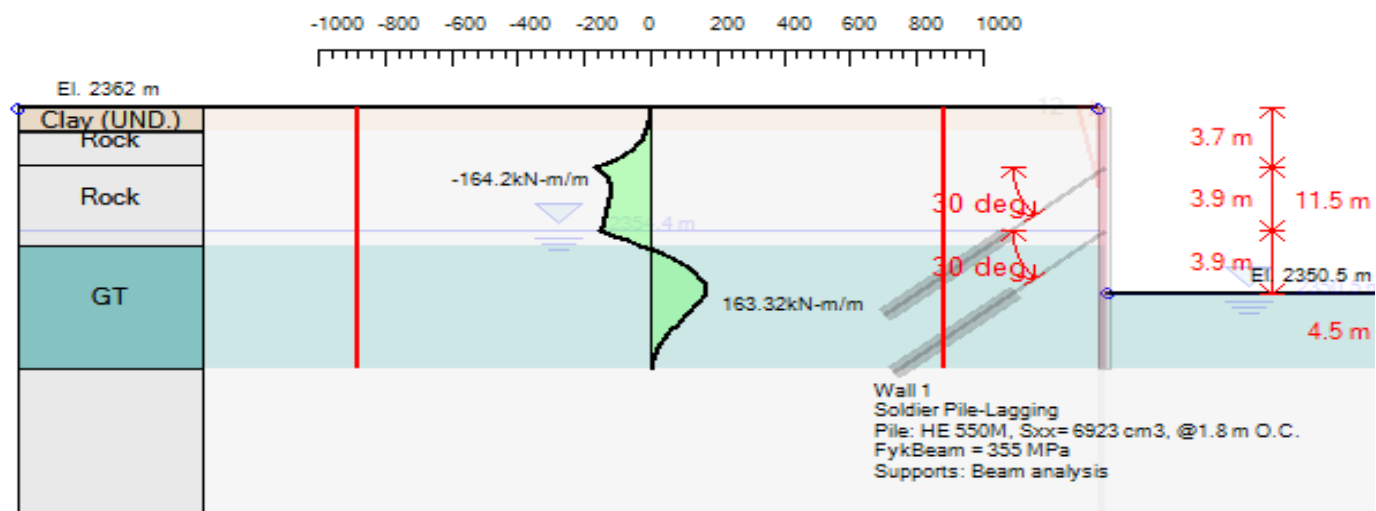


Figure 56: wall bending moment and moment capacity for 1.8 m and 3.7m anchor level

#Trail- 7 vertical spacing 1.5 m and 3.7m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.5 m

Hor. wall spacing: 1.5 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2358.3 m,, Lfree = 10 m, Lfix = 12 m, Rfix = 50 %

Second level Support type and length

X = 0.57 m, Z = 2354.4 m, Lfree = 7.4 m, Lfix = 11 m, Rfix = 50 %

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Table 49: analysis and checking summary for 1.5m and 3.7m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	166.85	145.15	0.61	249.29	0.952	1.765	Calculation

### Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful		0.61	0.56	166.85	250.27

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	145.15	217.73	0.099	0.158	0.176	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.29	538.47	0.952	0.647	0.952	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	6.88	5.693	2.739	N/A	1.765	1.85	1.601

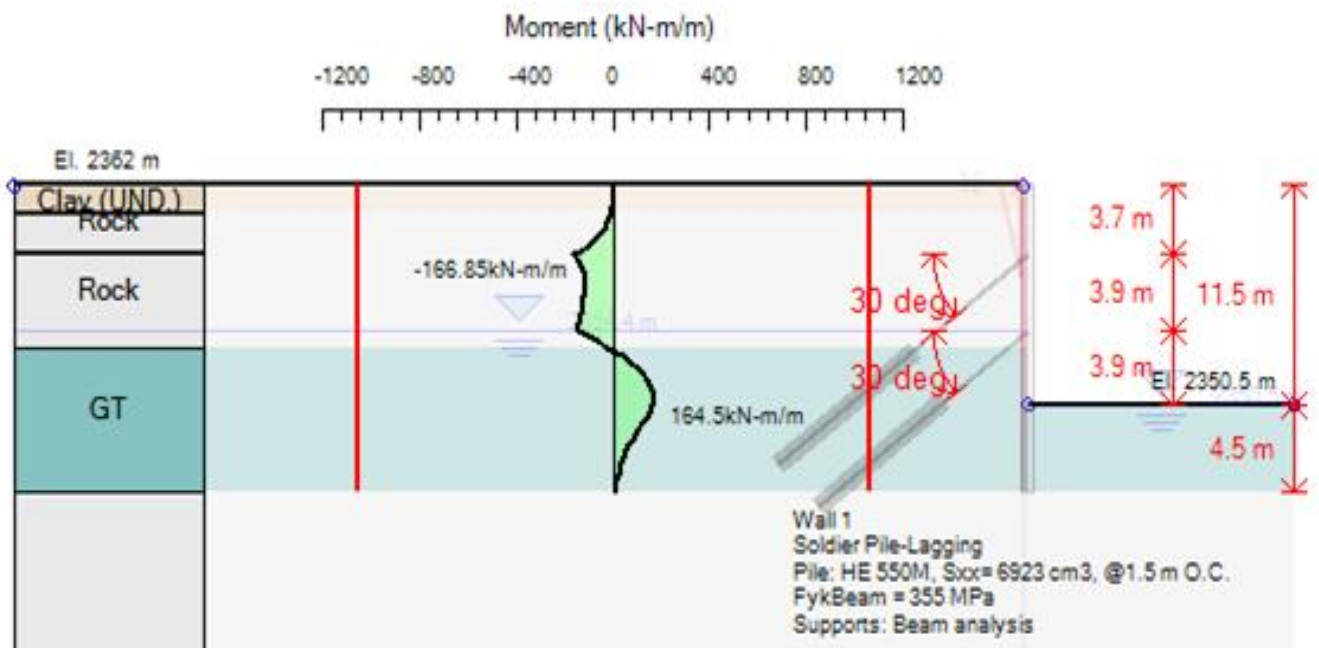


Figure 57: Wall bending moment and moment capacity for 1.5 m and 3.7m anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

**#Trail- 8** vertical spacing 1.2 m and 3.7m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.2m

Hor. wall spacing: 1.2 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2358.3 m, Lfree = 8 m, Lfix = 10 m, Rfix = 50 %

Second level Support type and length

X = 0.57 m, Z = 2354.4 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 50: analysis and checking summary for 1.2m and 3.7m anchor level

Summary vs Design Section							
Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	171.6	146.01	0.47	249.27	0.987	1.906	Calculation

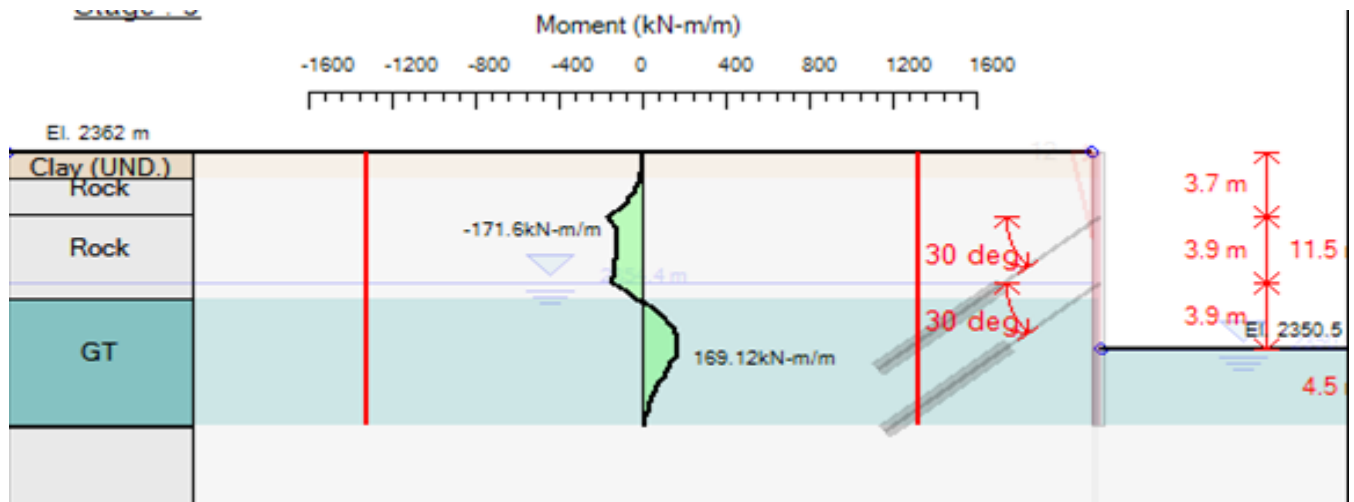
Extended Summary					
	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.47	0.47	171.6	205.92

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	146.01	175.21	0.081	0.13	0.142	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.27	538.42	0.987	0.646	0.987	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	8.617	6.239	3.316	N/A	1.906	1.766	1.601

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall



**Figure 58:** Wall bending moment and moment capacity for 1.2 m and 3.7m anchor level

#Trail- 9 vertical spacing 0.9m and 3.7m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.9 m

Hor. wall spacing: 0.9 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2358.3, Lfree = 8 m, Lfix = 10 m, Rfix = 50 %

Second level Support type and length

X = 0.57 m, Z = 2354.4 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 51: analysis and checking summary for 0.9m and 3.7m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	180.17	148.1	0.36	249.2	0.985	2.069	Calculation

