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# The effect of platform width on the deformation and internal force in quay wall structure using 2D and 3D finite element analysis

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**ABSTRACT:** From ancient times, people used the sea for transport and trade of goods. To make this easy and possible several types of quay wall were developed. The Design of quay wall is a problem in which designers make much effort to reach the best method for design of this important structure. Many methods were developed to design quay wall. These methods differ for each type of quay wall and local condition. The most popular method of design is the finite element method, this method calculates internal forces in the quay wall by calculating the relative movement and stresses of the surrounding soil and quay wall element. This paper focuses on a comparative study between two dimension and three-dimension finite element analysis for the effect of platform width on the deformation and internal force in the quay wall structure. The software which used is PLAXIS, which based on the finite element method. This method gives the possibility to work in a wider field of modelling and calculations.

## 1 INTRODUCTION

Quay walls are earth retaining structures for the morning of ships. They are used for transshipment of goods by crane that moves alongside the ship. Quay wall is usually equipped by bollard to provide morning, fendering to absorb the impact of ships to prevent the damage of quay wall and the body of the ship and rail for the crane. The system for quay wall must provide the necessary stability. All element of quay wall system must be able satisfy all requirements imposed by soil condition, loads (dead, live, crane, ice, earth quakes, crane, storage load, accidental loads), water level and the size of the ships.

## 2 CASE UNDER STUDY

In this paper a real case study using the D-wall and barrettes founded on reclaimed soil discussed from the point of design using the finite element program PLAXIS 2D,3D and studying the effect of platform width on the internal forces.

The case under study is the new multi-purpose terminal at Damietta Port. The project comprises the construction of approximately 630 m of quay wall fully equipped to accommodate large container vessels and dredging of an approximately 1000 × 280 m large berthing to a depth of -15.0 m in a first phase and to a depth of -17.0 m in a second phase.

## 3 SITE CONDITION

### 3.1 Site description

The proposed site for the port of Damietta is located on the Egyptian Mediterranean north eastern coast of the Nile Delta approximately 70 km west of Port Said. The ground level at the location of the quay wall is ranging between +3.50 to -12.50. there is a 17.00 thick loose sand overlaying a 15.0 thick very soft to medium stiff clay, this clay overlies a very dense sand of approximately 4.0 m thick underneath the sand is very stiff clay, approximately 7.0 m, followed by the very dense sand with 5.0 m thick and very stiff clay appear under the very dense sand and extended to the end of boreholes.

## 4 STRUCTURE DESIGN

### 4.1 Quay wall system

The diaphragm wall with barrettes support platform was adopted for the quay wall under study as shown in Figure 1. The main idea of the proposed quay wall divides the project into two main groups. The first group carrying the vertical loads of the quay wall as well as the lateral loads results from the bollard force as well as the lateral earth pressure forces resulting from the own weight of the soil plus the surcharge loads. The second group is the deck itself. The outlines of each group would be introduced in the following sections.

Group 1 (vertical elements):

- Front wall: The front wall is diaphragm wall with a thickness of 1.0m and tip level of -39.00.
- Rear wall: The rear wall is one row of barrettes down to -39.00 with dimensions of 2.50 m x 0.80 m and spacing of 4.00 m.
- Intermediate vertical supporting elements: The intermediate vertical supporting elements shall be two rows of barrettes down to -42.00 with dimensions of 2.50 m x 0.80 m and spacing of 4.00 m.

Group 2 (Horizontal elements):

- Connecting girders 1.25mx2.50m depth at spacing 4.00m.
- Cast in-situ slab 40cm thickness.
- Front capping beam 3.00m width and 2.50m thickness.
- Rear capping beam 3.00m width and 2.50m thickness.

- Berthing Loads: For berthing, berthing energy of 677 kNm. For the design of the fenders, a maximum hull pressure of 350 kN/m<sup>2</sup> shall be used. The berthing force shall be neglected for the design of the diaphragm wall and should be considered only in the design of fenders.

5 STRUCTURE CONSTRUCTION

The construction of the diaphragm walls with barrettes support platform include five stages:(I) Backfill to create working platform, (II) executed wick drain to increase consolidation of soft clay layer and improve the soft clay soil, (III) installation of the D-wall, barrettes and the deck, (IV) dredging of the waterfront area, and (V) Application of permanent loads. the period of the quay walls structure construction stage lasts for 9 months (This is to consider the effect of wick drains on consolidation process and associated soil improvement).

