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Numerical Modeling for Deepening in Front of Gravity Quay Wall

Case study: Alexandira port – Berth 65

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ABSTRACT

The focus of this paper is on examining various methods of enhancing quay walls to support the handling of larger vessels with increased drafts. The emergence of bigger ships necessitates upgrades in ports, including improvements in infrastructure, berths, and navigation channels. The primary objective of this research is to investigate different structural options available for the deepening of existing quays to facilitate the accommodation of these new categories of sizable vessels. These alternatives aim to address the discrepancy in bed levels resulting from the deepening process while ensuring successful operation. A numerical modeling study (PLAXIS, 2020) was conducted to investigate the deepening of a block-type quay wall in Alexandria port, Egypt. The study focused on two different techniques and their effects on factors such as global factor of safety, straining actions (bending moment, shear, normal), and deformation of the proposed shoring system. Two solutions were explored to deepen the quay wall while ensuring its overall stability. The first solution involved an anchored diaphragm wall with a tie connected to a back barrette, while the second proposed solution featured a diaphragm wall anchored by a relief slab supported by two rows of piles and a barrette. A comparison between the two proposed solutions was conducted to evaluate their effectiveness. please rephrase and shorten this paragraph, from main conclusion of this comparison is that second alternative is recommended in case of high loads, especially high surcharge loads, or the presence of gantry cranes. This recommendation is based on the advantages offered by the second alternative, which include the ability to minimize the significant lateral pressure exerted on the diaphragm wall also first alternative has low cost particularly when compared to the second alternative. This cost advantage stems from the relatively lower construction expenses associated with the connecting elements between the diaphragm wall and the barrette. In contrast, the second alternative incurs significantly higher costs due to the construction requirements for elements such as the relief slab and the two rows of piles.

Keywords: quay wall, deepening, PLAXIS, Diaphragm, anchoring, F.O.S, Straining actions

INTRODUCTION

The past two decades have witnessed a significant surge in global trade, largely facilitated by the remarkable expansion of maritime commerce and the cost-effectiveness of long-distance transportation per unit of weight. One notable trend associated with this growth is the substantial increase in the size of container vessels, which has been attributed to the reduction in transportation expenses. As a result, there is a pressing need for the swift development and upgrading of quays to accommodate these larger vessels. (Ruggeri et al., 2019).

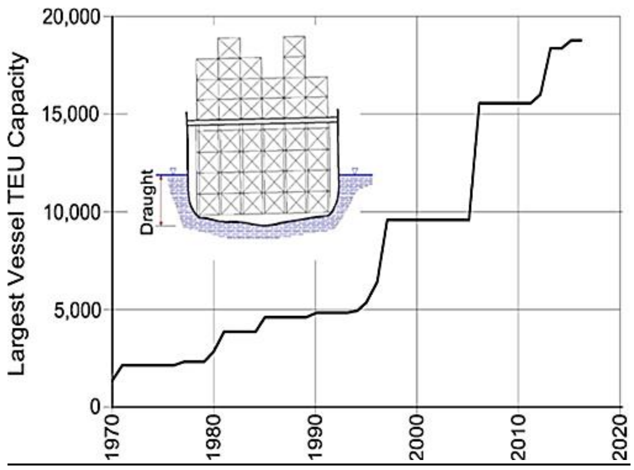

Figure 1-A: Development of vessels capacity with time (Ruggeri et al., 2019)

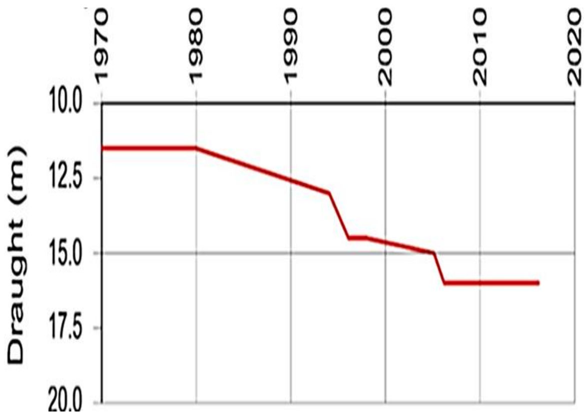

Figure 1-B: Development of vessels draught with time (Ruggeri et al., 2019)

Quay wall are composed of several types such as which are gravity, sheet pile and open quay walls. The focus of this paper is on gravity types. The function of retaining in gravity wall is achieved by the structure's own weight, which occasionally includes the weight of the soil above it. Gravity quay walls have many types and configurations in order to establish geotechnical functions. Among these types, blocks quay wall which is constructed by positioning precast concrete blocks to achieve stability condition due to its own weight. Other gravity type is caisson quay wall which may be considered as tank filled with soil to gain weight responsible for achieving stability condition. L-shaped quay is considered efficient gravity quay walls as soil weight on wall footing is stabilizing factor for quay.

Upgrading Techniques

(Bauduin et al., 2017) classifies types of upgrading to achieve deepening in front of quays as follows: -

- **Soft upgrade**: is executed by local structural strengthening or renovation with little geotechnical work. For example, soil grouting at active side behind quay wall to decrease active forces exerted on it.
- **Medium upgrade**: medium upgrades maintain the functionality of existing quay walls, but additional elements and treatments are needed to meet upgrade requirements. The upgraded quay wall structure includes the existing quay wall as an active element in upgrading

process by rehabilitation, supplemented by geotechnical works are largely applied as geotechnical improvement or additional anchors or (micro) piles. For example, medium upgrading works occurred during the development of Port of Genoa (San Giorgio Pier). as presented by (Ruggeri et al., 2019). An existing quay wall was upgraded by underpinning jet grouting columns beneath existing block wall and these grouting columns were reinforced by steel rods so that blocks and reinforced grouting columns as one unit to retain soil after deepening in front of existing quay wall.

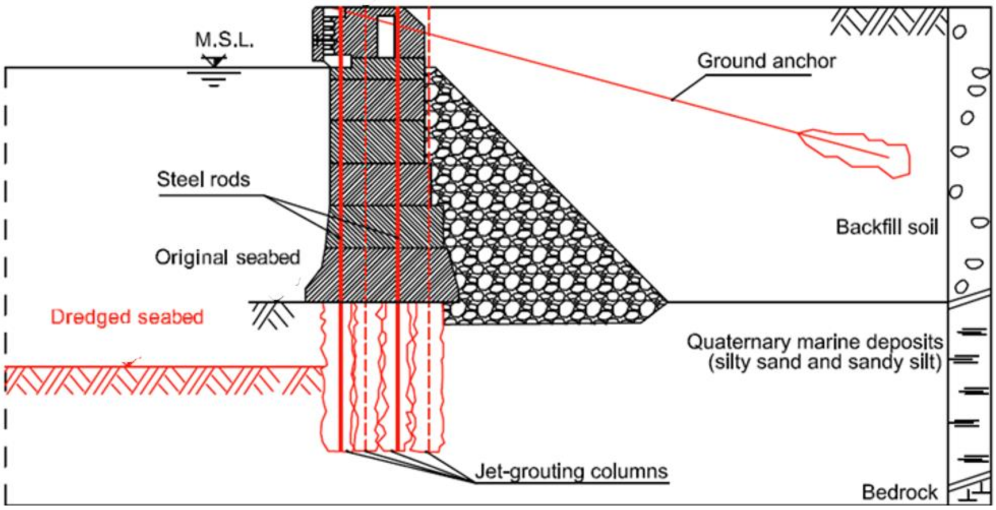

Figure 2 San Giorgio Pier (Port of Genoa): cross-section of the quay and representation (modified after Ruggeri et al., 2019)

- **Hard upgrade**: is executed by ignoring pre-existing wall by the new one. The old one can either be destroyed or a new building can be erected over and around the old one's remnants: No function considers the existing quay wall.

(Douairi, 2013) classified techniques of quay walls deepening from structural perspective as positive, negative or neutral alternatives. Positive alternative relies on increasing resistance either by new structure or by geotechnical improvement such as soil grouting in passive side. Negative alternative relies on decreasing driving forces such as elimination of surcharge effect by construction of relief platform. Neutral alternative concept is to construct new quay in front of existing quay.

Case study

- **Quay Wall Location**

In this paper, Berth 65 located at Port of Alexandria is used as a case study for studying different alternatives for deepening its quay wall using the software PLAXIS. The Port of Alexandria is considered the largest and oldest port in Egypt. Alexandria Port is one of the largest ports in the Mediterranean Sea and serves as a major hub for trade and transportation in the region. Figure 3 shows a satellite image of Alexandria Port. Figure 4 shows the location of Berth 65 highlighted in red color.

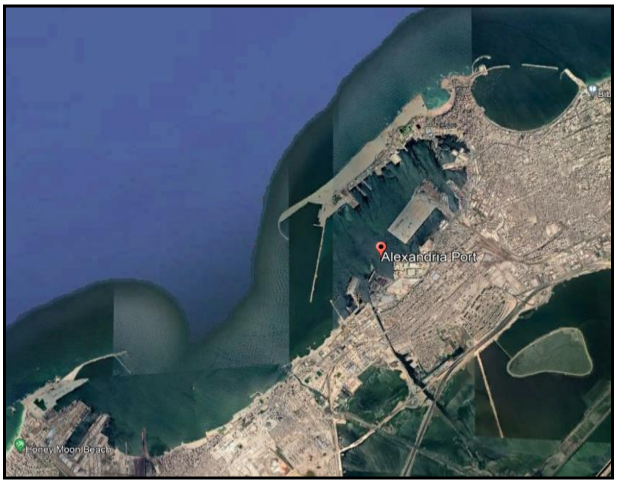

Figure 3 : General Layout of Alexandria Port

The port is divided into two parts separated by coal berths and the inner breakwater. The first part is called the inner dock and the second part is called the outer port with a water area of 600 hectares. The first part of port is used for handling general cargo while the second part of port is used for oil and bulk cargo traffic. Pilotage is mandatory for vessels arriving and departing from the port. Water Area equals 6.80 sq.km approximately where land area equals 1.6 sq.km approximately. Maximum Capacity for 37.9 million ton/year details as follows: General Cargo: 18.4-million-ton, Dry Bulk: 5.6 million ton. Liquefied Bulk: 3.9-million-ton, Containerized Cargo: 10 million ton and TEU Capacity: 1000000 (Alexandria port authority, 2023).

Berth 65 is located in Alexandria port which is mainly used for handling of general cargo and chemical products. The berth is existing in front of the new multipurpose terminal named as Tahya Masr, Existing bed level is below MLWL (mean low water level) by 10m which limits the size of berthing. In this paper, Berth 65 is used as a case study to investigate different alternatives of an existing quay wall deepening and upgrading.

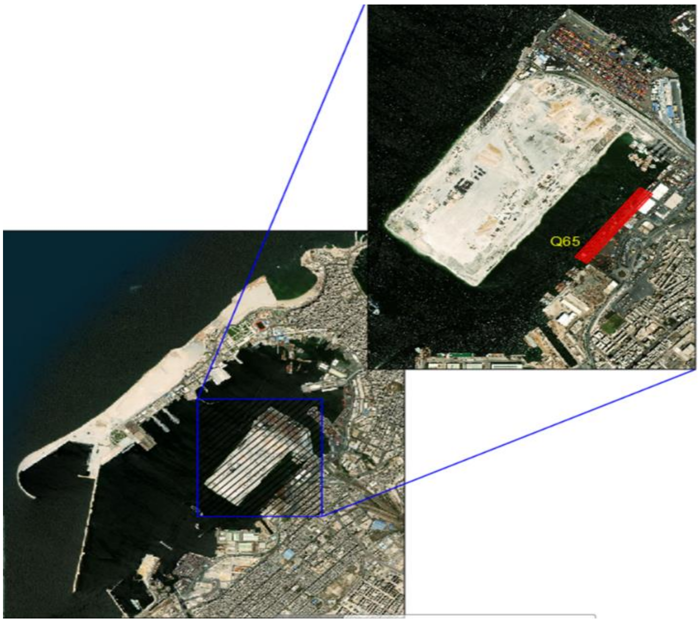

Figure 4 : satellite image for quay wall location

- **Description of the Existing Quay Structural elements**

Berth 65 is composed of five concrete blocks rested on rubble foundation with thickness of 1.50m. The soil beneath rubble foundation was previously replaced with sand fill with thickness of 5.00m. The total height of blocks is 12.40m. The blocks width increases with the increase of depth to resist the increase of soil active force.

The blocks height from top to down are 1.8, 3.00, 2.60, 2.50 and 2.50 m, respectively. The width of blocks from top to down are 3.00, 3.60, 5.00, 6.00 and 6.50m, respectively. The fill behind blocks is composed of rubble followed by sand backfill with high friction angle is positioned to decrease the active force on wall.