### Extended Summary

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.36	0.37	180.17	162.15

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	148.1	133.29	0.064	0.102	0.108	N/A

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.2	538.27	0.985	0.646	0.985	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	11.512	6.9	3.316	N/A	2.069	1.658	1.601

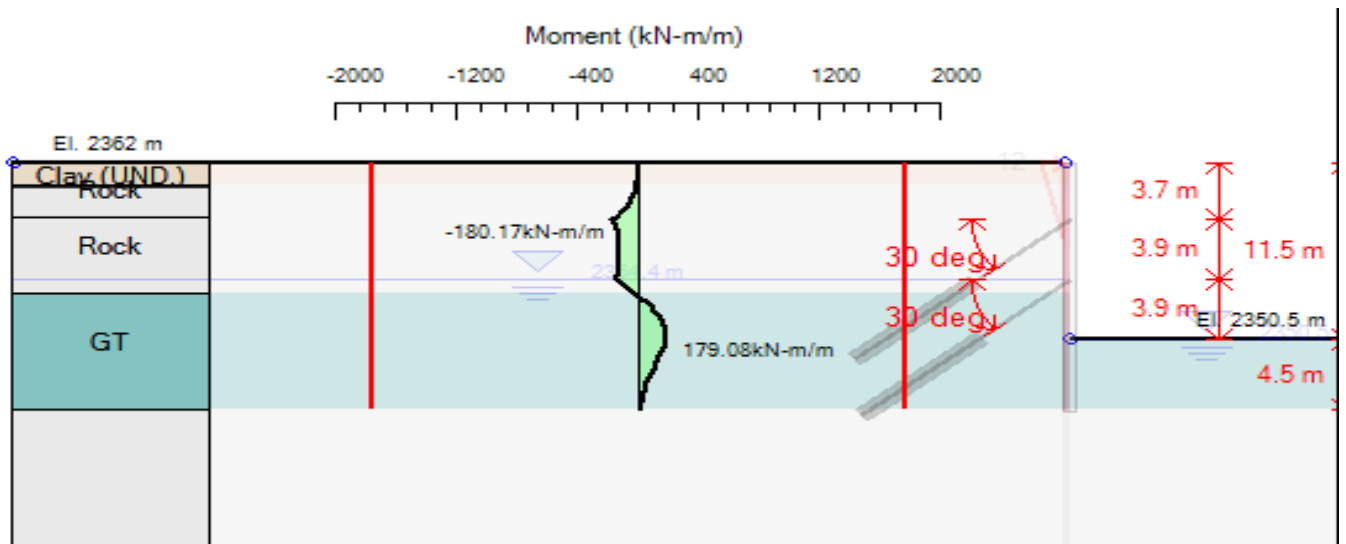


Figure 59: Wall bending moment and moment capacity for 0.9 m and 3.7m anchor level

#Trail- 10 vertical spacing 0.6m and 3.7m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.6 m

Hor. wall spacing: 0.6 Wall thickness = 0.57

Embedment length =6.5m

First level Support type and length

Z = 2354.4 m , Lfree = 8 m, Lfix = 10 m, Rfix = 50 %

Second level Support type and length

Z = 2354.4 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 52: analysis and checking summary for 0.6m and 3.7m anchor level

Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	234.43	161.4	0.34	249.13	0.986	2.674	Calculation

Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful		0.34	0.23	234.43	140.66

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	161.4	96.84	0.056	0.089	0.078	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.13	538.12	0.986	0.646	0.986	3.331

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	30.831	10.6	8.273	N/A	2.674	1.5	1.584

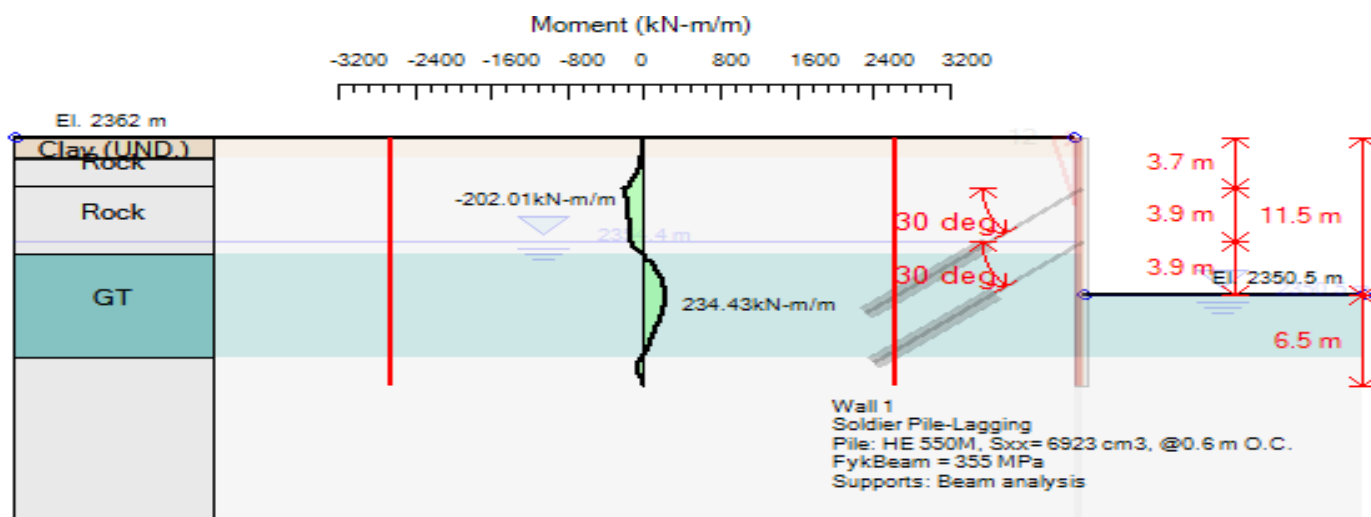


Figure 60: Wall bending moment and moment capacity for 0.6 m and 3.7m anchor level

#Trail- 11 vertical spacing 1.8 m and 4.5 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.8 m

Hor. wall spacing: 1.8 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2357.5 m, Lfree = 8 m, Lfix = 11 m, Rfix = 50 %

Second level Support type and length

Z = 2353.5 m, Lfree = 7.4 m, Lfix = 11 m

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Table 53: analysis and checking summary for 1.8m and 4.5m anchor level

Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	171.51	136.92	0.68	249.56	0.99	1.814	Calculation

Extended Summary

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.68	0.61	171.51	308.72

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	136.92	246.46	0.122	0.195	0.199	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.56	539.05	0.99	0.647	0.99	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	6.076	6.041	2.739	N/A	1.814	1.841	1.601

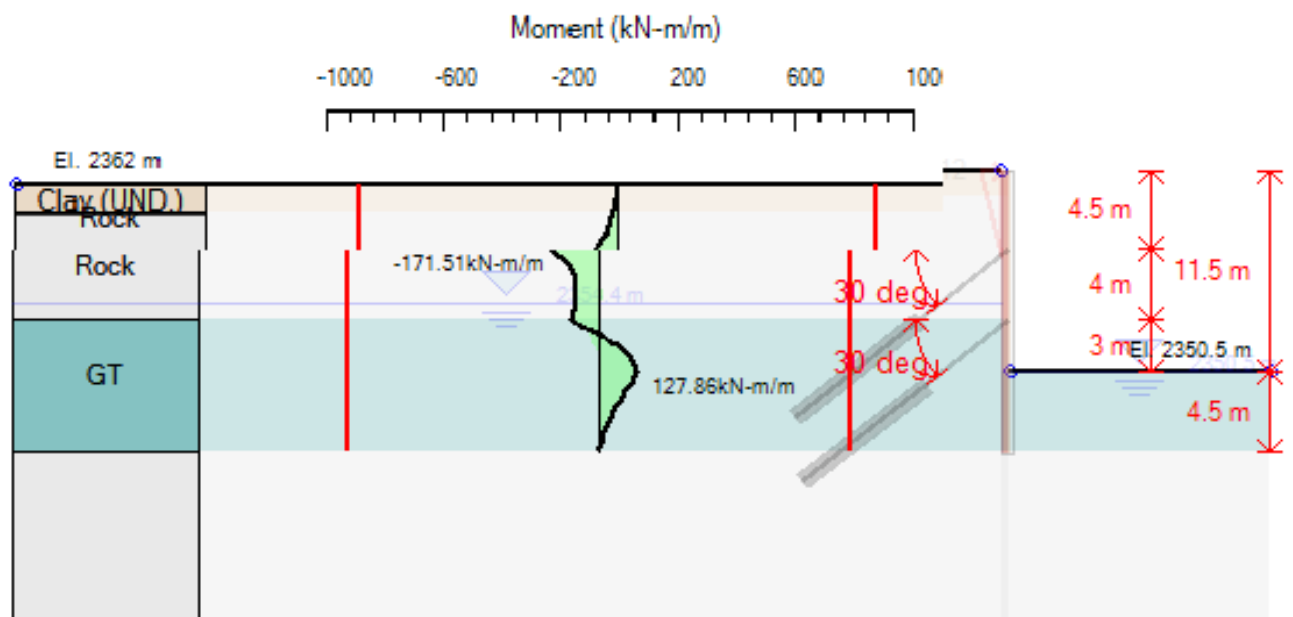


Figure 61: Wall bending moment and moment capacity for 1.8 m and 4.5m anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

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#Trail- 12 vertical spacing 1.5 m and 4.5 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.5 m

Hor. wall spacing: 1.5 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2357.5 m, Lfree = 8 m, Lfix = 11 m, Rfix = 50 %