6 NUMERICAL MODELLING

6.1 Finite element analysis

It is possible to analyse the diaphragm wall with barrettes support platform using two dimension or three-dimension analyses. The numerical analysis using finite element analysis software package called plaxis.2D&3D analysis are employed to investigate the behaviour of the new structure, Figures 2 and 3 show the finite element models adopted in the 2D and 3D analysis.

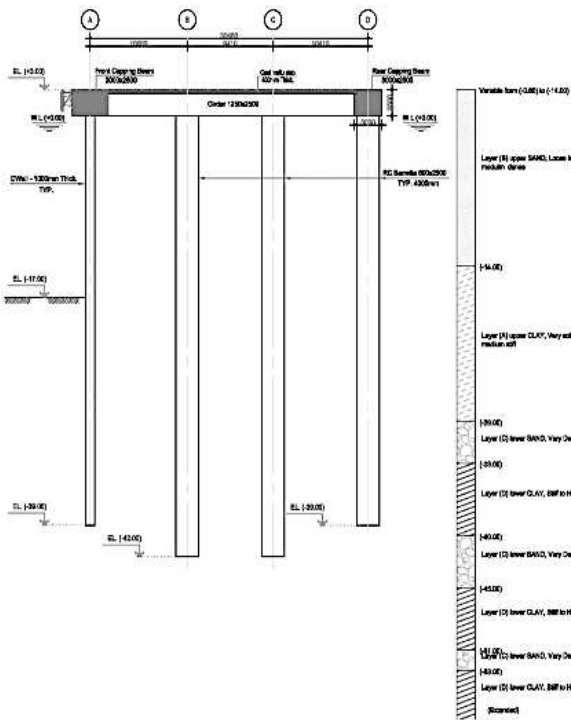


Figure 1. Static System for Quay Wall.

4.2 Loads on quay wall system

- Dead Loads: The loads from earth and water pressure shall be considered as dead load.
- Live Loads: Live loads between front and rear walls and behind rear wall equal to 50 kN/m<sup>2</sup>.
- Soil Pressure: The earth pressure load shall be calculated using drained shear strength parameters of the subsoil layers. The process of loading unloading reloading shall be considered in the analysis. The interface strength shall be taken 80% of the soil strength.
- Mooring Loads: Bollards with spacing 32 m: 1500 kN. The loads on the bollards shall be distributed over a length of 32 m given a maximum bollards force per linear meter is taken as 50 kN/m<sup>2</sup>.

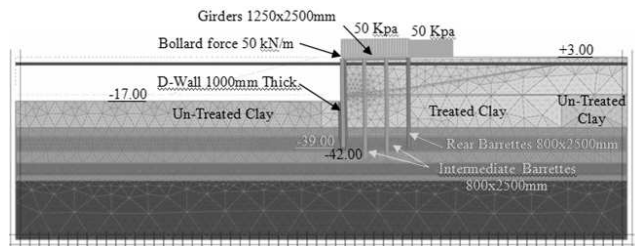


Figure 2. Adopted PLAXIS 2D Model.

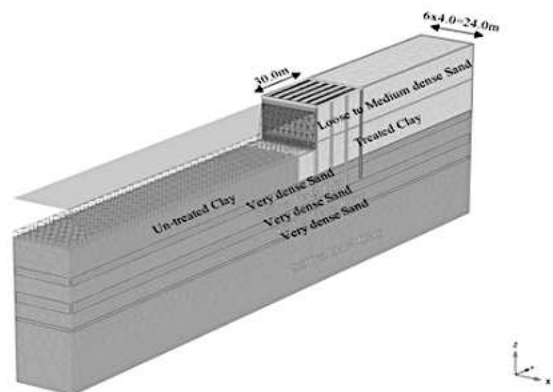


Figure 3. Adopted PLAXIS 3D Model.