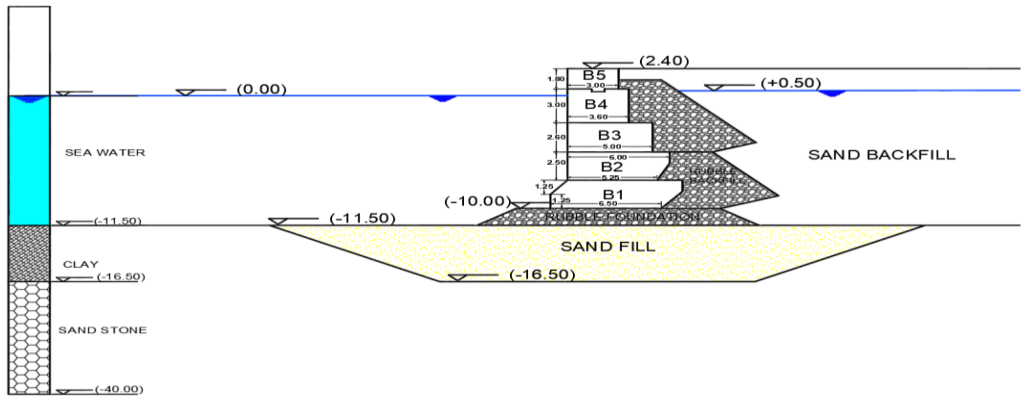

Figure 5: Existing quay wall cross section

- **Geotechnical data**

Some boreholes were drilled in the basin of port in front of quay wall 65. It is assumed that MLWL is the zero level of the boreholes. Boreholes indicated that from bed level (-11.5m) till level (-16.0m), the soil comprises silt clay and from level (-16.0m) till the borehole end is sandstone. The geotechnical parameters are indicated in the following Table 1. Geotechnical parameters are assumed based on description of soil layers across drilled boreholes (Alexandria port authority, 2023).

Table 1: geotechnical properties for soil types

Layer name	Soil model	Top level (m)	Saturated specific weight (kN/m^3)	Dry specific weight (kN/m^3)	Internal friction (degree)	Cohesion (kPa)	E_{50} (kN/m^2)	E_{oed} (kN/m^2)	E_{ur} (kN/m^2)	m
CLAY	H. S	-11.5	16	15	0	6.5	2.00E+03	2.00E+03	6.00E+03	1
SANDSTONE	H. S	-16.5	18	16	30	0	1.00E+05	1.00E+05	3.00E+05	0.5
BACKFILL SAND	H. S	-	18	16	35	0	5.00E+04	5.00E+04	1.50E+05	0.5
RUBBLE	H. S	-	20	18	40	0	1.00E+05	1.00E+05	3.00E+05	0.5
GROUTED RUBBLE	LINEAR ELASTIC	-	22	20	-	-	3.00E+06	-	-	-
CONCRETE	LINEAR ELASTIC	-	22	22	-	-	3.00E+07	-	-	-

- **Loads**

Dead loads: The loads resulted from structural elements and this load calculated by PLAXIS 2D.

Surcharge: The live loads acting on the slab behind quay wall. It was assumed to be 20 kN/m^2 according to the Egyption National Institution for Construction Reserches, 2001) s shown in Table 2.

Table 2: Surcharge load values according to (Egyption National Institution for Construction Reserches, 2001)

Type of berth	Surcharge (kN/m^2)
Containers	40.00
Dry bulk	30.00
General cargo	20.00
Passenger	10.00
Liquid bulk	10.00

The tidal range in Mediterranean Sea at Alexandria Port is about 0. 46 m. In the modelling, it was assumed that the water level behind the quay wall is higher than the sea level Infront of the quay wall by 0.46 m. This is known as tide lag (i.e, difference between MHWL and MLWL) as the water level behind the wall takes longer time to reach the same level of sea water Infront of the wall.

Bollard loads resulting from pull out from ship chains due to wind and current loads was assumed to be 2000 KN for each bollard with spacing of 30m based on the maximum value provided by the British Standards of Maritime Structures (BSI-6349, 2000). In this paper, it was assumed that the existing quay wall will be upgraded to accommodate super Panamax vessels of DWT exceeds 200,000 Tonnes.

Table 3: Bollard empirical load values according to (BSI-6349, 2000)

Ship displacement (tonnes)	Mooring point load (tonnes)
20 000 up to and including 50 000	80
Above 50 000 up to and including 100 000	100
Above 100 000 up to and including 200 000	150
Above 200 000	200

Some Main Techniques for deepening of gravity walls

The retaining function of gravity walls is obtained by the own weight of the structure and sometimes including the weight of the soil lying above it. According to this type of quay walls, high stresses occur below quay wall foundation, which makes deepening process more difficult. The main function of any proposed structural solution is to retain the dredged bed level during and after the upgrade process.

- **First technique**

Concept of first technique is to retain the difference of bed levels which called deepening depth by using shoring system which is mainly composed of retaining wall (diaphragm wall or sheet pile). This retaining wall may need anchorage system to decrease lateral deformation and straining actions of retaining wall. There are many types of anchorage systems as tie and dead man, tie and back sheet pile or barrette or by using grouted anchor where grouted body is located away from failure slip circle. Figure 6 presents sketch illustrating the first deepening technique.

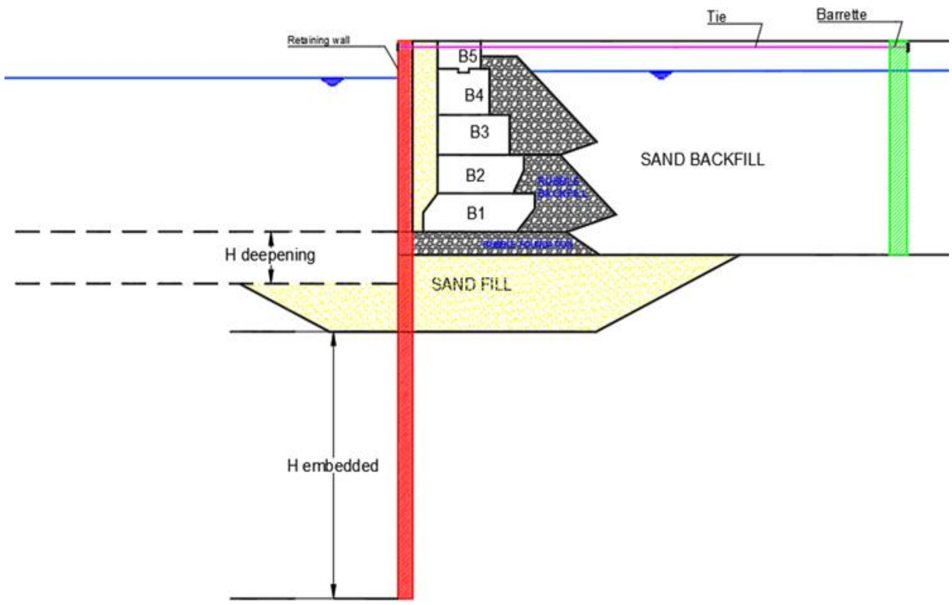

Figure 6: First deepening technique

A similar upgrade process was executed at port of Ancona in Italy as an example of the first technique where new structure was constructed in front of the existing wall. Sheet pile wall consisting of octagonal precast concrete columns (14m in length, with a total cross-section of (500×500 mm) were installed side-by-side in front of the blocks. The sheet pile was then anchored using horizontal steel rods placed at 3m intervals at the heads of the pilings, to a dead man consisting of a concrete block with dimensions of 2.1×2.0×1.2m (WxLxH) located at a distance of 15m from the seaside. Executed solution is shown in Figure 7. (Ruggeriet al.,2019)

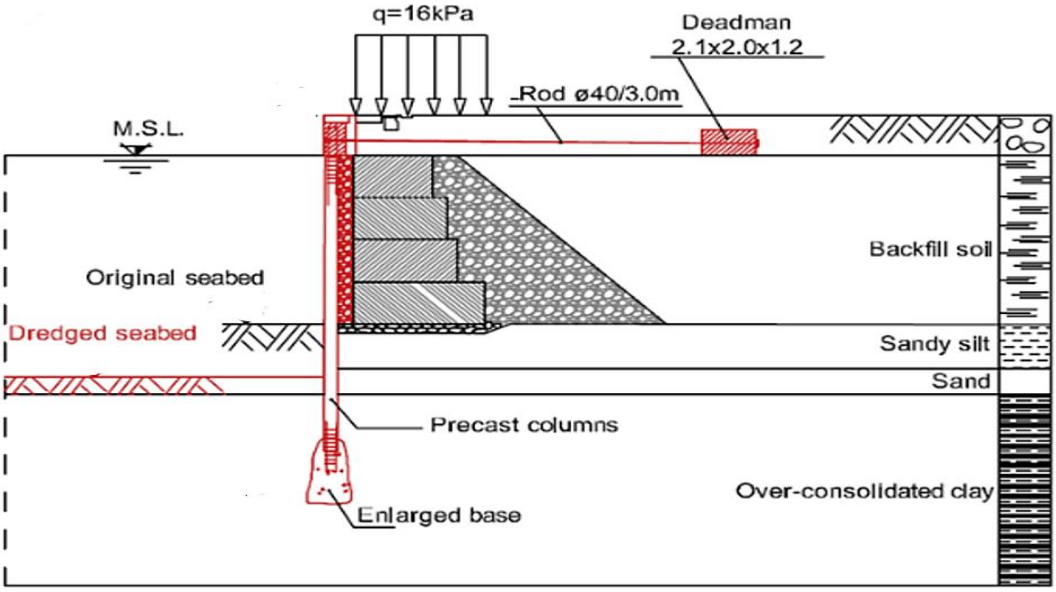

Figure 7 : Application for first deepening technique used for upgrade of gravity quay wall in Italy (modified after Ruggeri et al., 2019)

- **Second technique**

Concept of Second technique is to grout rubble foundation beneath gravity quay wall to act as concrete block below existing wall so that deepening process may be done in front of quay wall. This technique was studied by (Nguyen et al., 2021) as they studied caisson quay wall which get deepened by grouting rubble foundation. From examples of upgrading quay wall by using grouting is modernization of gravity quay wall at Port-of-Antwerp as introduced by and Ponnet et. al. (1992) . Upgrade project depended on installation of double row of soilcrete columns at the wall face have an inclination of 4° toward the sea and extends down to about 3.5 m below the new dredged bottom level. Additionally, transverse walls formed from similar soilcrete columns were installed at 6.0 m center-to-center along the wall.

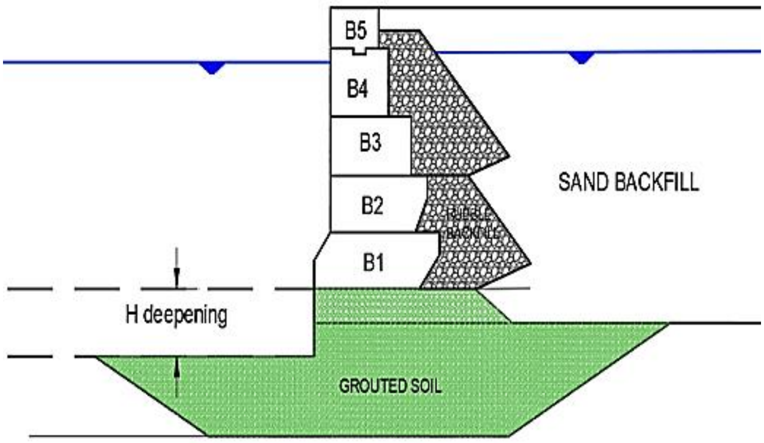

Figure 8: Second deepening technique

(Taricone, 1994) explained grouting technique as it is executed by producing "soilcrete" (a soil-cement mixture) components in horizontal, vertical, and interlocking rows, jet grouting can produce load-bearing structural parts. The in-situ soil and cement slurry are thoroughly and hydraulically mixed to create the soilcrete column.

- **Third technique**

Among the applicable solutions in case of deepening of gravity walls is to construct a new relieving platform in front of the existing quay. This platform is usually supported on piles penetrating soil slope between existing bed level and new bed level. This slope should be protected by revetment to prevent occurrence of any scour from ship propeller waves. Slope should start away from foundation by sufficient length to ensure slope stability. However, but this solution needs sufficient space in front of wall. This solution was introduced by Tsinker (1997).