Second level Support type and length

Z = 2353.5 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 54: analysis and checking summary for 1.5m and 4.5m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	172.66	137.3	0.55	249.45	0.99	1.929	Calculation

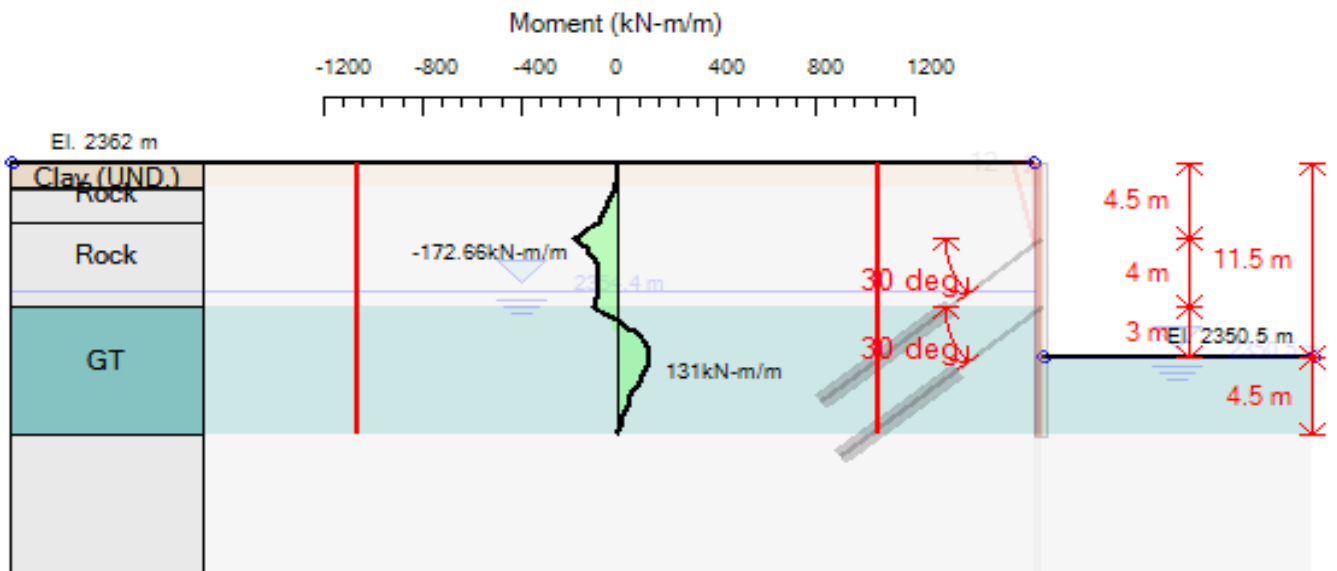
### Extended Summary

	Calculaion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.55	0.52	172.66	258.99

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	137.3	205.95	0.102	0.164	0.166	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.45	538.81	0.99	0.647	0.99	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	7.305	6.488	2.739	N/A	1.929	1.78	1.601



**Figure 62: Wall bending moment and moment capacity for 1.5 m and 4.5m anchor level**

#Trail- 13 vertical spacing 1.2 m and 4.5 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.2 m

Hor. wall spacing: 1.2 Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2357.5 m, Lfree = 9 m, Lfix = 12 m, Rfix = 50 %

Second level Support type and length

Z = 2353.5 m, Lfree = 8 m, Lfix = 12 m, Rfix = 50 %

Table 55: analysis and checking summary for 1.2m and 4.5m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	185.44	142.41	0.3	249.24	0.952	2.237	Calculation

### Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful		0.3	0.37	185.44	166.9

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	142.41	128.17	0.066	0.105	0.104	N/A

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.24	538.36	0.952	0.646	0.952	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	12.224	7.615	4.2	N/A	2.237	1.595	1.601

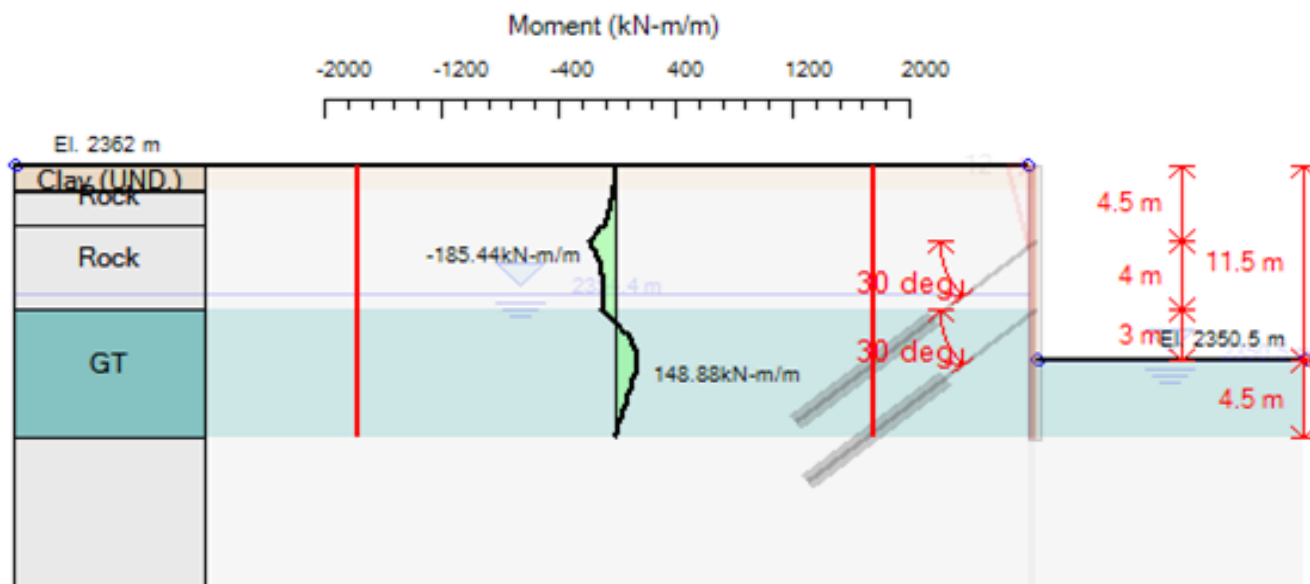


Figure 63: Wall bending moment and moment capacity for 1.2 m and 4.5m anchor level

#Trail- 14 vertical spacing 0.9 m and 4.5 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.9 m

Hor. wall spacing: 0.9m Wall thickness = 0.57

Embedment length =6.5m

First level Support type and length

Z = 2357.5 m, Lfree = 8 m, Lfix = 10m, Rfix = 50 %

Second level Support type and length

Z = 2353.5 m, Lfree =7.4 m, Lfix = 12 m, Rfix = 50 %

Table 56: analysis and checking summary for 0.9m and 4.5m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	212.25	158.9	0.29	249.15	0.989	2.787	Calculation

### Extended Summary

	Calculation Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.29	0.21	212.25	127.35

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	158.9	95.34	0.05	0.08	0.077	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.15	538.16	0.989	0.646	0.989	3.331

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	31.07	11.221	8.273	N/A	2.787	1.46	1.584

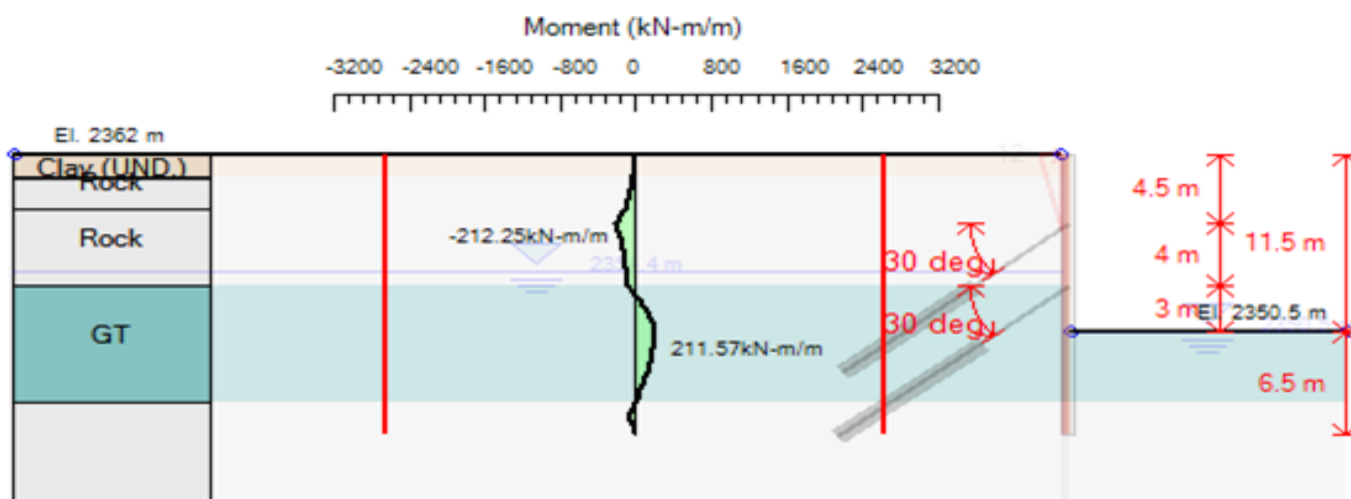


Figure 64: Wall bending moment and moment capacity for 0.9 m and 4.5m anchor level

#Trail- 15 vertical spacing 0.6 m and 4.5 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.6 m