## 6.2 Material model and parameters

The structures included the diaphragm wall, support platform with cross girders are modelled as an isotropic elastic material with young's modulus 20GPa and a Poisson ratio 0.15 and barrettes are modelled as embedded beam element, The PLAXIS embedded pile is considered as a beam which can cross the soil volume elements at any arbitrary location and with any arbitrary orientation. The barrettes are connected to the surrounding soils by means of special interfaces which are skin interfaces and foot interfaces (for more details see PLAXIS 2018 materials manual). For embedded piles, the ultimate skin friction and the ultimate bearing had been calculated for the middle barrettes (tip level -42.00) and rear barrettes (tip level -39.00) according to DIN 1054:2005-01. For purpose of analysis, it had been assumed that distribution of skin friction is linear with zero at top and maximum at bottom. The calculations showed that the ultimate end bearing force for barrette 2500 \* 800 mm with tip levels -42.00 and -39.00 is 8000 kN and 2330 kN respectively and the ultimate skin friction for the two barrettes is 332 kN/m and 260 kN/m respectively. The backfilling sand is modelled using a linear elastic - perfectly plastic model with Mohr-coulomb failure criterion. The Mohr-coulomb model requires five parameters: effective cohesion internal friction angle ( $\phi$ ), diltancy angle ( $\psi$ ), young modulus E and Poisson ratio ( $\nu$ ). The foundation soil below backfilling sand is modelled using Harding soil model (HSM). The

HSM considers the stress dependent stiffness of the soil according to the power. The HSM uses three stiffness parameters to define the soil non-linearity and to distinguish between the loading and the unloading stiffness of the soil. The stiffness parameters are reference drained tri-axial stiffness modulus ( $E_{50}^{ref}$ ), Reference drained Constrained Modulus ( $E_{oed}^{ref}$ ) and Reference drained unloading reloading modulus ( $E_{ur}^{ref}$ ). According to (Schanz et al. 1999), for primary devirtic loading, the power low is given as:

$$E_{50} = E_{50}^{ref} \left( \frac{c \cdot \cos\phi - \sigma'_3 \sin\phi}{c \cdot \cos\phi - p^{ref} \sin\phi} \right) \quad (1)$$

$$E_{ur} = E_{ur}^{ref} \left( \frac{c \cdot \cos\phi - \sigma'_1 \sin\phi}{c \cdot \cos\phi - p^{ref} \sin\phi} \right) \quad (2)$$

$$E_{oed} = E_{oed}^{ref} \left( \frac{c \cdot \cos\phi - \sigma'_1 \sin\phi}{c \cdot \cos\phi + p^{ref} \sin\phi} \right) \quad (3)$$

Power m values are used according to recommended values by Janbu (1963) and Von Soos (1990) such that a value of  $m = 1$  is considered for soft clay, 0.5 for sand. A typical coefficient of friction of 0.8 is used for the interface angle of friction according to Deltares (formerly known as Delft geotechnics) from this research it was concluded that the physical friction angle lies between  $\delta = 2/3\phi'$  and  $\delta = 0.8\phi'$ . The details of the required parameters had been outlined in Table 1.

Table 1. Soil Parameters

Model	Soil Name	$c$ kPa	$\phi$ deg.	$E_{50\%ref}$ MPa	$E_{oed-ref}$ Mpa	$E_{ur-ref}$ Mpa	$E_d$ MPa	$\gamma$ kN/m <sup>3</sup>
MC	Backfilling	2	34	---	---	---	30	18
HSM	Clay, v. soft to med. stiff	2	25	3.5	1.5	15	---	17
HSM	Silty/clayey SAND	---	40	35	37	138	---	18
HSM	Silty/clayey SAND	---	40	62	73	246	---	18
HSM	Clay, stiff to Hard	5	25	43	33	216	---	18
HSM	Medium Clay, stiff to Hard	5	25	28	21	139	---	18
HSM	Clay, stiff to Hard	5	25	22	17	110	---	18

## 6.3 Verification of soft clay parameters using lab test option in PLAXIS software

The laboratory tests had been performed for the undisturbed samples collected from the top soft clay layer. The lab test is one dimensional consolidation as shown in Figure 4.

The results of laboratory testing had been used for verification/selection of the advanced soil parameters. Constitutive model had been calibrated to be used in analysis. The model is the hardening soil model (HSM). The parameters in table.1 had been used to check the available consolidation test and the result is summarized in Figure 5.