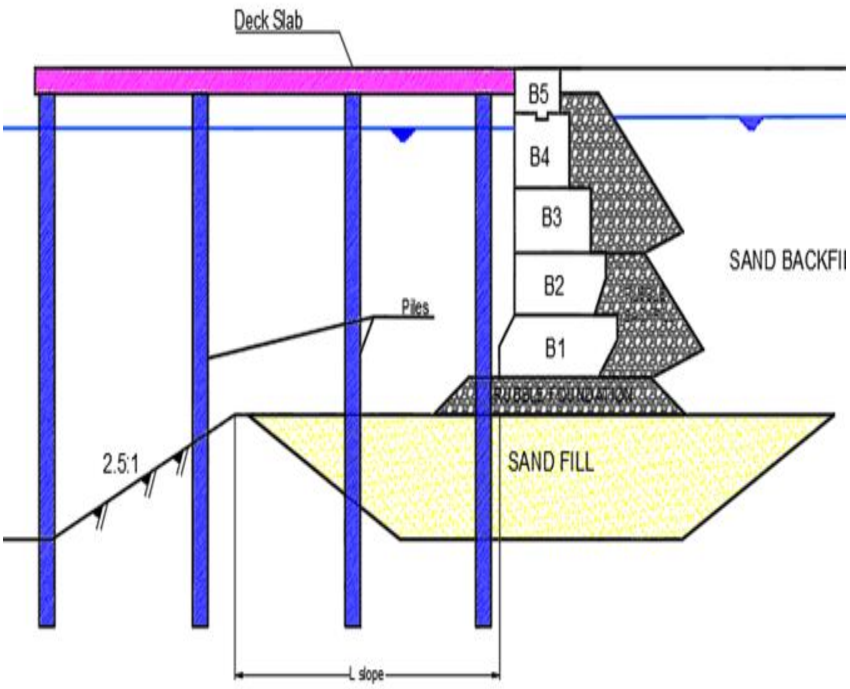

Figure 9: Third deepening technique

Proposed alternatives

In this paper, two alternatives are considered for deepening berth 65. The two alternatives comprise a diaphragm wall placed in front of the existing block quay wall. Before the construction of diaphragm wall, a temporary embankment is constructed to facilitate construction of concrete diaphragm wall. Concrete diaphragm wall is chosen instead of steel sheet pile due to difficulties in embedding sheet pile in sand stone layer.

Alternative 1

Alternative 1 is based on retaining the difference in bed level deepening depth (H_d) which is the difference between the bottom level of the last block at El. -10.00m and the proposed new level at

El.-16.50m by using anchored diaphragm wall. Wall is anchored by using tie rod with diameter of120mm which is connected to barrette (800*2000) mm which acts as a Deadman.

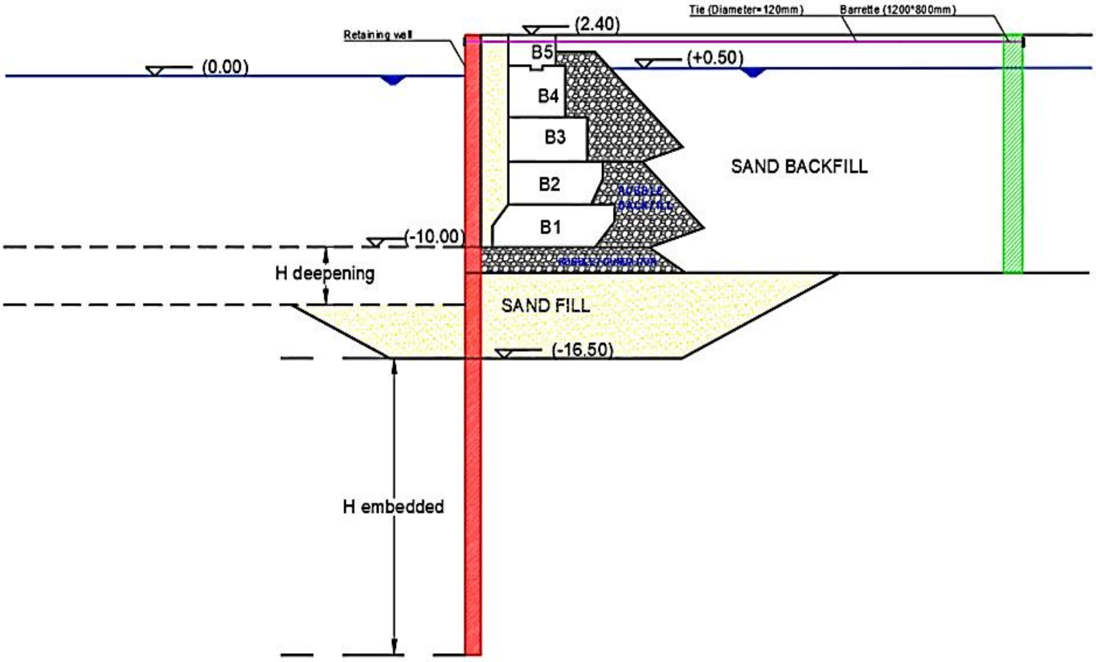

Figure10: Section Elevation for alternative 1

Effect of increasing Deepening Depth (H_d) on Global Factor of Safety (Global F.O.S)

Deepening process in front of quay wall leads to a considerable effect on stability of proposed structural system and the straining actions across proposed the structural elements. This may be happened due to decrease of passive resistance in front of proposed diaphragm wall.

Global factor of safety of upgraded structure is affected by many factors such as geotechnical characteristics, structure properties, assigned loads, deepening depth (Hd) and embedded depth (He). Increasing deepening depth leads to increase in retaining height which has a severe effect on soil stresses, deformation and global factor of safety.

To investigate such effect, six values of (Hd) have been adopted, (Hd = 1.5, 2.5,3.5,4.5,5.5 and 6.5) m. The other parameters of model were kept constant as geotechnical properties which mentioned in detail in Table 1, structural elements properties as embedded depth of diaphragm wall inside soil (He=5m), thickness of diaphragm wall (Td=1000mm) and position of proposed diaphragm wall with respect to existing block wall where diaphragm wall is located in front of existing wall.

It was found that by increasing (Hd) by 1.50, 2.50,3.50,4.50,5.50 and 6.50m factor of safety decreased to 2.57, 2.51, 2.45, 2.41, 2.38 and 2.34 respectively as shown in Figure 11.

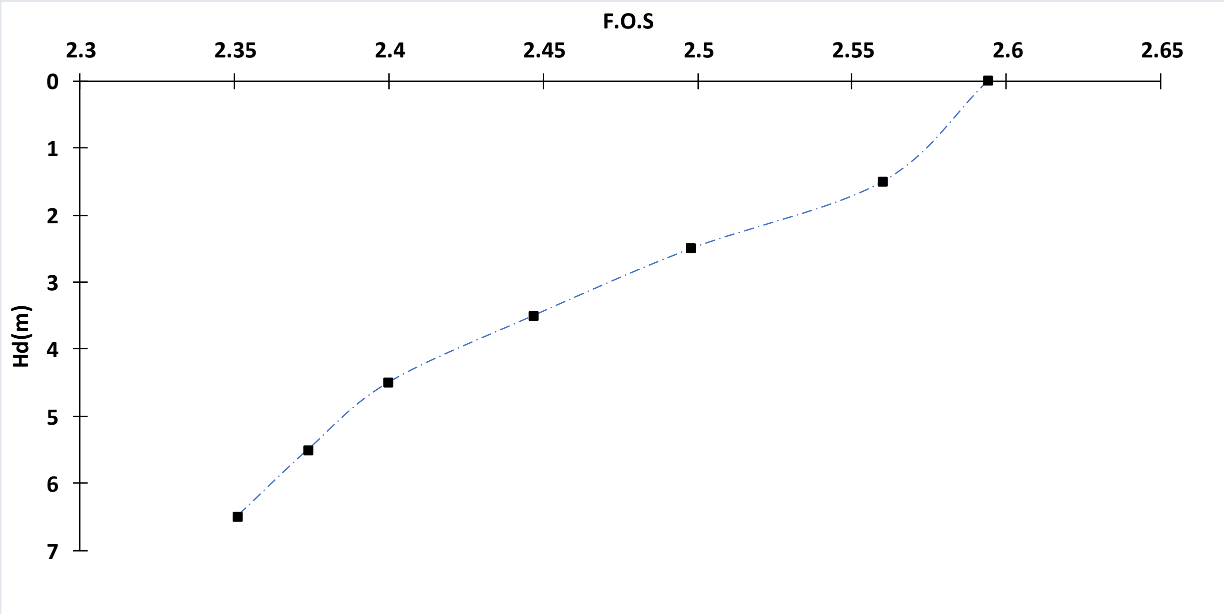

Figure 11: F.O.S vs H_d at (H_e=5m)

Effect of increasing Deepening Depth (H_d) on Straining actions of diaphragm wall

To study the effect of increasing the deepening depth on straining actions of the diaphragm wall, a case with no deepening in the presence of diaphragm wall is taken as a reference. Figure 12 presents effect of Hd on tension force of anchor. Figure 13, Figure 14, Figure 15 and Figure 16 present the effect of deepening depth (Hd) on straining actions like bending moment, shear force, normal force and lateral deformation along the proposed diaphragm wall. The straining actions and deformation are increasing with different ratios as illustrated in Table 4

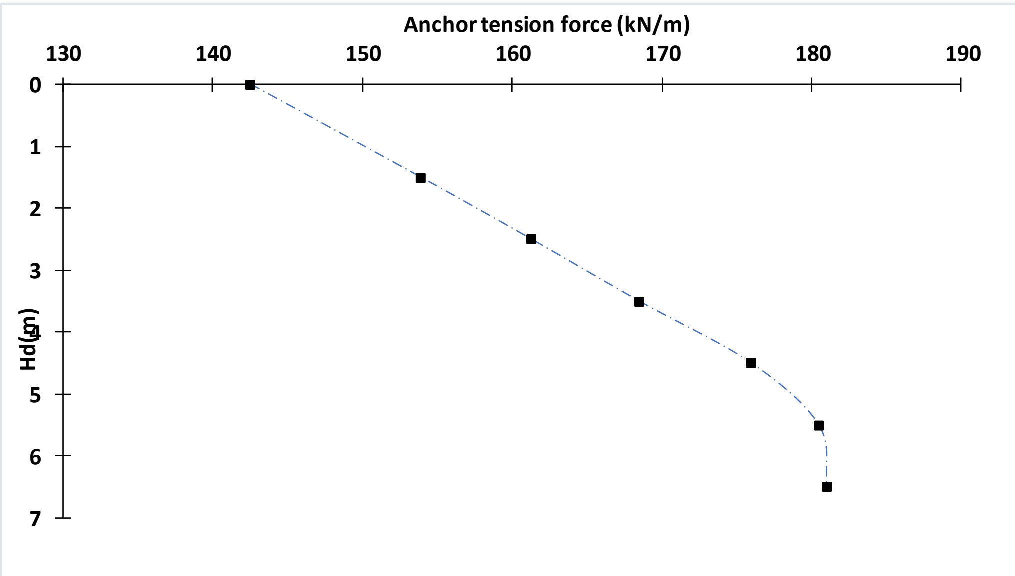

Figure 12: Fa vs H_d at (H_e=5m)

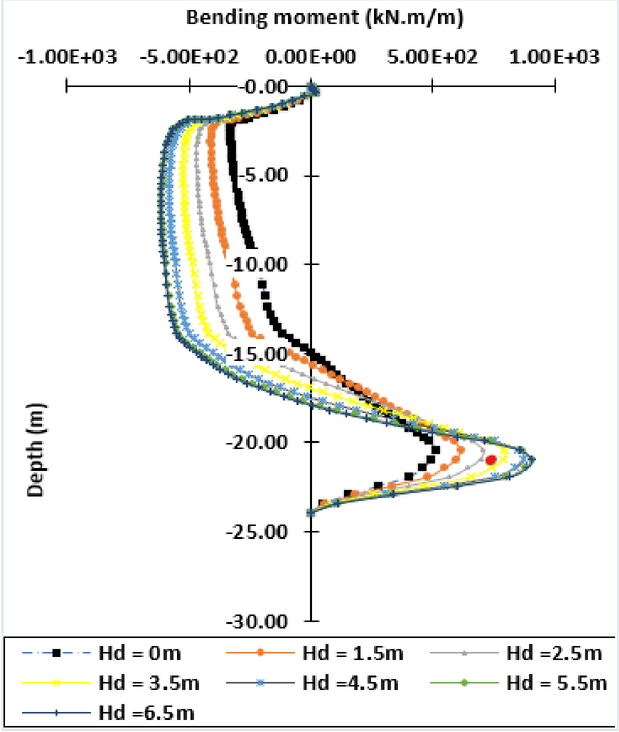

Figure 13: B.M. Vs Depth of DW at (H_e=5m)