Hor. wall spacing: 0.6m Wall thickness = 0.57

Embedment length =6.5m

First level Support type and length

Z = 2357.5 m, Lfree = 8 m, Lfix = 12m, Rfix = 50 %

Second level Support type and length

Z = 2353.5 m, Lfree =7.4 m, Lfix = 12 m, Rfix = 50 %

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Table 57: analysis and checking summary for 0.6m and 4.5m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	212.25	158.9	0.29	249.15	0.989	2.787	Calculation

### Extended Summary

	Calcuiaon Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.29	0.21	212.25	127.35

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	158.9	95.34	0.05	0.08	0.077	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.15	538.16	0.989	0.646	0.989	3.331

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	31.07	11.221	8.273	N/A	2.787	1.46	1.584

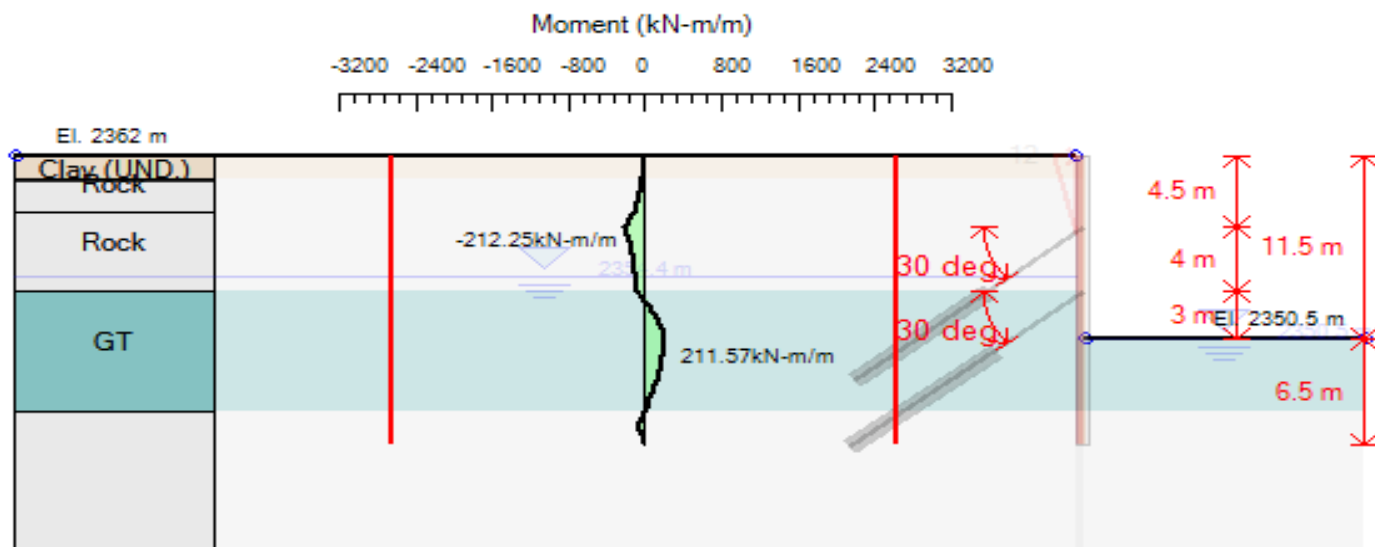


Figure 65: Wall bending moment and moment capacity for 0.6 m and 4.5m anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

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**#Trail- 16** vertical spacing 1.8 m and 5.0 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.8 m

Hor. wall spacing: 1.8m Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2357 m, Lfree = 9 m, Lfix = 12 m, Rfix = 50 %

Second level Support type and length

Z = 2353 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 58: analysis and checking summary for 1.8m and 5.0m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	169.21	130.98	0.69	249.64	0.954	1.948	Calculation

### Extended Summary

	Calculaion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.69	0.55	169.21	304.58

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	130.98	235.76	0.12	0.192	0.19	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.64	539.27	0.954	0.648	0.954	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	6.131	6.663	2.739	N/A	1.948	1.817	1.601

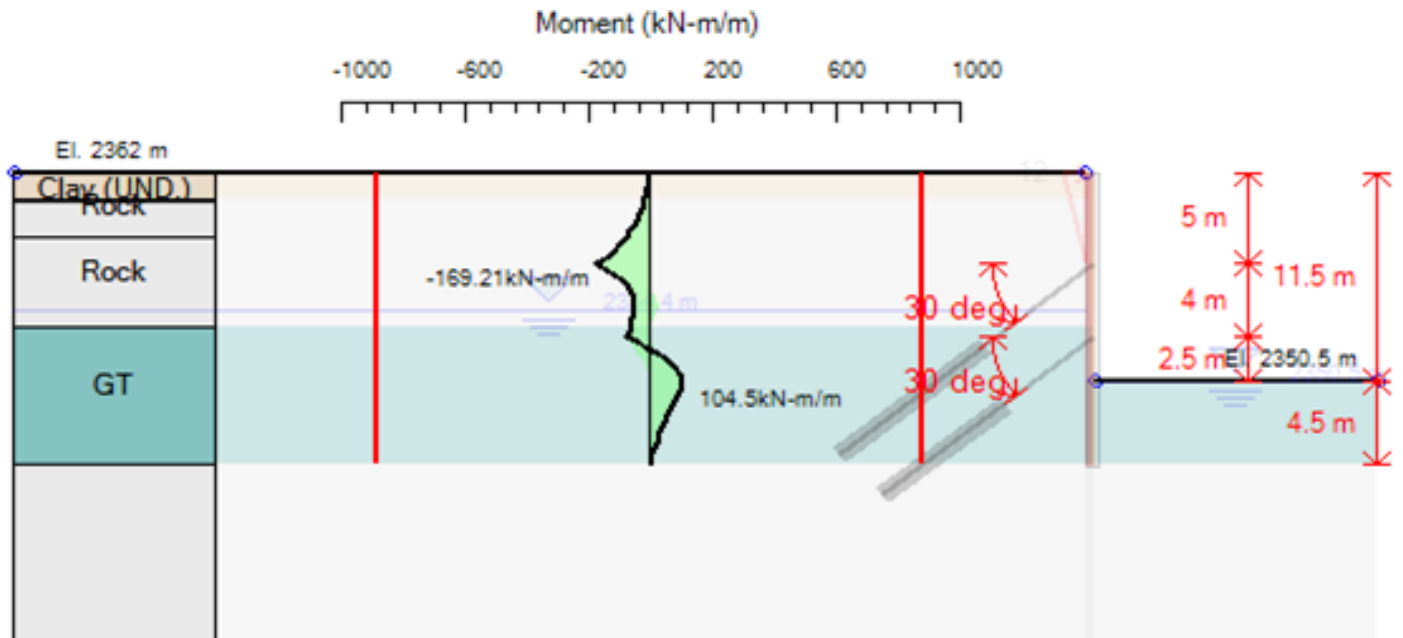


Figure 66: Wall bending moment and moment capacity for 1.8 m and 5.0m anchor level

#Trail- 17 vertical spacing 1.5 m and 5.0 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.5 m

Hor. wall spacing: 1.2m Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2357 m, Lfree = 9 m, Lfix = 12 m, Rfix = 50 %

Second level Support type and length

Z = 2353 m, Lfree = 7.4 m, Lfix = 11 m, Rfix = 50 %

Table 59: analysis and checking summary for 1.5m and 5.0m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	171.86	129.94	0.56	249.5	0.953	2.054	Calculation

### Extended Summary

	Calculaion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.56	0.46	171.86	257.79

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Wall Shear (kN/m)	Wall Shear (kN)	STR Combined Wall Ratio	STR Moment Wall Ratio	STR Shear Wall Ratio	Wall Concrete Stress Ratio FIC
Soldier pile	129.94	194.91	0.102	0.163	0.157	N/A

	Wall Stress Ratio FIS	Max Support Reaction	Max Support Reaction (kN)	Critical Support Check	STR Support Ratio	Support Capacity Ratio	FS Basal
Soldier pile	N/A	249.5	538.92	0.953	0.647	0.953	3.342

	Toe FS Passive	Toe FS Rotation	Toe FS Length	Zcut (Paratie)	FS Mobilized Passive	FS True/Active	Hydraulic Heave FS
Soldier pile	7.372	7.089	2.739	N/A	2.054	1.753	1.601