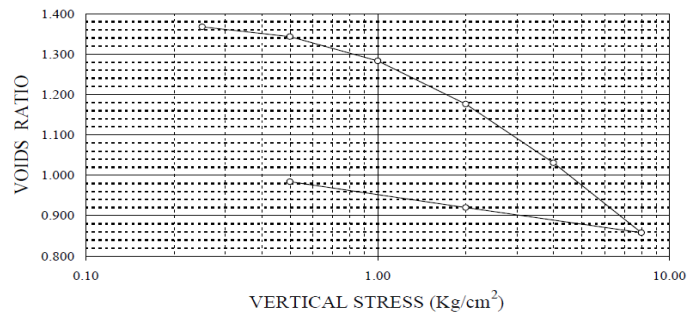


Figure 4. Odometer Test Result.

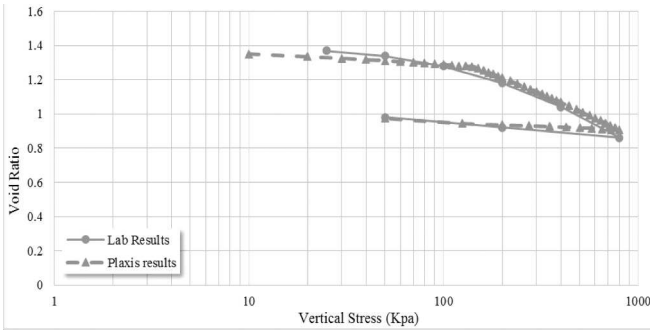


Figure 1. PLAXIS soil test results using HSM with respect to laboratory Oedometer test.

From this figure, it is clear that the assumed parameters show close agreement between the concluded stress- strain curves from PLAXIS and odometer.

6.4 Numerical models

Six numerical models have been adopted. The table2 summarizes the numerical models implemented in the analysis:

Table 2. Adapted Models description

Model number	Type of analysis	Analysis section	Platform width
M1	2D analysis	Typical section with deepest bed level - Hardening soil model (HSM)	H
M2			1.25H
M3			1.5H
M4	3D analysis	Typical section with deepest bed level - Hardening soil model (HSM)	H
M5			1.25H
M6			1.5H

\*H is the retained height.

7 COMPUTED RESULTS

7.1 Structure lateral deformation

Figures 6 and 7 show the maximum computed results 2D & 3D for lateral deformation of the quay wall system.

The results show a continuous increase in lateral deformation along the structure height, and maximum occur at the barrettes head and lateral deformation decrease with increase platform width.

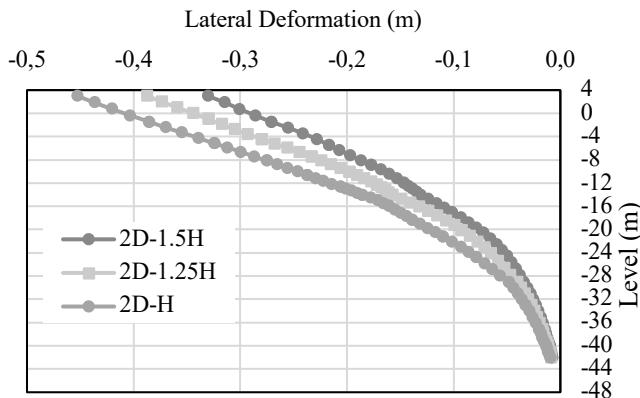


Figure 2. PLAXIS 2D Lateral Deformation for quay wall system.

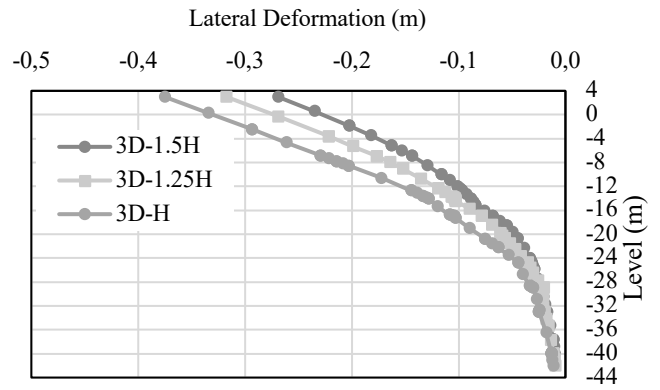


Figure 7. PLAXIS 3D Lateral Deformation for quay wall system.