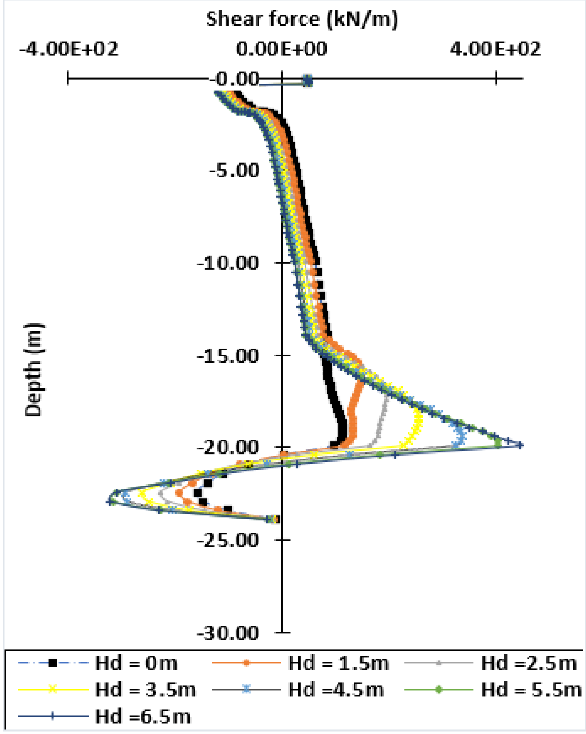

Figure 14: S.F vs Depth of DW at (H_e=5m)

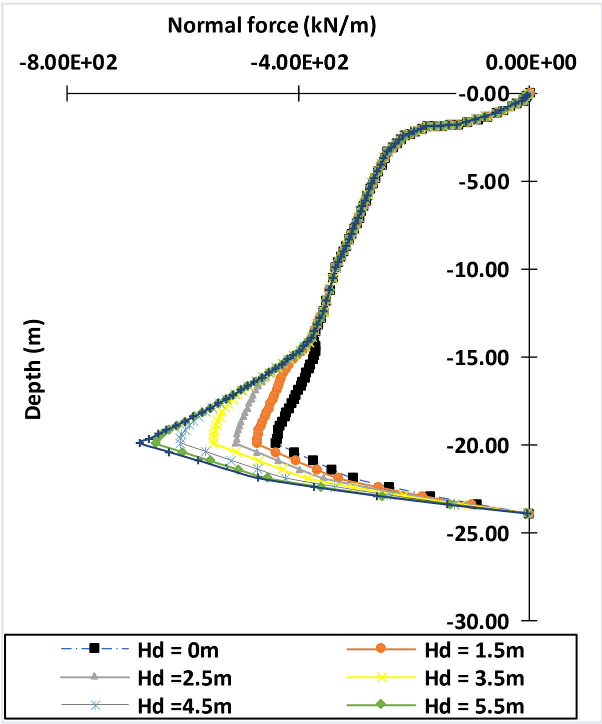

Figure 15: N.F vs Depth of DW at (He=5m)

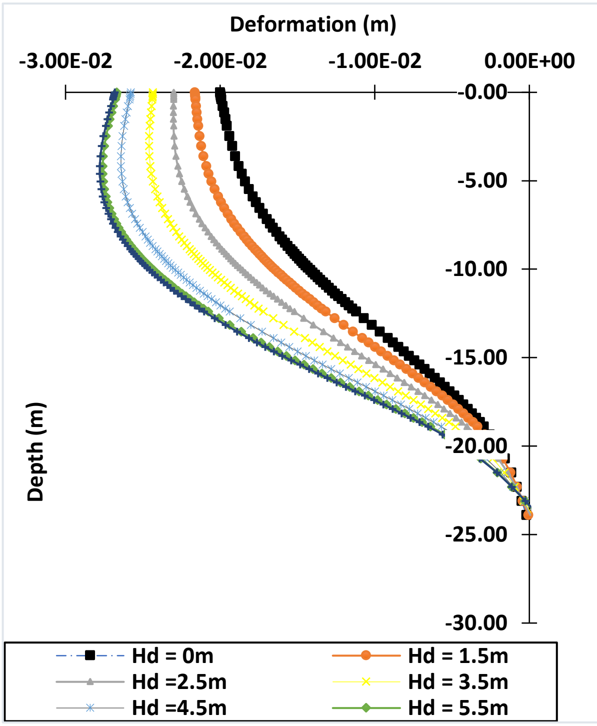

Figure 16: Deformation vs Depth of DW at (H_e=5m)

Table 4: Maximum straining actions of diaphragm wall Vs H_d

H_d (m)	Anchor tension force (kN/m)	Tension force change (%)	Maximum (-ve) Bending Moment (kN.m/m)	Bending Moment change (%)	Maximum. Shear force kN/m	Shear force change (%)	Maximum. Normal force kN/m	Normal force change (%)	Maximum. Deformation in (m)	lateral deformation change (%)
0	1.43E+02	0.00%	-3.34E+02	0.00%	1.14E+02	0.00%	-4.39E+02	0.00%	-2.00E-02	0.00%
1.5	1.54E+02	7.98%	-4.12E+02	23.32%	1.49E+02	30.25%	-4.73E+02	7.69%	-2.16E-02	8.13%
2.5	1.61E+02	13.17%	-4.69E+02	40.14%	1.97E+02	71.92%	-5.08E+02	15.75%	-2.30E-02	15.03%
3.5	1.68E+02	18.23%	-5.24E+02	56.62%	2.56E+02	124.27%	-5.47E+02	24.58%	-2.46E-02	22.95%
4.5	1.76E+02	23.49%	-5.81E+02	73.62%	3.37E+02	194.80%	-6.04E+02	37.54%	-2.64E-02	32.02%
5.5	1.80E+02	26.63%	-6.14E+02	83.55%	4.04E+02	253.12%	-6.48E+02	47.68%	-2.76E-02	37.95%
6.5	1.81E+02	27.00%	-6.17E+02	84.39%	4.46E+02	290.37%	-6.75E+02	53.75%	-2.78E-02	38.87%

From the previous figures and tables, increasing deepening depth by 1.00 m leads to decrease in F.O.S by a value of about 1% and increasing in the maximum negative bending moment by 17%, while rate of increase of shear force is considered to be exponential as H_d increases, Maximum. Normal with avg. 8% and deformation with avg. %7.

Effect of increasing Deepening Depth (H_d) on Straining actions of barrette

To study the effect of increasing the deepening depth on straining actions of the barrette, a case with no deepening in the presence of diaphragm wall is taken as a reference. Figure 17, Figure 18, Figure 19 and Figure 20 present the effect of deepening depth (Hd) on straining actions like bending moment, shear force, normal force and lateral deformation along the proposed diaphragm wall. It is clearly seen that as Hd increased, the straining actions and deformation increased with different ratios as illustrated in Table 5.

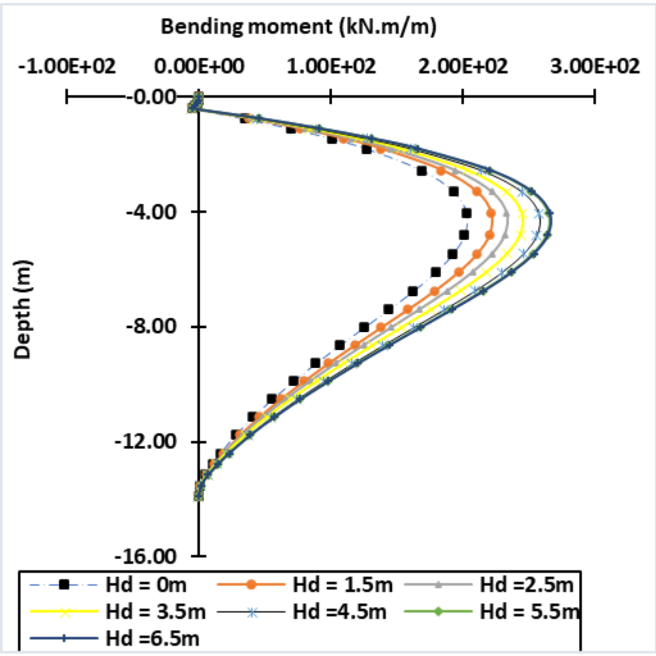

Figure 17: B.M vs Depth of barrette at (H_e=5m)

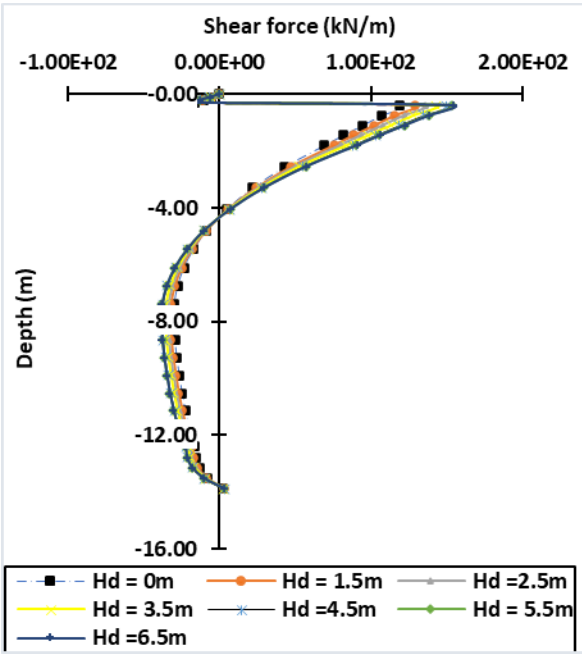

Figure 18: S.F vs Depth of barrette at (H_e=5m)

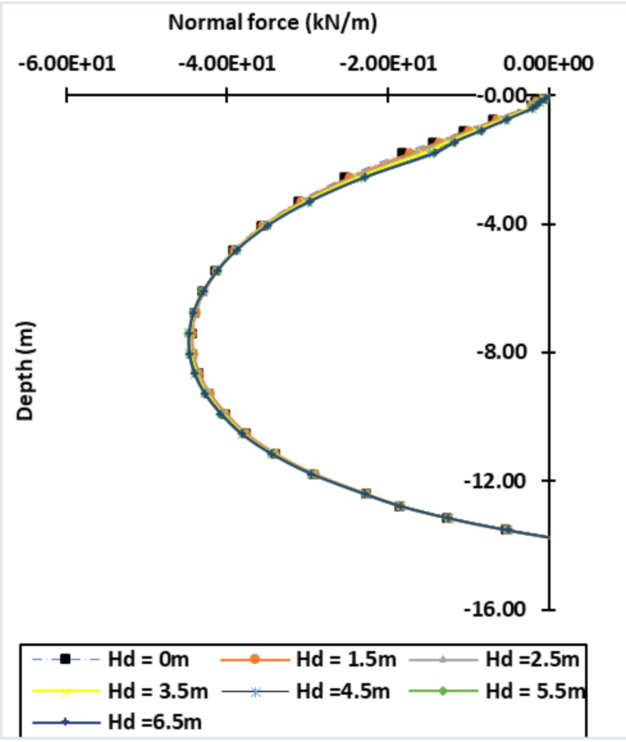

Figure19: N.F vs Depth of barrette at (H_e=5m)

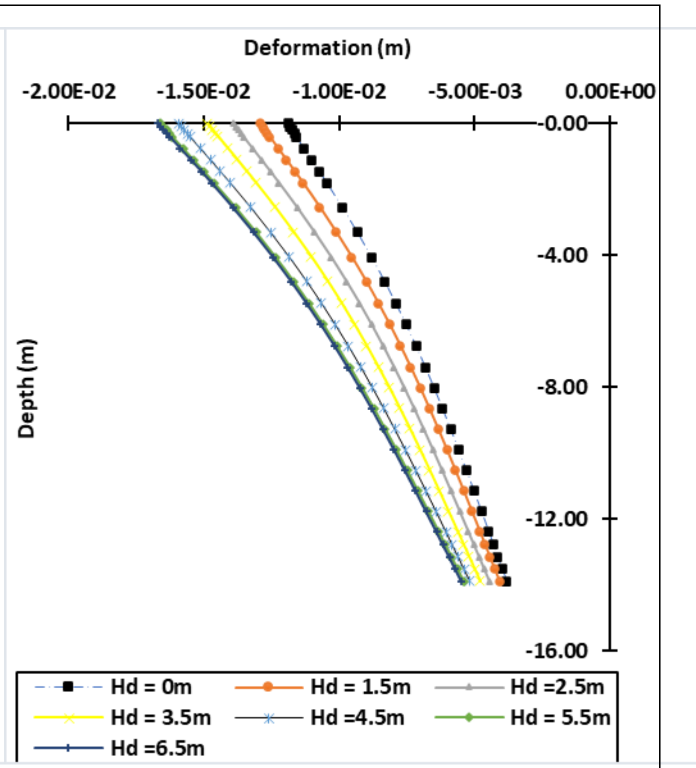

Figure 20: Deformation vs Depth of barrette at (H_e=5m)

Table 5: Maximum straining actions of barrette Vs H_d

H_d (m)	Maximum (+ve) Bending Moment (kN.m/m)	Bending Moment change (%)	Maximum Shear force kN/m	Shear force change (%)	Maximum Noraml force kN/m	Normal force change (%)	Maximum Deformation in (m)	lateral deformation change (%)
0	2.02E+02	0.00%	1.19E+02	0.00%	-4.44E+01	0.00%	-1.19E-02	0.00%
1.5	2.21E+02	9.21%	1.29E+02	8.41%	-4.44E+01	-0.12%	-1.29E-02	8.70%
2.5	2.33E+02	15.15%	1.36E+02	14.20%	-4.45E+01	0.09%	-1.39E-02	17.00%
3.5	2.45E+02	21.00%	1.42E+02	19.82%	-4.46E+01	0.27%	-1.49E-02	25.07%
4.5	2.57E+02	27.12%	1.49E+02	25.68%	-4.47E+01	0.60%	-1.59E-02	33.86%
5.5	2.65E+02	30.79%	1.53E+02	29.17%	-4.48E+01	0.73%	-1.66E-02	39.52%
6.5	2.66E+02	31.17%	1.54E+02	29.58%	-4.47E+01	0.67%	-1.67E-02	40.43%

From the previous figures and tables, increasing deepening depth by 1.00 m leads to increasing in maximum bending moment, maximum shear force, maximum normal force and deformation by about 6.5%, 5%, 2% and 8%, respectively.