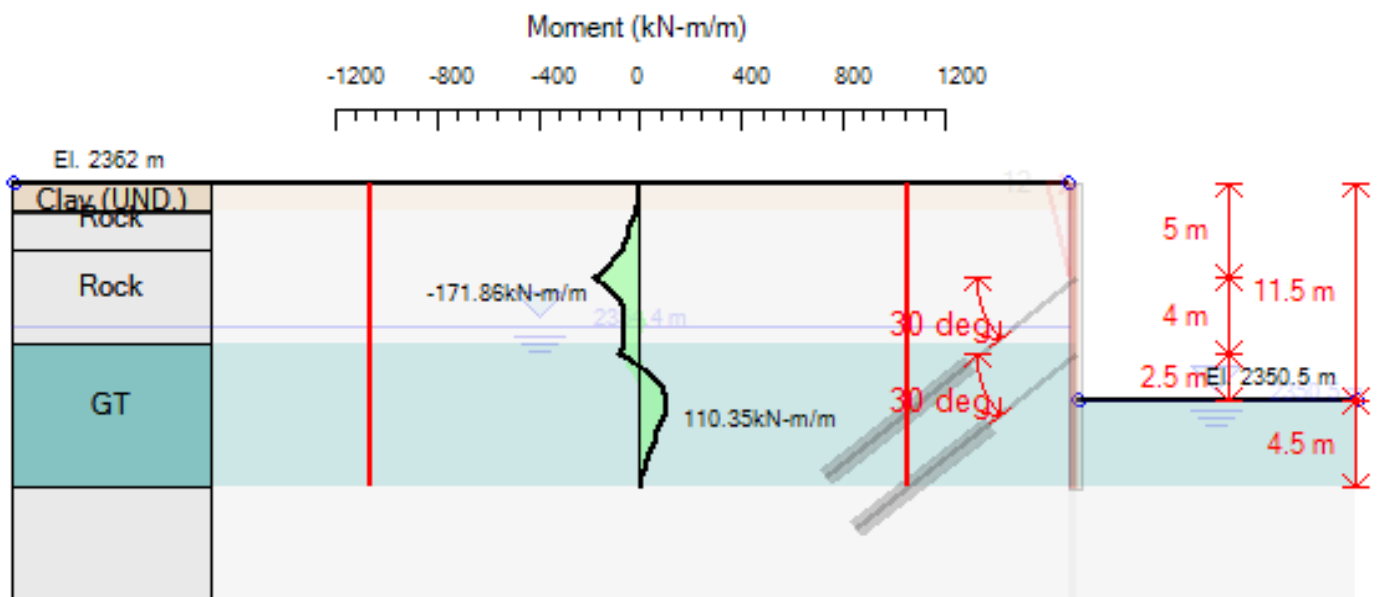


Figure 67: Wall bending moment and moment capacity for 1.5 m and 5.0m anchor level

#Trail- 18 vertical spacing 1.2 m and 5.0 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 1.2 m

Hor. wall spacing: 1.2m Wall thickness = 0.57

Embedment length = 3.5m

First level Support type and length

Z = 2357 m, Lfree = 9 m, Lfix = 12 m, Rfix = 50 %

Second level Support type and length

Z = 2353 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

Table 60: analysis and checking summary for 1.2m and 5.0m anchor level

Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	169.58	129.15	0.43	249.36	0.952	1.401	Calculation

Extended Summary

	Calculaion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.43	0.75	169.58	203.5

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	129.15	154.98	0.08	0.128	0.125	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.36	538.62	0.952	0.647	0.952	3.338

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	5.318	5.245	2.364	N/A	1.401	1.83	1.466

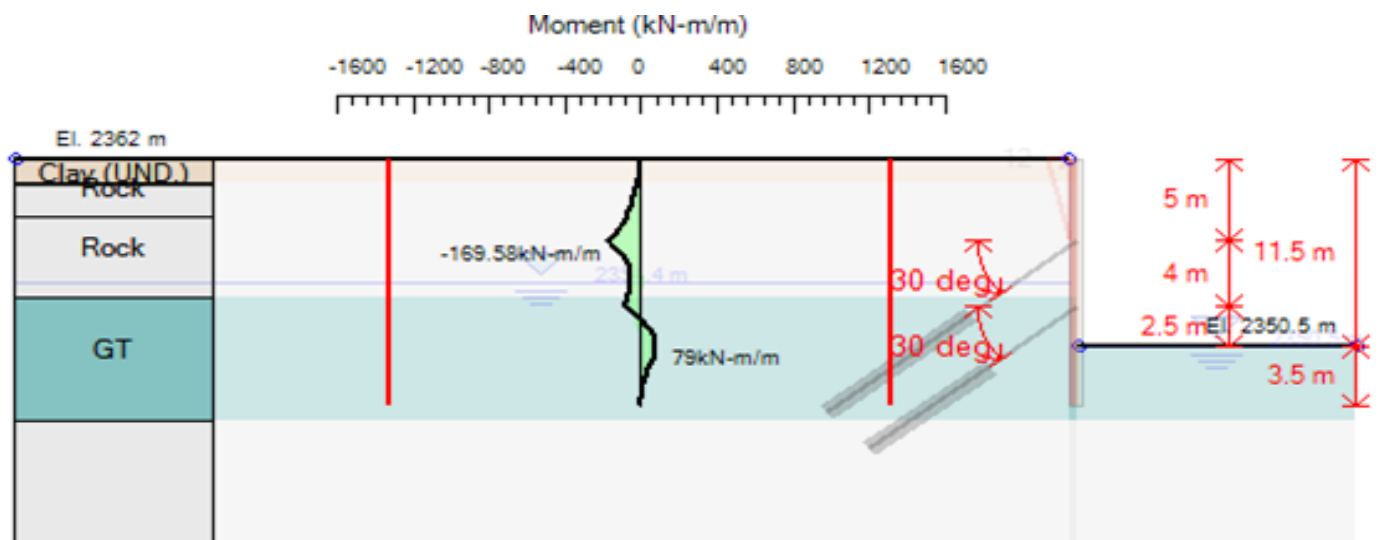


Figure 68: Wall bending moment and moment capacity for 1.2 m and 5.0m anchor level

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

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**#Trail- 19** vertical spacing 0.9 m and 5.0 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.9m

Hor. wall spacing: 0.9m Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2357 m, Lfree = 9 m, Lfix = 12 m, Rfix = 50 %

Second level Support type and length

Z = 2353 m, Lfree = 7.4 m, Lfix = 10 m, Rfix = 50 %

Table 61: analysis and checking summary for 0.9m and 5.0m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	181.52	134.06	0.31	249.26	0.952	2.304	Calculation

### Extended Summary

	Calculaion Result	Wall	Settlement	Wall Moment	Wall Moment
		(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful	0.31	0.35	181.52	163.37

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	134.06	120.65	0.064	0.103	0.097	N/A

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.26	538.4	0.952	0.646	0.952	3.342

	Toe FS	Toe FS	Toe FS	Zcut	FS Mobilized	FS	Hydraulic
	Passive	Rotation	Length	(Paratie)	Passive	True/Active	Heave FS
Soldier pile	12.335	8.131	4.2	N/A	2.304	1.572	1.601

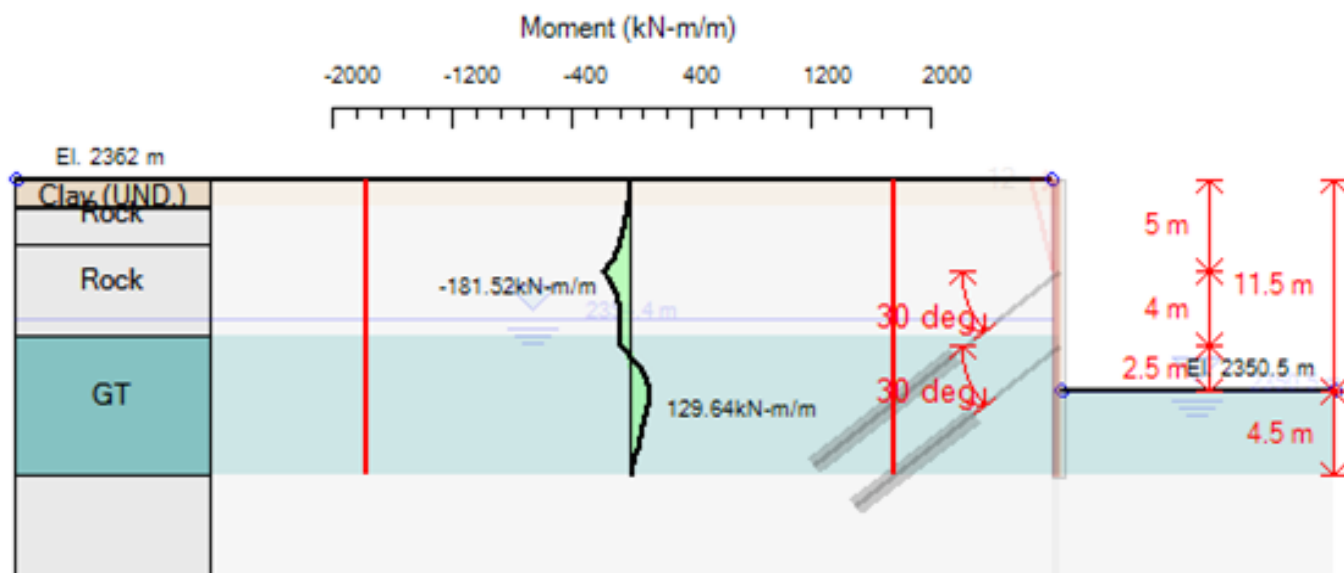


Figure 69: Wall bending moment and moment capacity for 1.2 m and 5.0m anchor level

#Trail- 19 vertical spacing 0.6 m and 5.0 m anchor level

This design type has HE 550 hot rolled steel pile wall with a spacing of 0.6m

Hor. wall spacing: 0.6m Wall thickness = 0.57

Embedment length =4.5m

First level Support type and length

Z = 2357 m, Lfree = 9 m, Lfix = 12 m, Rfix = 50 %

Second level Support type and length X = 0.57 m, Z = 2353 m, Lfree = 9 m, Lfix = 10 m, Rfix = 50 %

Table 62: analysis and checking summary for 1.5m and 5.0m anchor level

### Summary vs Design Section

Soldier pile	Wall	Wall Shear	Wall	Max Support	Critical Support	Embedment	Comments
	(kN-m/m)	(kN/m)	(cm)	Reaction	Check	Wall FS	
Soldier pile	196.28	141.84	0.23	249.15	0.952	2.447	Calculation

### Extended Summary

	Calculation Result		Wall	Settlement	Wall Moment	Wall Moment
			(cm)	(cm)	(kN-m/m)	(kN-m)
Soldier pile	Calculation successful		0.23	0.28	196.28	117.77