7.2 Quay wall structure bending moment

Figures 8 to 15 show the bending moment of each element of quay wall system. The FEM results show that the bending moment value markedly increases after dredging and surface load. The bending moment value decrease with increase platform width.

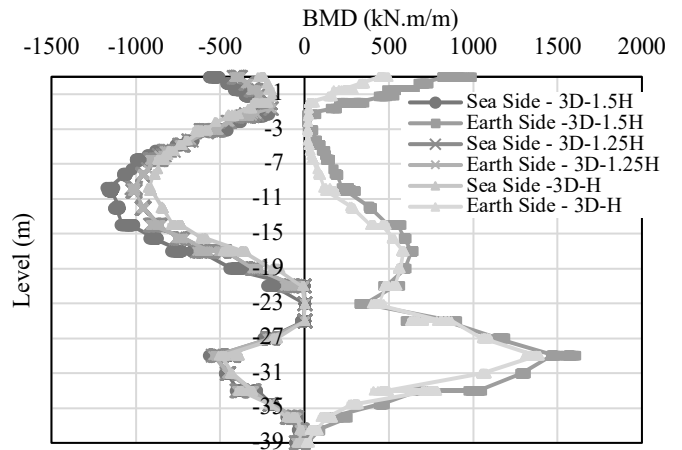


Figure 8. PLAXIS 2D B.M.D. for front wall.

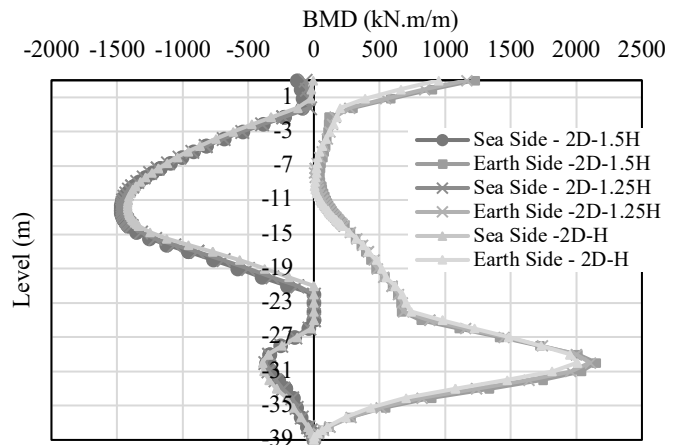


Figure 3. PLAXIS 3D B.M.D. for front wall.

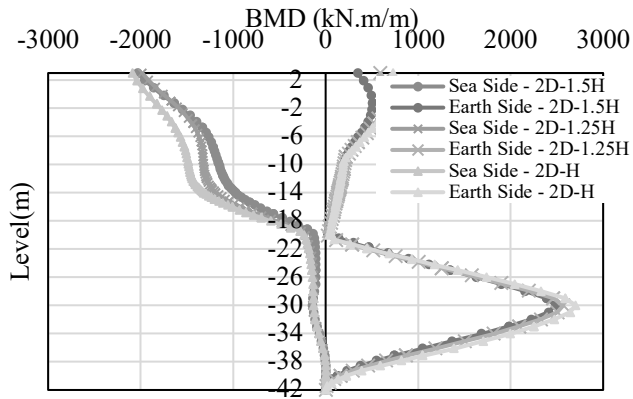


Figure 10. PLAXIS 2D B.M.D. for the middle barrette first row.

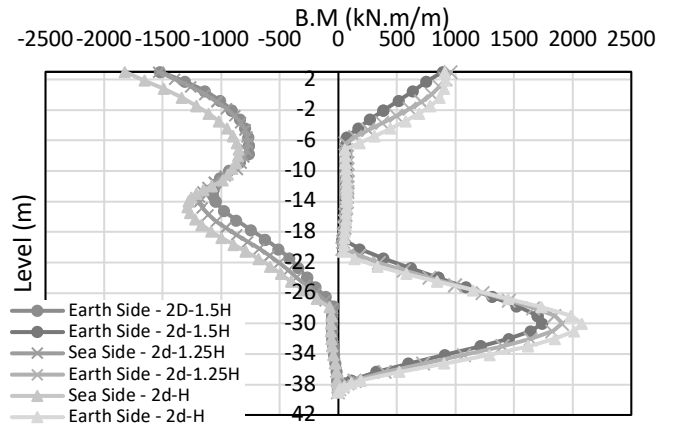


Figure 14. 2D B.M.D. for rear barrette.