Alternative 2

Alternative 2 is based on retaining difference in bed level deepening depth (H_d) which is the difference between the bottom level of the last block at El. (-10.00m) and proposed new level at El. (-16.50m) by using anchored diaphragm wall. Wall is anchored by using a relief slab of thickness 400mm with beams of thickness 2000mm with spacing 4m, this slab connected to barrette (800*2000) mm which acts as a Deadman, also this slab supported on two rows of piles (diameter = 1200mm) to transfer vertical loads to sandstone layer to reduce lateral earth pressure resulted from surcharge on diaphragm wall.

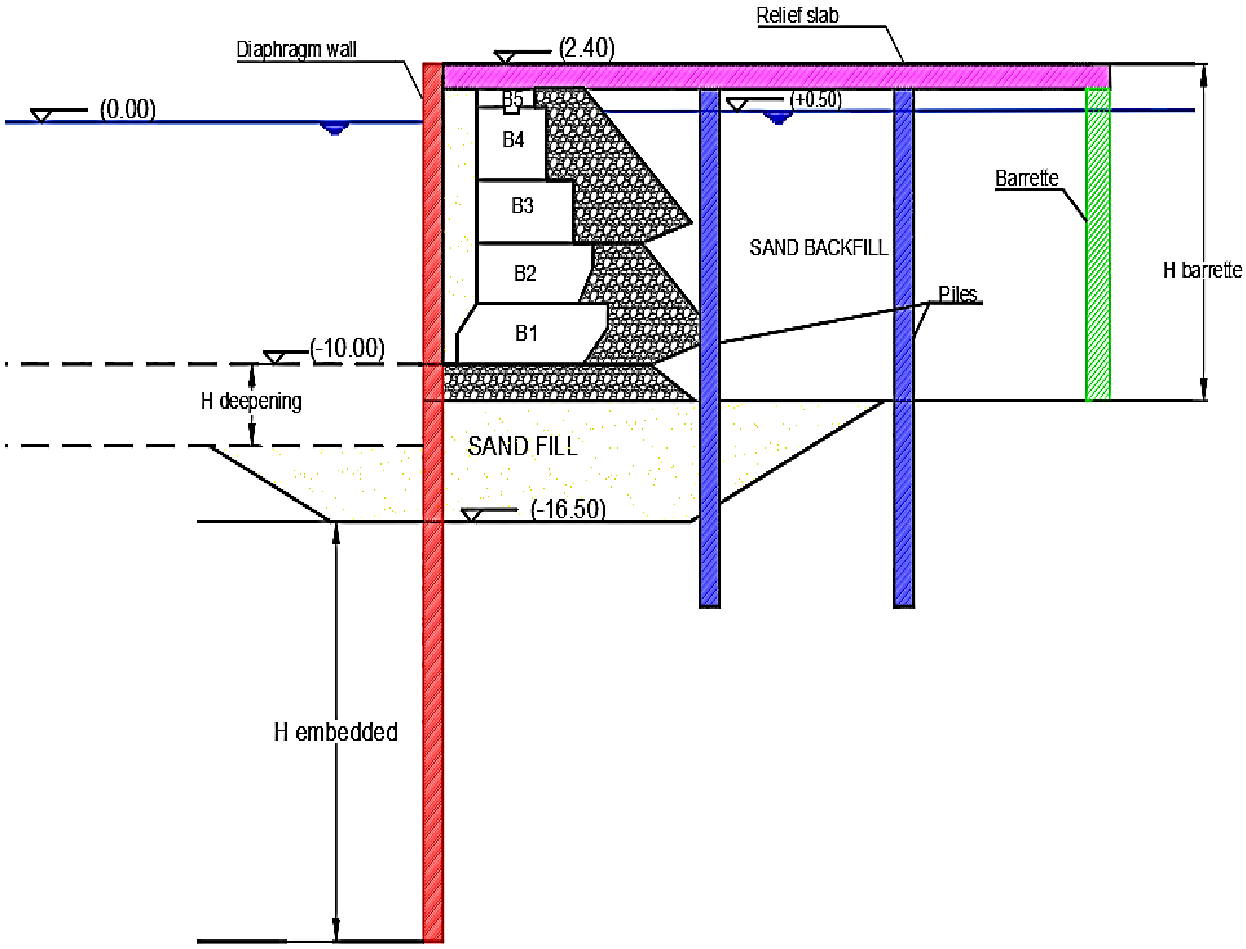

Figure 21 : Section Elevation for alternative 2

Effect of increasing Deepening Depth (H_d) on Global Factor of Safety (Global F.O.S)

Deepening process in front of quay wall leads to a considerable effect on stability of structural system composed from existing quay wall and proposed shoring system as well as on straining actions across proposed structural elements as diaphragm wall. This may be happened due to decrease of passive resistance in front of proposed diaphragm wall.

Global factor of safety of upgraded structure is affected by many factors as geotechnical characteristics, structure properties, assigned loads, deepening depth (H_d) and embedded depth (H_e). Increasing deepening depth, leads to increase in retaining height which has a severe effect on soil stresses and deformation also on global factor of safety.

To investigate such effect, six values of (H_d) have been adopted, (H_d = 1.5, 2.5,3.5,4.5,5.5 and 6.5) m. The other parameters of model were kept constant as geotechnical properties which mentioned in detail in Table 1, structural elements properties as embedded depth of diaphragm wall inside soil (H_e=5m), thickness of diaphragm wall (T_d=1000mm) and position of proposed diaphragm wall with respect to existing block wall where diaphragm wall is located in front of existing wall.

It was found that by increasing (H_d) to (1.50, 2.50,3.50,4.50,5.50 and 6.50) m factor of safety decreased to 3.67, 3.64, 3.60, 3.50, 3.36 and 3.11 respectively as shown in Figure 22.

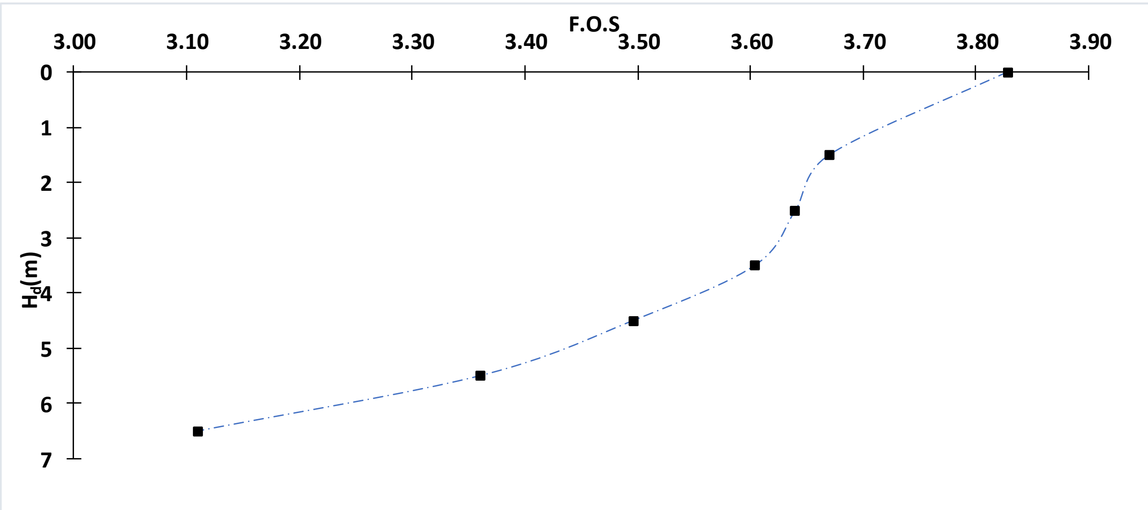

Figure 22: F.O.S vs H_d at (H_e=5m)

Effect of increasing Deepening Depth (H_d) on Straining actions of diaphragm wall

To study the effect of increasing the deepening depth on straining actions of the diaphragm wall. A case with no deepening in the presence of diaphragm wall is taken as a reference. Figure 23, Figure 24, Figure 25 and 26 present the effect of deepening depth (Hd) on straining actions like bending moment, shear force, normal force and lateral deformation along the proposed diaphragm wall. It is clearly seen that as Hd increased, the straining actions and deformation is increasing with different ratios as illustrated in Table 6.

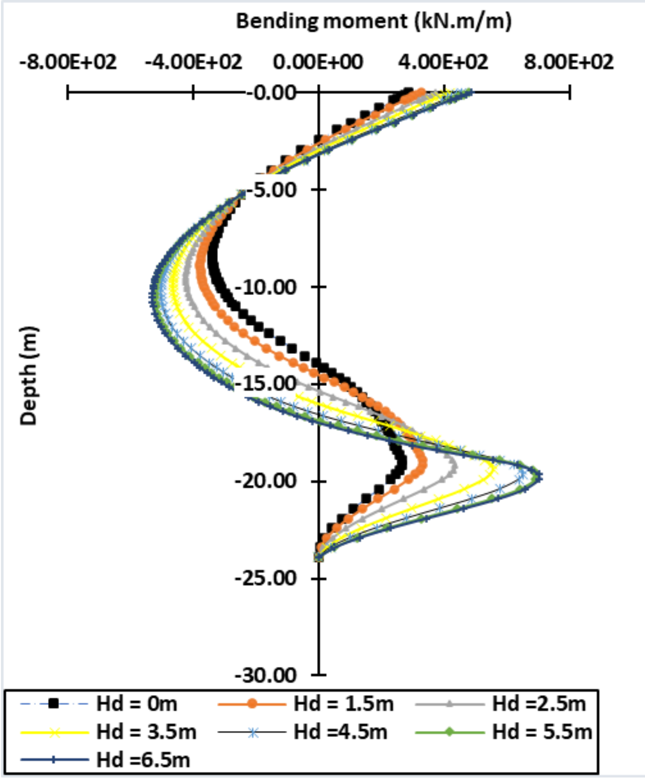

Figure 23: B.M vs Depth of DW at (H_e=5m)