	Wall Shear	Wall Shear	STR Combined	STR Moment	STR Shear	Wall Concrete
	(kN/m)	(kN)	Wall Ratio	Wall Ratio	Wall Ratio	Stress Ratio FIC
Soldier pile	141.84	85.1	0.046	0.074	0.069	N/A

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

	Wall	Max Support	Max Support	Critical	STR Support	Support	FS
	Stress Ratio FIS	Reaction	Reaction (kN)	Support Check	Ratio	Capacity Ratio	Basal
Soldier pile	N/A	249.15	538.16	0.952	0.646	0.952	3.342

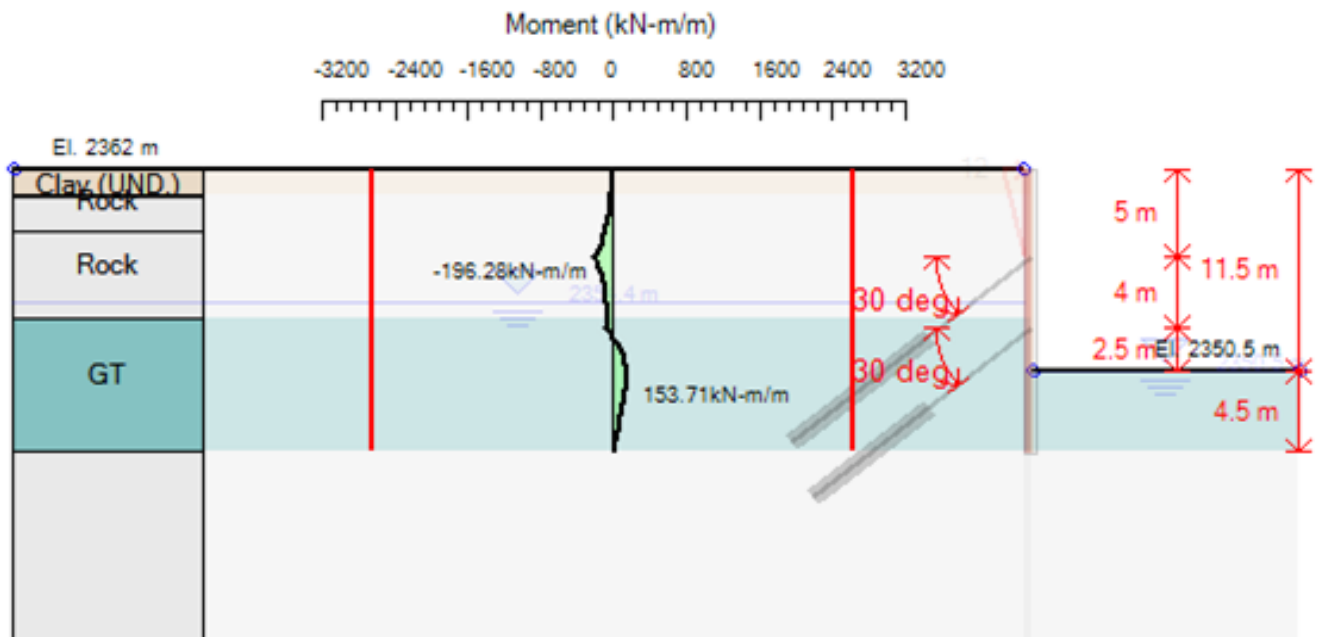
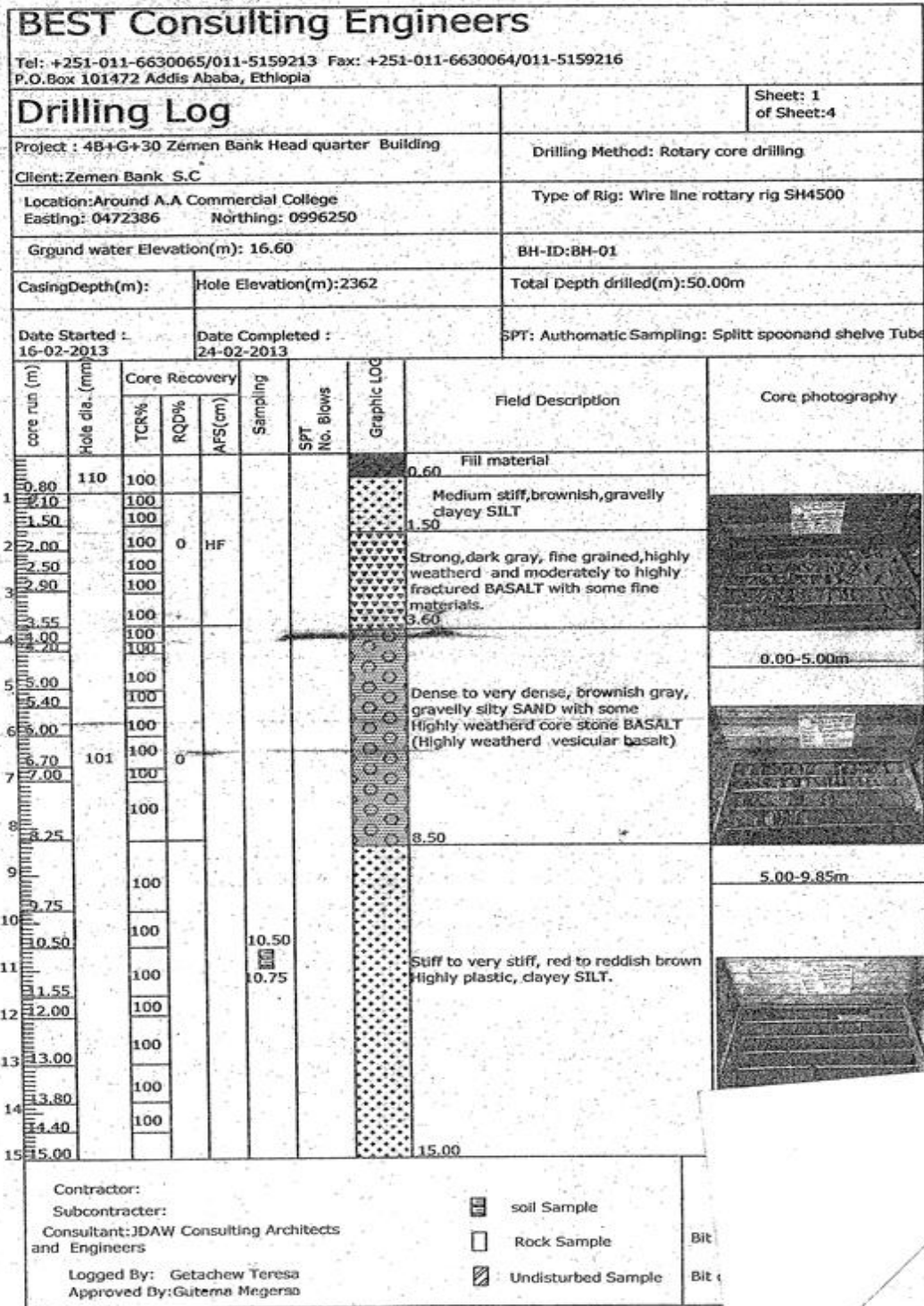


Figure 70: Wall bending moment and moment capacity for 0.6 m and 5.0m anchor level

# **ANNEX –III**

## **Borehole log and piezometer factual data**

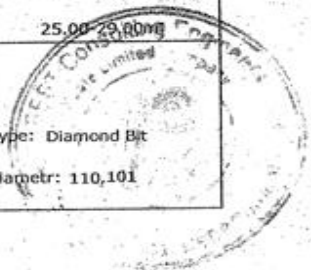



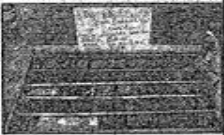

BEST Consulting Engineers									
Tel: +251-011-6630065/011-5159213 Fax: +251-011-6630064/011-5159216 P.O.Box 101472 Addis Ababa, Ethiopia									
<b>Drilling Log</b>								Sheet: 2 of Sheet:4	
Project : 4B+G+30 Zemen Bank Head quarter Building						Drilling Method: Rotary core drilling			
Client:Zemen Bank S.C						Type of Rig: Wire line rottary rig SH1000			
Location:Around A.A Commercial College Easting: 0472386 Northing: 0996250						Ground water Elevation(m): 16.60			
BH-ID: BH-01						Total Depth drilled(m):50.00m			
CasingDepth(m):			Hole Elevation(m):2362			SPT: Authomatic Sampling: Splitt spoonand shelve Tube			
Date Started : 16-02-2013			Date Completed : 24-02-2013						
core run (m)	Hole dia. (mm)	Core Recovery			Sampling	SPT No. Blows	Graphic LOG	Field Description	Core photography
		TCR%	RQD%	AFS(cm)					
15.20		100			15.20		Stiff to very stiff, red to reddish brown, highly plastic, clayey SILT.		
15.45		100			15.45	8/15/20			
16.70		100			15.45	15.90	stiff to very stiff, gray to yellowish gray, gravelly clay SILT with some core stone Highly weatherd Basalt (Decomposed rock)		
17.60		100			17.60	6/8/10			
18.05		100			18.05				
19.40		100			19.40	19.60			
19.60		100			20.10	23/R	Very stiff to hard, red to reddish brown Highly plastic, clayey SILT		
20.40		100			20.10	19.85			
21.00		100				21.60	Very stiff to Hard, brownish gray sandy clayey SILT with some gravel embeded to the clay matrix. The gravels are very weak ,weatherd , moist and vesicular basalt.		
21.60	101	100			21.60	21.67			
22.30		100				22.30			
23.40		100			23.40	23.68			
23.68		100			23.68	7/16/20			
24.13		100			24.13				
24.50		100				25.65			
25.00		100			25.00	35/R			
25.65		100				25.94			
26.45		100			26.45	27.60			
27.25		100			27.25	28.40			
27.70		100			27.70	3/39/R			
28.65		100				28.14			
29.00		100			29.00	29.55			
29.55		100			29.55	28/32/3			
30.00		100			30.00	30.00			