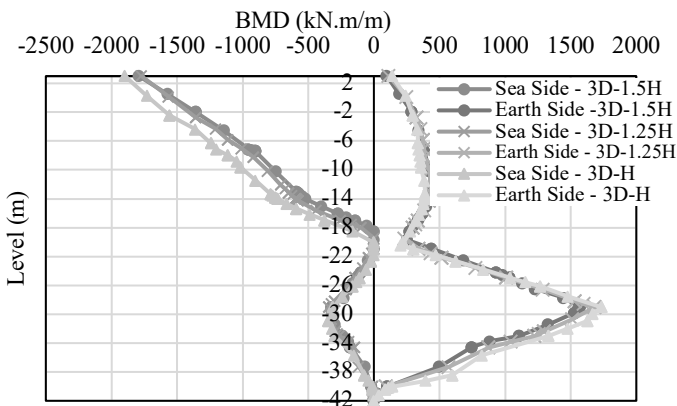


Figure 4. 3D B.M.D. for middle barrette first row.

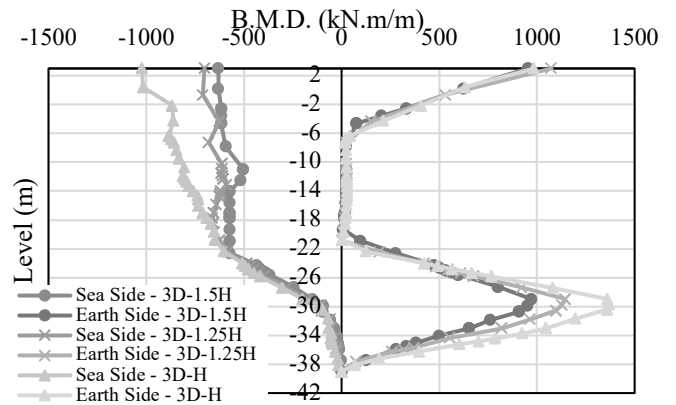


Figure 15. 3D bending moment for rear barrette.

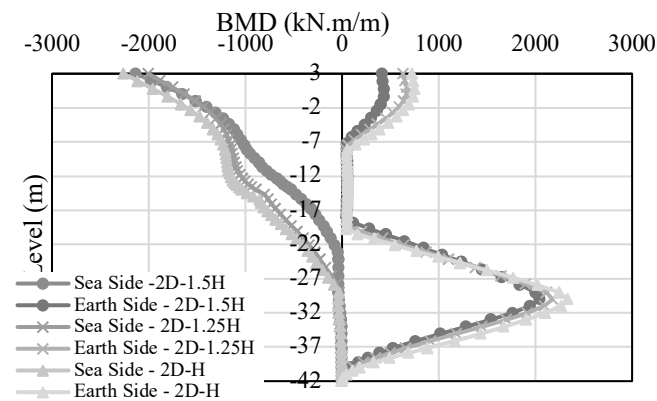


Figure 5. 2D B.M.D. for middle barrette second row.

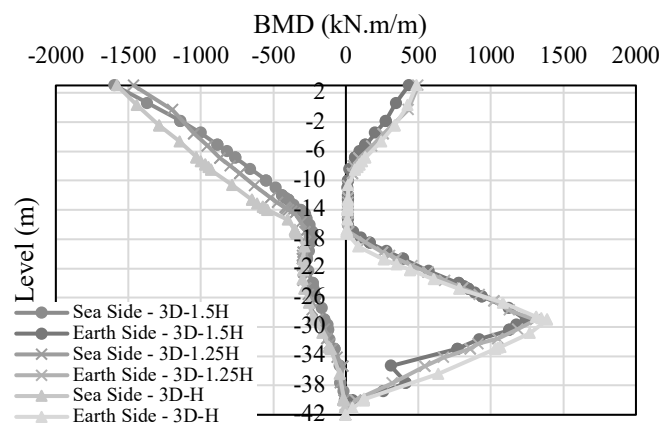


Figure 6. 3D bending moment for middle barrette second row.