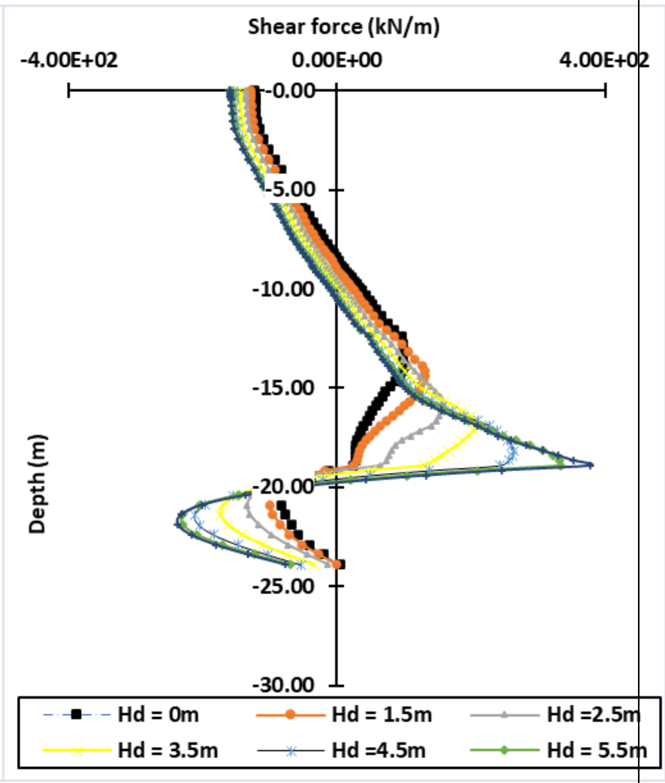

Figure 24: B.M vs Depth of DW at (H_e=5m)

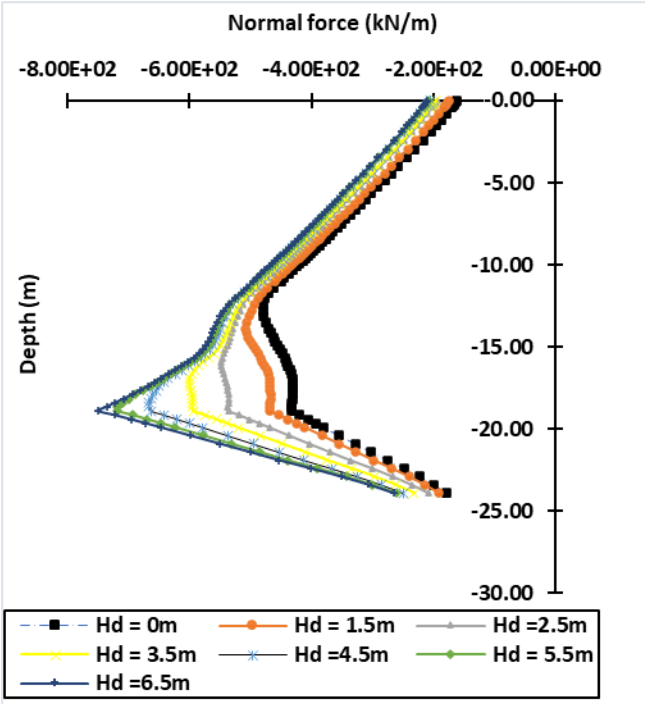

Figure25: N.F vs Depth of DW at (H_e=5m)

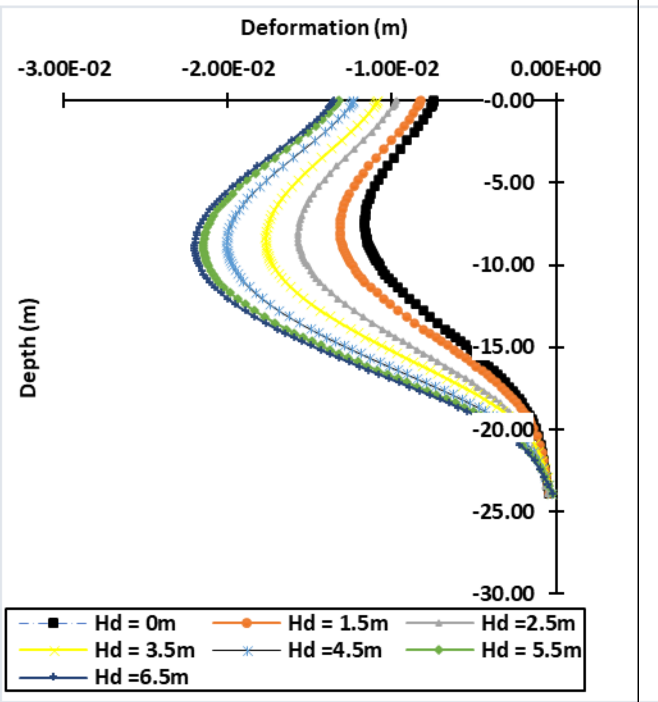

Figure26: Deformation Vs Depth of DW at (H_e=5m)

Table 6: Maximum straining actions of diaphragm wall Vs H_d

H_d (m)	Maximum (-ve) Bending Moment (kN.m/m)	Bending Moment change (%)	Maximum. Shear force kN/m	Shear force change (%)	Maximum. Normal force kN/m	Normal force change (%)	Maximum. Deformation in (m)	lateral deformation change (%)
0	-3.38E+02	0.00%	1.02E+02	0.00%	-4.79E+02	0.00%	-1.17E-02	0.00%
1.5	-3.77E+02	11.46%	1.31E+02	29.15%	-5.09E+02	6.24%	-1.32E-02	13.08%
2.5	-4.23E+02	25.00%	1.60E+02	57.11%	-5.48E+02	14.35%	-1.57E-02	34.86%
3.5	-4.64E+02	37.20%	2.09E+02	105.10%	-6.00E+02	25.25%	-1.77E-02	51.70%
4.5	-5.02E+02	48.35%	2.64E+02	159.18%	-6.66E+02	39.05%	-2.00E-02	71.88%
5.5	-5.23E+02	54.61%	3.34E+02	228.03%	-7.18E+02	49.97%	-2.15E-02	84.41%
6.5	-5.29E+02	56.39%	3.79E+02	272.53%	-7.49E+02	56.32%	-2.20E-02	88.90%

From the previous figures and tables, increasing deepening depth by 1.00 m leads to decrease in F.O.S by a value about 3.5% and increasing in Maximum. (-ve) Bending moment by 12%, while rate of increase of shear force is considered to be exponential as H_d increase. Normal with avg.12% and deformation with avg. 20%.

Effect of increasing Deepening Depth (H_d) on Straining actions of barrette

To study the effect of increasing the deepening depth on straining actions of the barrette, a case with no deepening in the presence of diaphragm wall is taken as a reference. Figure 17, Figure 18, Figure 19 and Figure 20 present the effect of deepening depth (Hd) on straining actions like bending moment, shear force, normal force and lateral deformation along the proposed diaphragm wall. It is clearly seen that as Hd increased, the straining actions and deformation increased with different ratios as illustrated in Table

5.

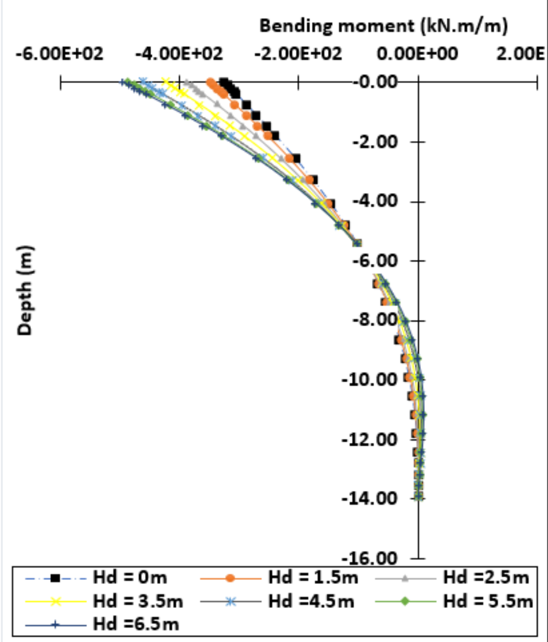

Figure27: B.M vs Depth of Barrette at (H_e=5m)

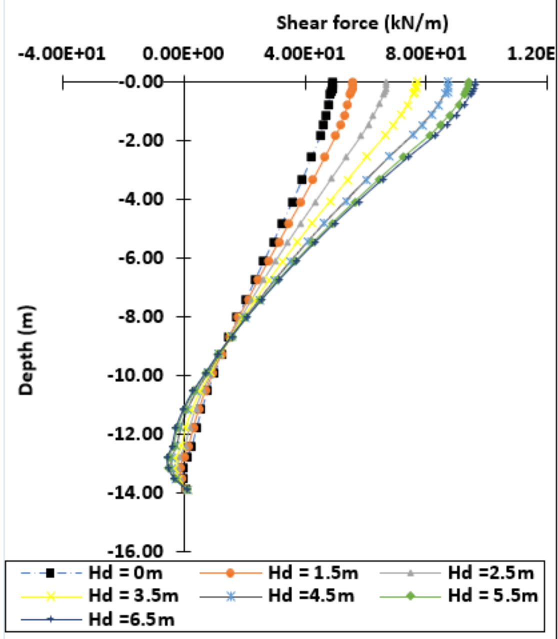

Figure28: S.F vs Depth of Barrette at (H_e=5m)

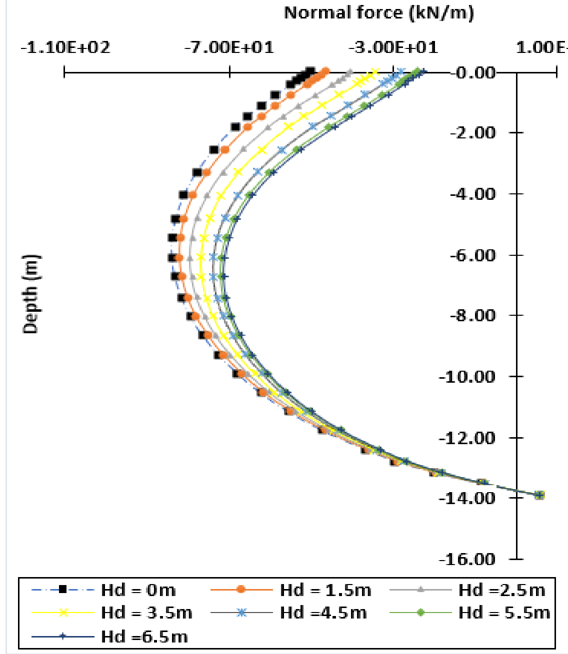

Figure29: N.F vs Depth of Barrette at (H_e=5m)

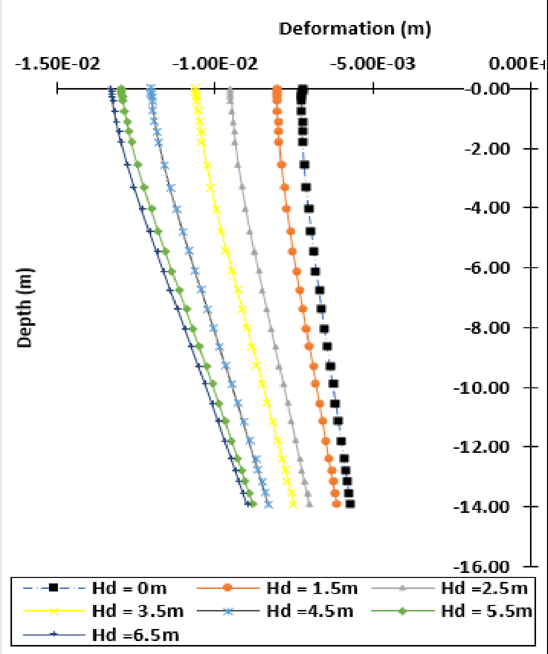

Figure 30: Deformation vs Depth of Barrette at

Table 7: Maximum straining actions of barrette Vs H_d

H_d (m)	Maximum (-ve) Bending Moment (kN.m/m)	Bending Moment change (%)	Maximum. Shear force kN/m	Shear force change (%)	Maximum. Normal force kN/m	Normal force change (%)	Maximum. Deformation in (m)	lateral deformation change (%)
0	-3.24E+02	0.00%	4.91E+01	0.00%	-8.38E+01	0.00%	-7.26E-03	0.00%
1.5	-3.48E+02	7.32%	5.59E+01	13.88%	-8.22E+01	1.89%	-8.04E-03	10.79%
2.5	-3.87E+02	19.36%	6.69E+01	36.41%	-7.95E+01	5.12%	-9.51E-03	31.05%
3.5	-4.22E+02	30.22%	7.68E+01	56.52%	-7.69E+01	8.31%	-1.06E-02	46.14%
4.5	-4.62E+02	42.36%	8.74E+01	78.18%	-7.38E+01	12.00%	-1.21E-02	66.10%
5.5	-4.86E+02	49.88%	9.39E+01	91.43%	-7.20E+01	14.13%	-1.30E-02	78.72%
6.5	-4.94E+02	52.40%	9.61E+01	95.89%	-7.14E+01	14.86%	-1.33E-02	83.13%

From the previous figures and tables, increasing deepening depth by 1.00 m leads to increasing in Maximum. (-ve) Bending moment by 12%, Maximum. Shear with 20%, Maximum. Normal with avg. 3% and deformation with avg. %22.