Contractor:  
 Subcontractor:  
 Consultant: JDAW Consulting Architects and Engineers  
 Logged By: Getachew Teresa  
 Approved By: Gutema Megersa




Disturbed soil Sample  
 Rock Sample  
 Undisturbed Sample

Bit Type: Diamond Bit  
 Bit diameter: 110,101

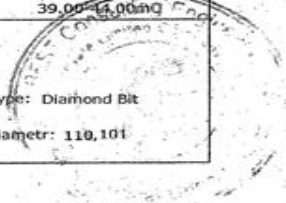



BEST Consulting Engineers									
Tel: +251-011-6630065/011-5159213 Fax: +251-011-6630064/011-5159216 P.O.Box 101472 Addis Ababa, Ethiopia									
<b>Drilling Log</b>							Sheet: 3 of Sheet:4		
Project : 4B+G+30 Zemen Bank Head quarter Building					Drilling Method: Rotary core drilling				
Client: Zemen Bank S.C					Type of Rig: Wire line rottary rig SH1000				
Location: Around A.A Commercial College Easting: 047286 Northing: 0996250					Ground water Elevation(m): 16.60				
CasingDepth(m):		Hole Elevation(m):2362			Total Depth drilled(m):50.00m				
Date Started : 16-02-2013		Date Completed : 24-02-2013			SPT: Authomatic Sampling: Splitt spoonand shelve Tube				
core run (m)	Hole dia. (mm)	Core Recovery			Sampling	SPT No. Blows	Graphic LOG	Field Description	Core photography
		TCR%	RQP%	AFS (cm)					
30.70		100							
31.40		100			31.20 31.40 8/17/23		Very stiff to hard, red to reddish brown, Highly plastic, clayey SILT.		
32.40		100			32.00 31.85				
33.40		100			32.20 32.40				
34.40		100				33.40 R			29.00-33.80m
35.80	101	100			35.80 14/R		Very stiff to hard, brownish gray gravelly sandy SILT with occasional cobbles of weatherd basalt.		
37.00		100			36.07				
38.00		100			38.00 10/26/44				
39.00		100			38.45				
40.00		100				40.20			33.80-39.00m
41.40		100			41.40 R		Moderately strong to strong, fine grained dark gray, slightly weatherd and Highly fractured BASALT.		
42.00		70			41.82				
43.00		80	0	HF			Moderately strong to strong, fine grained dark gray, slightly weatherd and Highly fractured BASALT.		
43.70		40	0	HF					
45.00		100				43.70			
						45.00			39.00-45.00m

Contractor:  
Subcontractor:  
Consultant: JDAW Consulting Architects and Engineers  
Logged By: Getachew Teresa  
Approved By: Gutema Megersa




-  Disturbed soil Sample
-  Rock Sample
-  Undisturbed Sample

Bit Type: Diamond Bit  
Bit diametr: 110,101



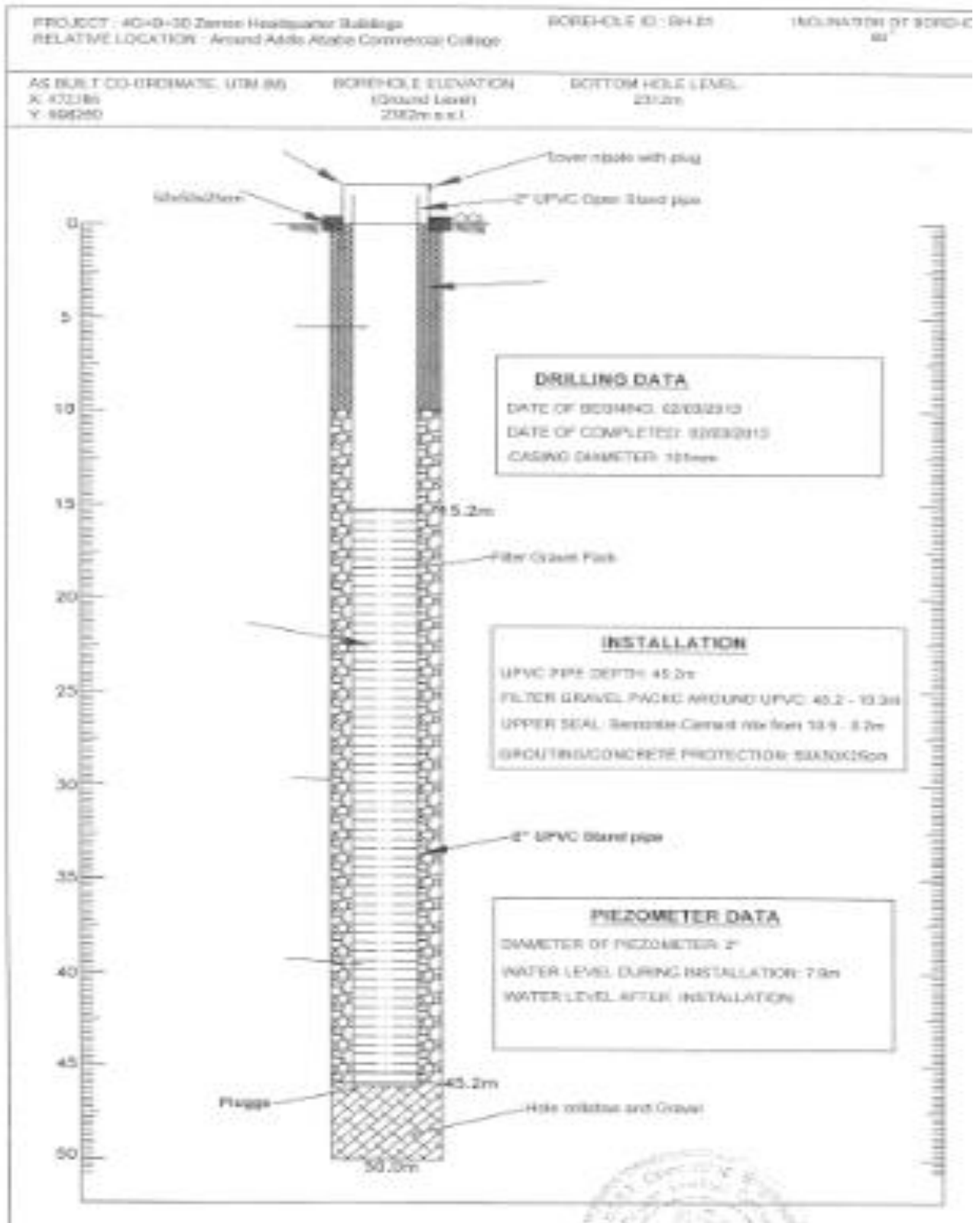
BEST Consulting Engineers									
Tef: +251-011-6630065/011-5159213 Fax: +251-011-6630064/011-5159216 P.O.Box 101472 Addis Ababa, Ethiopia									
<b>Drilling Log</b>							Sheet: 4 of Sheet:4		
Project : 4B+G+30 Zemen Bank Head quarter Building					Drilling Method: Rotary core drilling				
Client:Zemen Bank S.C					Type of Rig: Wire line rottary rig SH1000				
Location:Around A.A Commercial College Easting: 0472386 Northing: 0996250					Ground water Elevation(m): 16.60				
BH-ID: BH-01					CasingDepth(m):				
Hole Elevation(m):2362					Total Depth drilled(m):50.00m				
Date Started : 12-02-2013					Date Completed : 19-02-2013				
SPT: Authomatic Sampling: Splitt spoonand shelve Tube									
core run (m)	Hole dia. (mm)	Core Recovery			Sampling	SPT No. Blows	Graphic LOG	Field Description	Core photography
		TCR%	RQD%	AFS(cm)					
45.50	101	100			45.00	8/14/48	Very stiff ,red to reddish brown Highly plastic, clayey SILT		
46.70		100			45.95				45.50
47.00		100					very stiff to hard, brownish gray, gravelly sandy SILT with occasional slightly weatherd core stone basalt		
47.80		100				47.80			
48.40		100				R 47.90			
50.00	100					50.00	44.00-50.00		
END OF BORE HOLE									

Contractor:  
Subcontractor:  
Consultant: JDAW Consulting Architects  
and Engineers  
Logged By: Getachew Teresa  
Approved By: Gutema Megersa

-  Disturbed soil Sample
-  Rock Sample
-  Undisturbed Sample

Bit Type: Diamond Bit  
Bit diametr: 110,101

Comparative study on reinforced concrete -and- soldier with timber lagging pile wall



**Water level reading after piezometer installation**

BH-01	03/03/13	7:00AM	7.8	
	04/03/13	7:00AM	7.6	
	05/03/13	6:30AM	7.6	
	06/03/13	6:30AM	7.5	
	07/03/13	6:30AM	7.6	
	08/03/13	6:00AM	7.6	
	09/03/13	6:00AM	7.6	
<b>Average</b>			<b>7.6</b>	