### 7.3 Quay wall structure axial force

Figures 16 to 20 show the axial forces of the front diaphragm wall and barrettes by FEA. The axial force increases to the maximum value at a certain elevation and then gradually decreases until the bottom of the barrette. The increase in axial force at higher elevations is caused by the down drag force from soils. The upward friction force at lower elevations results in a decrease in axial force, and the axial force reaches the maximum value when the differential settlement of the barrettes and surrounding soils is equal to zero. Furthermore, it can be observed that the maximum axial force below the dredging level.

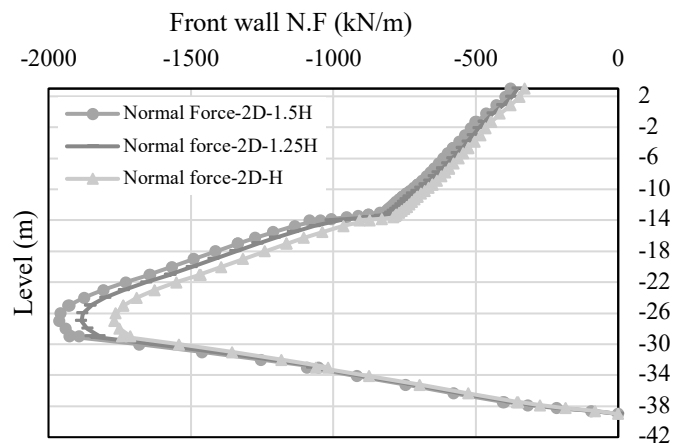


Figure 16. 2D Axial Force for Front wall.

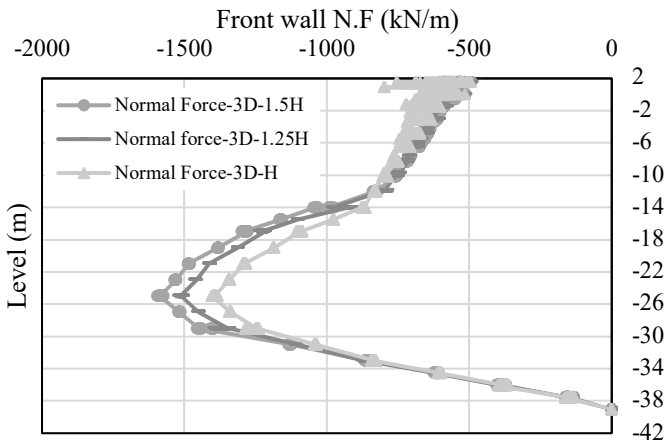


Figure 17. 3D Axial Force for Front Wall.

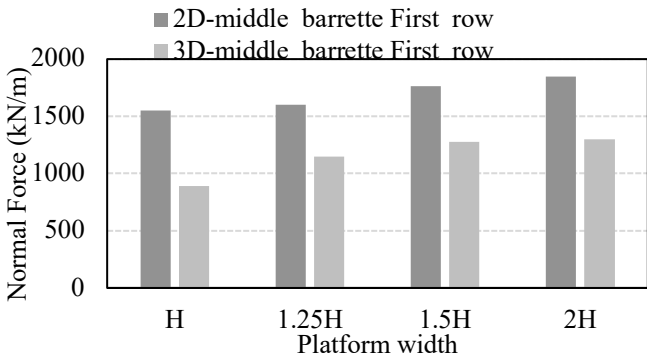


Figure 18. 2D&3D Maximum Axial Force for middle barrette First row.

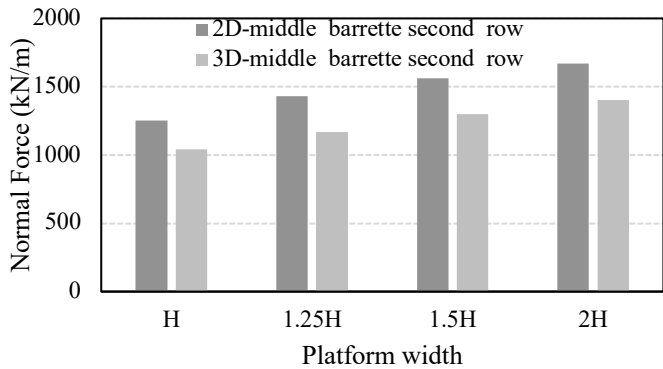


Figure 19. 3D&2D Maximum Axial Force for middle barrette First row.