Effect of increasing Deepening Depth (H_d) on Straining actions of relief slab

To study the effect of increasing the deepening depth on straining actions of the relief slab. A case with no deepening in the presence of diaphragm wall is taken as a reference. Figure 31 and Figure 32 present the effect of deepening depth (Hd) on straining actions like bending moment and normal force along the proposed relief slab. It is clearly seen that as Hd increased, the straining actions and deformation is increasing with different ratios as illustrated in Table 8.

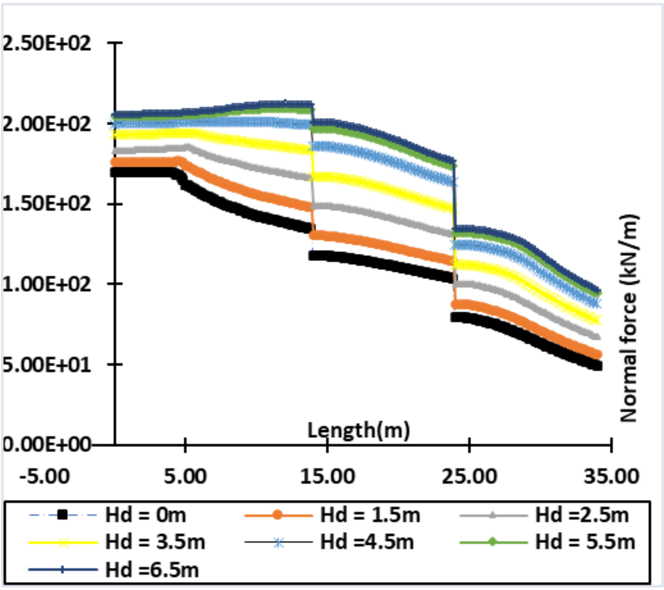

Figure31: N.F vs Length of slab at (H_e=5m)

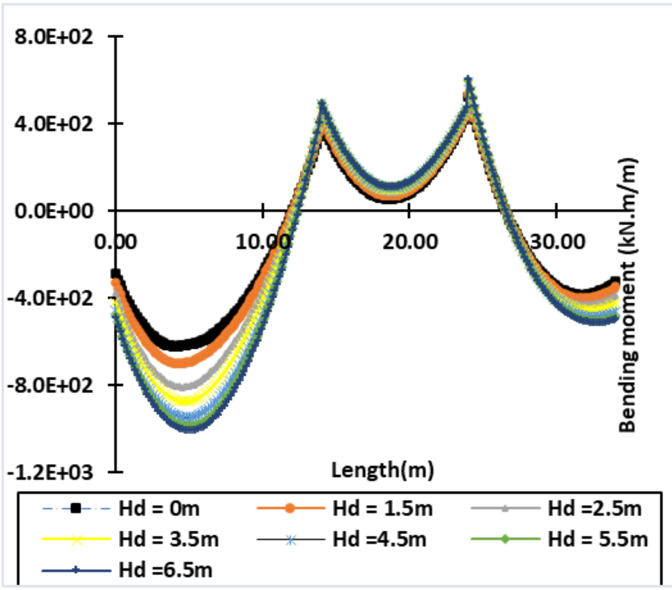

Figure32: B.M vs Length of slab at (H_e=5m)

Table 8: Maximum straining actions of relief slab Vs H_d

H_d (m)	Maximum (-ve) Bending Moment (kN.m/m)	Bending Moment change (%)	Maximum. Normal force (kN/m)	Normal force change (%)
0	-6.20E+02	0.00%	1.70E+02	0.00%
1.5	-6.99E+02	12.74%	1.77E+02	13.78%
2.5	-8.07E+02	30.22%	1.86E+02	36.19%
3.5	-8.74E+02	40.99%	1.94E+02	56.17%
4.5	-9.47E+02	52.83%	2.02E+02	77.68%
5.5	-9.89E+02	59.51%	2.10E+02	90.84%
6.5	-1.01E+03	62.18%	2.12E+02	95.27%

From the previous figures and tables, increasing deepening depth by 1.00 m leads to increasing in Maximum. (-ve) Bending moment by 15%, Normal with avg. 20%.

Effect of structure system on deformation and straining actions

For alternative 2 diaphragm wall is anchored as in alternative 1 but with great advantage that relief slab carries surcharge load and transfers it to strong soil layer through two rows of bearing piles. This slab has great role in decreasing lateral earth pressure resulted from surcharge as relief slab transfers this high load to sandstone layer through vertical structural members as piles, this significant role has impact on straining actions and reduction of lateral deformation of diaphragm wall, in alternative 2 lateral deformation at top of wall equals 13.28mm which is less than alternative 1 by 25.68%. Also, existence of piles and barrette contributes to anchorage of relief slab with addition to friction between slab and beneath soil. At Figure 34 it is very clear that overall stability is higher in case of diaphragm wall which anchored by relief slab but at same time it is the more expensive system than that anchored by tie and back sheet pile.

Effect of structure system on Global Factor of Safety (Global F.O.S) at different values of (Hd)

Deepening process in front of quay wall leads to a considerable effect on stability of structural system composed from existing quay wall and proposed shoring system as well as on straining actions across proposed structural elements as diaphragm wall which responsible for retaining difference the new deepening (H_d).

Global factor of safety of upgraded structure is affected by many factors as geotechnical characteristics, structure properties, assigned loads, deepening depth (H_d) and embedded depth (H_e). Increasing deepening depth, leads to increase in retaining height which has a severe effect on soil stresses and deformation also on global factor of safety. F.O.S for relief platform system is higher than system anchored by tie by 32.7 % at H_d = 6.5m, difference of F.O.S between two system decrease as Hd increase as shown in Figure 34.

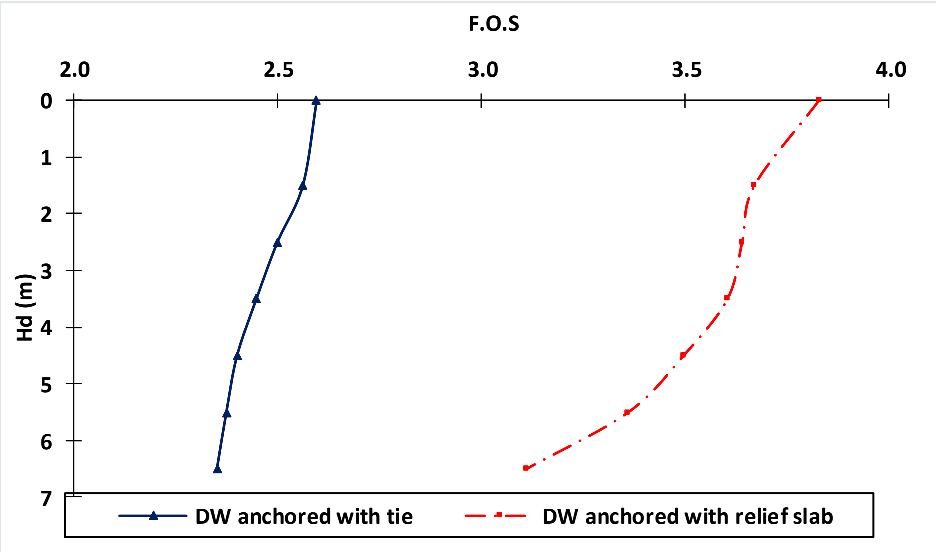

Figure 33: F.O.S vs H_d at (H_e=5m)

Effect of structure system on straining actions of diaphragm wall at different values of (H_d). Both of two proposed alternatives are similar in concept of structural behavior as diaphragm wall used to retain difference in bed level between existing bed level and new deepened level, this diaphragm wall is anchored by different system at each alternative, for first one wall is anchored by tie which connected to barrette and for second alternative wall is anchored by relief platform which has another function which is decreasing effect of surcharge as a lateral pressure on diaphragm wall which is clear in Figure 36, Figure 37 and Figure 39 as positive moment in alternative 2 is less than Alternative 1 by 21.5% at H_d =6.5m, also there is another major difference in configuration of bending moment in two alternative as value of moment at top of wall. For alternative 1 moment is almost neglectable while at second alternative there is high value of positive moment which equals 485 kN at H_d = 6.5m, this moment is resulted from rigid joint between relief slab and wall as high negative moment at edge of relief slab transferred to top of diaphragm wall through this joint.

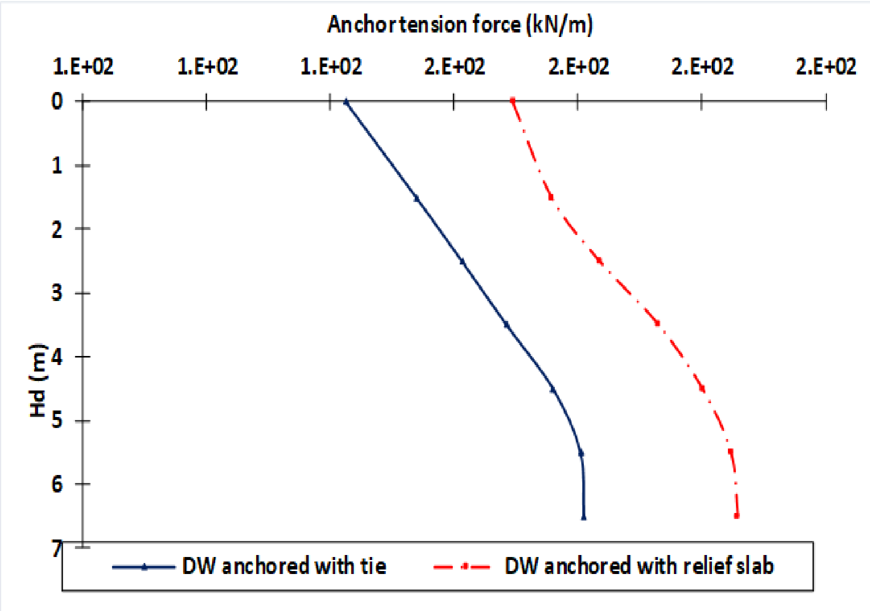

Figure 34: F_a vs H_d at (H_e=5m)

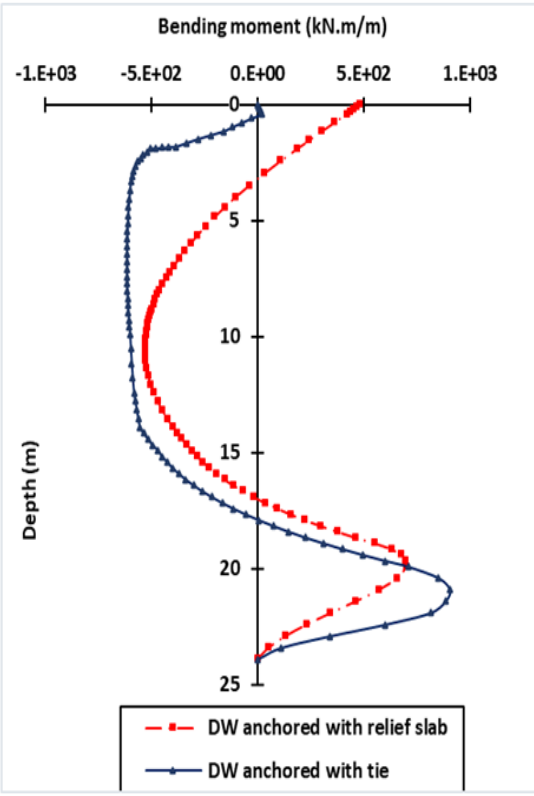	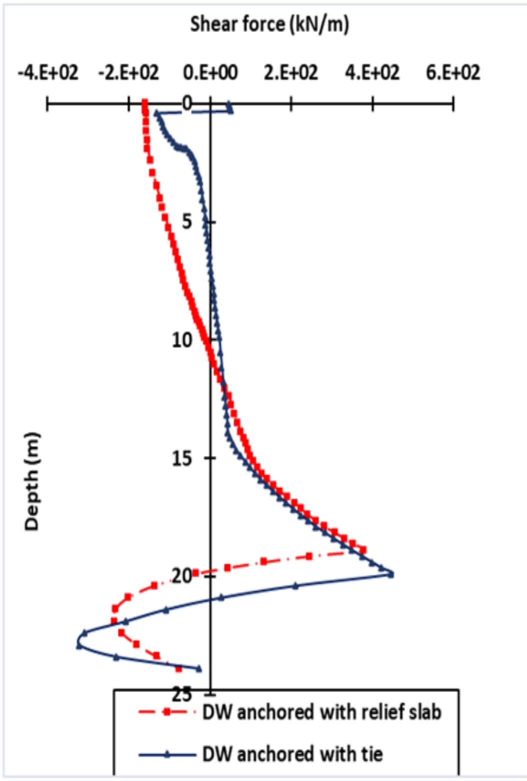
Figure 35: B.M vs Depth of DW at (H_e=5m)	**Figure 36: S.F vs Depth of DW at (H_e=5m)**