## **ANNEX –IV**

# Cost breakdown and bill of quantity

## Comparative study on reinforced concrete -and- soldier with timber lagging pile wall

### ANALYSIS SHEET FOR DIRECT & INDIRECT UNIT COSTS

<b>PROJECT : REINFORCEMENT BARS</b>					<b>LABOUR HOURLY OUTPUT:</b> 12.5 kg./hr														
<b>WORK ITEM: ( 4.2 )</b> dia. 10 - dia. 16 mm. deformed bars					<b>EQUIPEMENT:</b>														
<b>TOTAL QUANTITY OF WORK ITEM:</b> 1 kg					<b>RESULT:</b> 38.04 Birr/kg.														
Material Cost (1:01)					Labour (1:02)					Equipment Cost (1:03)									
Type of Material	Unit	Qty *	Rate	Cost per Unit	Labour by Grade	No.	UF	Indexed Hourly Cost	Hourly Cost	Type of Equipment	No.	Hourly Rental	Hourly Cost						
0 10- 0 16 mm deformed bars	kg	1.05	21	22.05	foreman	1	0.25	35	8.75	steel cutter	1	10	10.00						
1.5 mm black Annealed wire	"	0.0125	31	0.3875	bar bender	1	1	20	20.00	hand tools	1	3	3.00						
				0	D/L	3	1	10	30.00				-						
				0					0.00				-						
				0					0.00				-						
				0					0.00				-						
				0					0.00				-						
				0					0.00				-						
				0					0.00				-						
				0					0.00				-						
<b>Total (1-01)</b>				22.4375	<b>Total (1:02)</b>				58.75	<b>Total (1:03)</b>				13.00					
A= Materials Unit Cost		22.4375	Birr/kg.		B= Manpower Unit Cost		4.70	Birr/kg.		C= Equipment Unit Cost		1.04	Birr/kg.						
<b>Total of (1:02)</b>					<b>Total of (1:03)</b>														
Hourly Output:					11.25/12.5=0.90					Hourly output:									
Direct Cost of Work Item = A+B+C =					28.18					Birr/kg.									
Over head cost :					20%					5.636					"				
Profit Cost:					15%					4.227					"				
Total Unit Cost :					38.040					Birr/kg.									
Remark																			
UF: UTILIZATION FACTOR																			
*: INCLUSIVE OF WASTAGE, TRANSPORTING, HANDLING, ETC.																			
**: INCLUSIVE OF BENEFITS, TRAVEL SUBSIDES AND COST OF OVERTIME RELATED TO TARGETED OUTPUT.																			

<b>PROJECT: CONCRETE WORK</b>					<b>LABOUR HOURLY OUTPUT:</b> 0.7 m <sup>3</sup> / hr.														
<b>WORK ITEM: ( 3.5 )</b> C-25 Concrete 1:2:3 for super structure					<b>EQUIPEMENT: Mixer &amp; Vibrator</b> 1 m <sup>3</sup> / hr.														
<b>TOTAL QUANTITY OF WORK ITEM:</b> 1 m <sup>3</sup>					<b>RESULT:</b> 3520.46 Birr/m <sup>3</sup>														
Material Cost (1:01)					Labour (1:02)					Equipment Cost (1:03)									
Type of Material	Unit	Qty *	Rate	Cost per Unit	Labour by Trade	No.	UF	** Indexed Hourly Cost	Hourly Cost	Type of Equipment	No.	UF	Hourly Rental	Hourly Cost					
Cement	Qnt.	1.6	330	528	Foreman	1	0.25	35	8.75	Mixer	1		300	300					
Sand	m <sup>3</sup>	0.6	550	330						Vibrator	2		150	300					
Gravel (02)	m <sup>3</sup>	0.86	550	473	gang chief	1	1	20	20	spay mashine									
					D/L	35	1	10	350										
									0										
									0										
									0										
<b>Total (1-01)</b>				1331	<b>Total (1:02)</b>				378.75	<b>Total (1:03)</b>				600					
A= Materials Unit Cost		1331.00	Birr/m <sup>3</sup>		B=Manpower Unit Cost		518.01	Br./m <sup>3</sup>		C= Equipment Unit Cost :		600.00	Br./m <sup>3</sup>						
<b>Total of (1:02)</b>					<b>Total of (1:03)</b>														
Hourly Output					2449.01					Birr/m <sup>3</sup>									
Direct Cost of work item = A+B+C =					612.25					"									
Overhead Cost:					25%					3061.27					"				
Total					15%					459.19					"				
Profit Cost:					3520.46					Birr/m <sup>3</sup>									
Total Unit Cost :					3520.46					Birr/m <sup>3</sup>									
Remark																			
UF: UTILIZATION FACTOR																			
*: INCLUSIVE OF WASTAGE, TRANSPORTING, HANDLING, ETC.																			
**: INCLUSIVE OF BENEFITS, TRAVEL SUBSIDES AND COST OF OVERTIME RELATED TO TARGETED OUTPUT.																			

**Table 63 : 3.7 m first level anchor and 1.5m spacing for reinforced concrete pile wall Bill of quantity**

item No	Description	Estimated quantity	unit	unit price	Amount
1	Mobilization of all equipment, tools auxiliary accessories and staff for shoring work and complete shoring system design	LS		150,000	15000
<b>Sub total</b>					15000
2	Installation of anchored pile shoring wall for Zemen bank head quarter project depth of maximum 17.0 m depth including supply of all equipment, manpower and material				
	Bored cast in situ piles to design of maximum 17m one and two layer of three strand tie back anchors and reinforced shot crete between piles				
2.1	Drilling of piles appx, Diam 600m piles in all soil formation to SI report provided				
	Appx	1472	m	1800	2,649,600.00
2.2	Installation of drilling casing for Diam.600mm piles in all soil formation according to SI report provide				-
	Appx		m	400	-
2.3	Supply and install reinforcement for board cast in situ piles diam 600m				-
	Appx				-
	a)Φ 24 deformed bar	93792.9	kg	38.04	3,567,530.19
	b)Φ 12 deformed bar	4791.7	kg	38.04	182,258.30
2.4	Installation of concrete in diam .600mm piles including supply of cement for C-25 concrete pumpable filing concrete. Installation and pouring of concrete with tremie method and crane and complete supervision				-
	Appx	419	m <sup>3</sup>	3520.46	1,475,073.79

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2.5	Supply and install double strand tension wires with grouted anchor blocks at 30 degree inclination including performing the grouted body with grouting mix, anchor head, cement and any other related accessories and equipment. Two strand of different length each shall be used for each pile with anchor blocks of length and as per the drawing respectively. Each strand is with 7 tension wire of grade 1670/1860 Mpa of different length with tensile characteristic strength of 250 KN				-
	a)double strand tension wire	3036	m	1900.00	5,768,400.00
	b)Grouted anchor blocks	1564	m	1900.00	2,971,600.00
2.6	Proof testing of anchor in acc.to DIN 0414				-
	Appx	184	No	800.00	147,200.00
2.7	Perform shot-Crete membrane between installed reinforced concrete pile thickness of 20 cm. including supply of OPC cement Appx 1.6 qt per m2	2070	m <sup>2</sup>	1231.88	2,549,981.25
	Appx				-
2.8	reinforcement bars of for shot crete wall cut to size ,bent to shape tied and placed in position according to structural drawings				-
	a)Φ 12 deformed bar	17646.47	kg	38	670,565.86
	a)Φ 8 deformed bar	5331.81	kg	38	202,608.78
3	Stand –by charge for complete plant and equipment for idle hours caused by non-performance of the client		Hr	3400	-
	Appx				-
<b>Sub total</b>					<b>20,184,818.17</b>
<b>Total</b>					<b>20,199,818.17</b>

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Table 64: 3.7 m first level anchor and 1.5m spacing for soldier pile wall

item No	Description	Estimated quantity	unit	unit price	Amount
1	Mobilization of all equipment, tools auxiliary accessories and staff for shoring work and complete shoring system design	LS		150,000	150,000
<b>Sub total</b>					150,000
2	Installation of soldier pile shoring wall for Zemen bank head quarter project depth of maximum 15.0 m depth including supply of all equipment, manpower and material				
	install piles to design of maximum 17m one and two layer of three strand tie back anchors and reinforced shot crete between piles				
2.1	Drilling of piles appx, HE 550 -piling set in predrilled holes tf =4cm ,bf=30.6 cm piles in all soil formation to SI report provided				
	Appx	1350	m	1800	2,430,000.00
2.2	Installation of drilling casing for HE 650 -piling set in predrilled holes tf =4cm ,bf=30.6 cm piles in all soil formation according to SI report provide				-
	Appx		m	400	
2.3	Supply and install Soldier piles or soldier beams are HE 550 -piling set in predrilled holes tf =4cm ,bf=30.6 cm				-
	Appx	292,531.15	kg	55.00	16,089,213.25
2.5	Installation of including temporary grouted anchors, including performing the grouted body with grouting mix and anchor heads, including supply of materials, anchor strands grouting pipe and anchor head, including supply of OPC				-

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	cement. Installation of casing priced separately				
	Appx	2400	m	2200.00	5,280,000.00
2.6	Proof testing of anchor in acc.to DIN 0414				
	Appx	180	No	800.00	144,000.00
2.7	supply and install 5cm timber lagging cut to fit between the webs of adjacent soldier piles is place in back of the front the front flanges of the pile price shall be included Anti-termite or varnish painting , bolts	1362.75	m <sup>2</sup>	650.00	885,787.50
	Appx				-
3	Stand –by charge for complete plant and equipment for idle hours caused by non-performance of the client		Hr	3400	-
	Appx				-
				<b>Sub total</b>	<b>24,829,000.75</b>
				<b>Total</b>	<b>24,979,000.75</b>