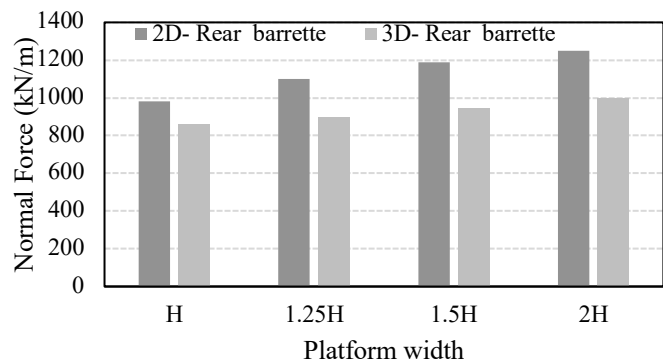


Figure 20. 2D & 3D Maximum Axial Force for middle barrette second row.

## 8 EFFECT OF BARRETTES-SUPPORTED PLATFORM ON INTERNAL FORCES

The objective of the barrettes-supported platform behind the front diaphragm wall is to reduce the lateral earth pressure acting on the wall, accordingly the bending moment and lateral deformation decrease. Figures 21 & 22 show the relation between platform width, internal force, and lateral deformation.

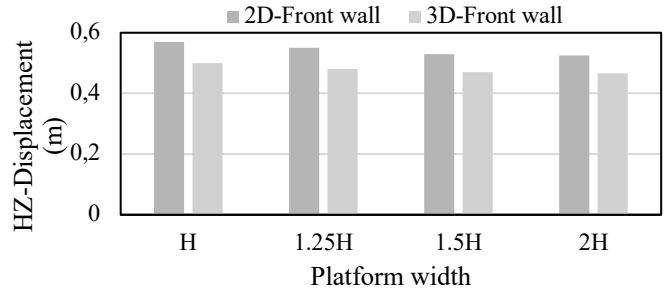


Figure 21. The effect of platform width on lateral deformation.

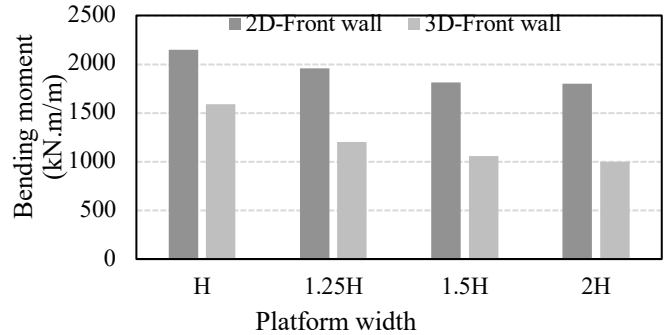


Figure 22. The effect of platform width on bending moment.

The results show that the increase in the width of platform decrease lateral deformation and bending moment. the effect of platform width decrease after platform width reaches to twice the retained height. The PLAXIS 3d analysis results lower than PLAXIS 2d analysis.

## 9 CONCLUSIONS

The paper presents the effect of platform width and the behaviour of quay walls with front diaphragm wall and barrettes-supported platform by 2D and 3D finite element analysis. The soil parameters for 2D&3D numerical models are calibrated based on the measured data from lab tests. Based on FEA, the following conclusions can be obtained:

1. The increase in platform width decrease the lateral deformation as the fixation of the system increase as the mobilized resistance increase.
2. The lateral deformations of the walls and barrettes initially increase significantly and then gradually decrease towards the barrettes tip.

3. The bending moment values of the front-diaphragm wall are always the largest. The maximum axial force for barrettes and front wall always below the dredging level.
4. The barrettes axial force gradually increases significantly and then gradually decreases towards the barrettes tip because of the soil friction forces in different directions. The increase in platform width due to a slight decrease in bending moment and significantly increase in axial force.
5. 3-D model gives lower internal forces, lateral deformation and bending moments compared to 2-D analysis. For conservative design, 2-D modelling shall be used but 3-D modelling is more realistic.
6. The effect of platform width decreases when the platform width reaches to twice the retained height.

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