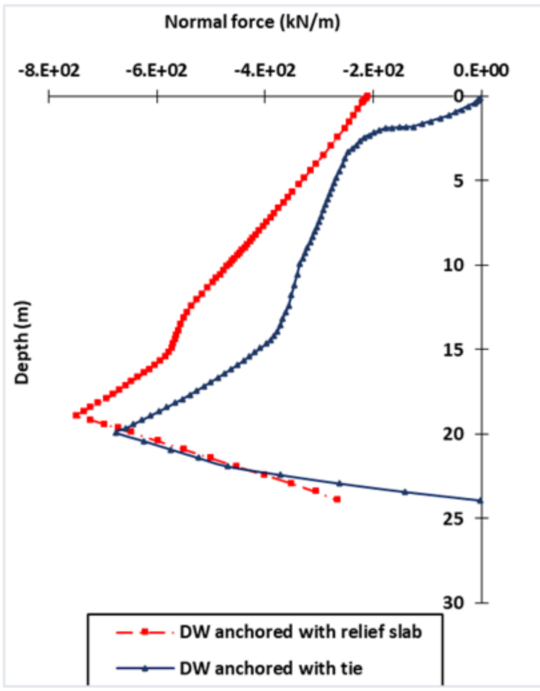	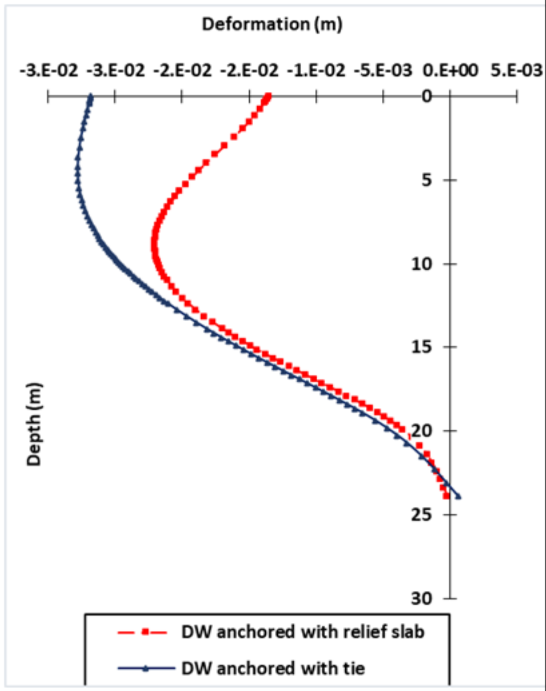
Figure 37: N.F vs Depth of DW at (H_e=5m)	**Figure 38: Deformation vs Depth of DW at (H_e=5m)**

Effect of structure system on straining actions of barrette at different values of (Hd) there is main difference in configuration of bending moment in two alternatives as value of moment at top of barrette. For alternative 1 moment is almost neglectable while at second alternative there is high value of negative moment which equals -485 kN at H_d = 6.5m, this moment is resulted from rigid joint between relief slab and barrette as high negative moment at edge of relief slab transferred to top of barrette through this joint, this negative moment is reduced gradually due to passive lateral stresses which is considered main resistant against lateral deformation of barrette. For shear force alternative 2 is less than alternative 1 by 34% at H_d =6.5m, effect of anchorage is very clear at shear force diagram in Figure 41 as in case of alternative 1 there is drop in shear force at position of anchor by 178 kN while in case of alternative 2 drop in shear force by 96 kN is at top of barrette due to its connection with relief slab.

For normal force diagram it is clear that compression normal force is much higher in second alternative because barrette is considered as vertical support for relief slab beside its function as retaining structure.

Deformation of diaphragm wall is mainly affected by structural system as deformation at top of wall at alternative 2 is less than alternative 1 by 31 %

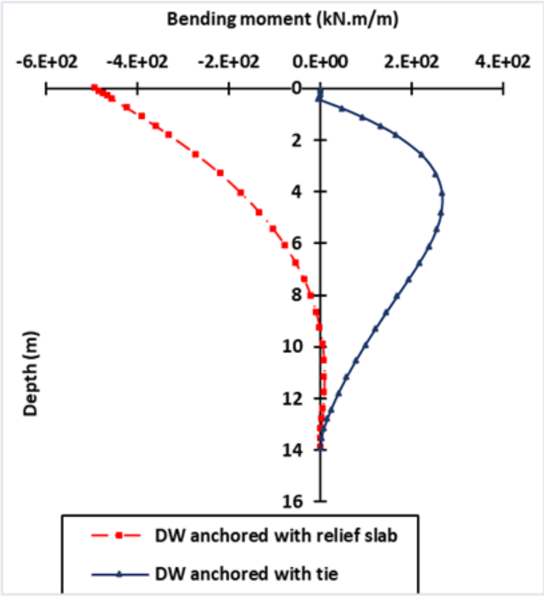

Figure 39: B.M vs Depth of barrette at (H_e=5m)

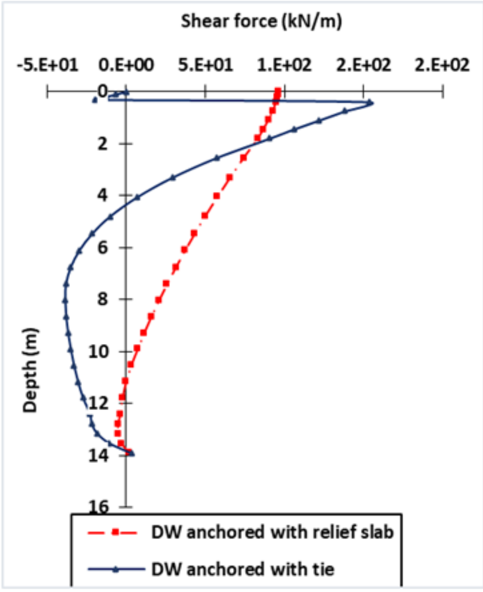

Figure 40: S.F vs Depth of barrette at (H_e=5m)

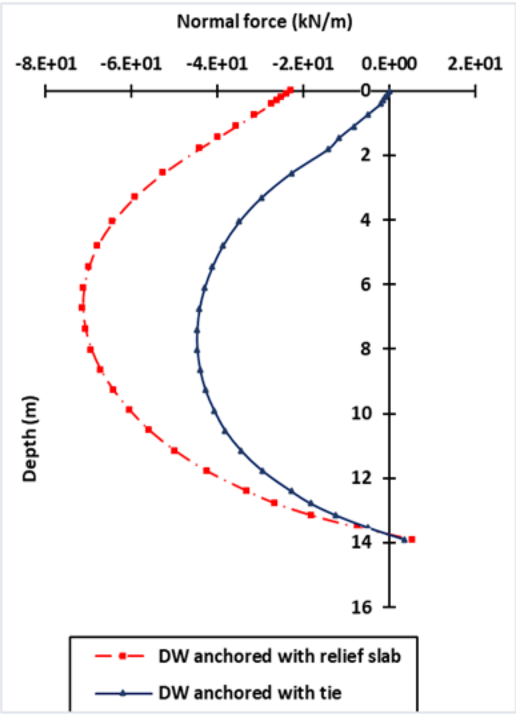

Figure 41: N.F vs Depth of barrette at (H_e=5m)

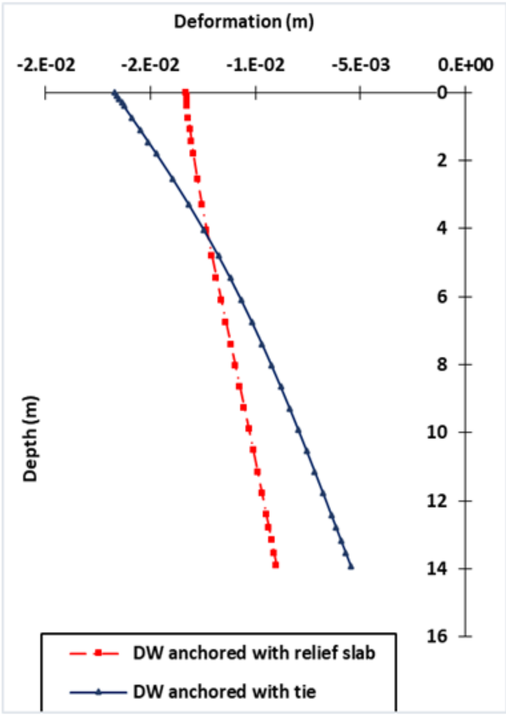

Figure 42: Deformation vs Depth of barrette at (H_e=5m)

CONCLUSION

In this paper, two alternatives have been proposed for deepening the soil in front of existing lock block quay walls. The first alternative involves the use of a diaphragm wall anchored by a tie and barrette, while the second alternative utilizes a diaphragm wall anchored by a relief platform. The case study focuses on Berth 65 at the Port of Alexandria. Based on the analysis conducted, the following conclusions can be drawn:

Both alternatives are considered to be hard upgrade for existing quay wall according to classification of (Bauduin et al., 2017)

1. The utilization of a relief platform system proves to be more efficient in anchoring the diaphragm wall and effectively eliminates the impact of high surcharges on the apron located behind the quay.
2. In order to take advantage of the relief slab, it is proposed to excavate the backfill soil, which results in a reduction of the active earth pressure acting on the existing quay wall. This reduction leads to a decrease in the lateral pressure on the diaphragm wall. However, it should be noted that this excavation also decreases the passive resistance in front of the barrette, subsequently reducing the efficiency of the anchorage system.
3. The system anchored by a relief platform achieves minimum horizontal deformation at the top of the proposed diaphragm wall. This is primarily attributed to the frame action that occurs as a result of the rigid joints between the vertical structural elements. Additionally, the presence of the relief slab plays a crucial role in minimizing the impact of surcharges on both the existing block wall and the diaphragm wall. This reduction in surcharge helps decrease the lateral pressure exerted on the diaphragm wall, contributing to lower horizontal deformation.
4. In case of alternative 2, high negative moment resulted at wall anchored by relief slab due to frame action achieved by rigid joint between slab and wall.
5. One of the notable advantages of the first alternative is its cost-effectiveness, particularly when compared to the second alternative. This cost advantage stems from the relatively lower construction expenses associated with the connecting elements between the diaphragm wall and the barrette. In contrast, the second alternative incurs significantly higher costs due to the construction requirements for elements such as the relief slab and the two rows of piles. By opting for the first alternative, project stakeholders can benefit from a more affordable solution while still achieving the desired objectives of deepening the quay wall.
6. On the other hand, the second alternative proves to be a more efficient structural solution when considering the aspect of lateral deformation. In comparison to the first alternative, the second alternative exhibits significantly smaller lateral deformation. In fact, the lateral deformation of the diaphragm wall in the first alternative is nearly twice as large as that observed in the second alternative. This significant reduction in lateral deformation highlights the superior performance and stability achieved by the second alternative. By opting for this solution, the project can benefit from enhanced structural integrity and minimized deformations, ensuring the long-term reliability of the deepened quay wall.
7. Designers are strongly recommended to consider the second alternative, particularly in situations involving high loads, especially high surcharge loads, or the presence of gantry

cranes. This recommendation is based on the advantages offered by the second alternative, which include the ability to minimize the significant lateral pressure exerted on the diaphragm wall. By opting for this alternative, designers can ensure the structural integrity and stability of the deepened quay wall, even under demanding conditions. The use of the second alternative becomes particularly crucial in scenarios where there is a need to mitigate the adverse effects of high loads, ensuring the long-term performance and reliability of the structure.

8. During the construction of a concrete diaphragm wall, it is necessary to build temporary fills with flat side slopes. However, it is important to note that these temporary fills have a substantial footprint on the basin bed. As a result, this construction phase can potentially complicate navigation in the basin area located in front of the upgraded quay wall. The presence of the temporary fills may restrict vessel maneuverability or require additional navigation precautions to ensure the safety and efficiency of maritime traffic during the construction period. Therefore, careful planning and coordination are essential to minimize any disruptions or challenges posed by the construction activities on the basin's navigation operations.

Notations

- H_d Deepening depth between existing and new bed level.
- H_e Embedded depth of diaphragm wall below new bed level.
- T_d Thickness of diaphragm wall
- F_a Anchor force.
- B.M Bending moment inside structural element.
- S. F shear force inside structural element.
- N. F Normal force inside structural element.
- DW Diaphragm wall.

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