COMPARATIVE ANALYSIS OF A CONTAINER TERMINAL AND A MULTIPURPOSE TERMINAL AT ABU QIR PORT

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1. **ABSTRACT:** This paper provides a structural comparative analysis between a container terminal quay wall with a 22 m draft and a multipurpose terminal quay wall with a 17 m draft, both located at Abu Qir Port, Alexandria, Egypt. New Abu Qir Port hosts 6,250 m of quay walls with a draft of 22 m and 650 m of quay walls with a draft of 17 m. The front wall of both quay walls is a combined wall structural system, comprised of tubular steel piles encasing a reinforced concrete bored pile connected by steel sheet piles. The anchor system of the container terminal quay wall is two intermediate reinforced concrete bored piles and a reinforced concrete barrette pile, while the anchor system of the multipurpose terminal quay wall is a barrette pile. The comparative analysis focuses on the anticipated performance of both structural systems since the containership quay wall terminal is typically subject to higher loads due to the crane wheel load and corresponding earth pressure load. The comparative analysis demonstrates how the structure system can be modified in terms of pile tip levels and anchor piles configuration and how each quay wall structural system responds to the operational loads in terms of deformations and straining actions. The analysis was performed using PLAXIS 3D V21 to conduct a three-dimensional numerical model. The study emphasizes the need for an infrastructure resilience capable of safely accommodating varying operational demands with cost effectiveness.

2. INTRODUCTION

Abu Qir Port is becoming one of the most important Egyptian ports due to its distinctive location on the Mediterranean, it will be the largest Egyptian port with berths reaching 22 m draft and 6,250 m length, in addition to a berth of 17 m draft and 650 m length (Maritime Transport Sector 2024) [10]. The 17 m draft multipurpose terminal quay wall was studied by (Kamel, et al. 2025) [8] where the location of the back anchor was varied to determine an optimal ratio relating a quay wall's draft to its anchor length.

This paper provides a structural comparative analysis between a container terminal quay wall with a 22 m draft and a multipurpose terminal quay wall with a 17 m draft. The comparative analysis focuses on the anticipated performance of both structural systems since the containership quay wall terminal is typically subject to higher loads due to the crane wheel load and corresponding earth pressure load.

3. STRUCTURAL SYSTEM

3.1 Front wall

The front wall structural system for both quay walls is a combined wall system, comprised of tubular steel piles 2250/18 mm encasing a reinforced concrete bored pile with a diameter of 2.15 m connected by double AZ 26-700 steel sheet piles with a 3.71 m spacing. The difference in the front wall between the 17 m and the 22 m quay walls are tabulated as follows:

Table 1. Front wall differences

	Combined wall			*Reinforced concrete bored pile*		
Quay wall	*Combined wall length (m)*	*Top level (m)*	*Bottom level (m)*	*RC bored pile length (m)*	*Top level (m)*	*Bottom level (m)*
17 m	27	+0.7	-22.3	11.7	-22.3	-34.0
22 m	23	+1.0	-26.0	17.0	-26.0	-43.0

3.2 Anchor system

Both quay walls use reinforced concrete piles as anchor systems, the 22 m quay wall uses two reinforced concrete bored piles with a diameter of 1.2 m and one reinforced concrete barrette pile 2.8x0.8 m with a 7.42 m spacing, while the 17 m quay wall uses only one reinforced concrete barrette pile with a 7.42 m spacing. The differences in the anchor system are tabulated as follows:

Table 2. Anchor system differences (reinforced concrete bored pile)

Quay wall	*Number*	*Centerline spacing (m)*	*Length (m)*	*Top level (m)*	*Bottom level (m)*
17 m	-	-	-	-	-
22 m	2	9.2	39	+1.0	-38

Table 3. Anchor system differences (reinforced concrete barrette pile)

	Reinforced concrete barrette pile				
Quay wall	*Number*	*Centerline spacing (m)*	*Length (m)*	*Top level (m)*	*Bottom level (m)*
17 m	1	13	11.7	-22.3	-34.0
22 m	1	9.2	17.0	-26.0	-43.0

3.3 Beams and slabs

Both quay walls use a reinforced concrete capping beam connecting the front wall and a reinforced concrete transverse beam connecting the front wall to the anchor piles. The deck slab is 0.5 m thick supporting the live load of the quay platform. The cross sections of both quay walls are shown in **Figure 1** and **Figure 2**.

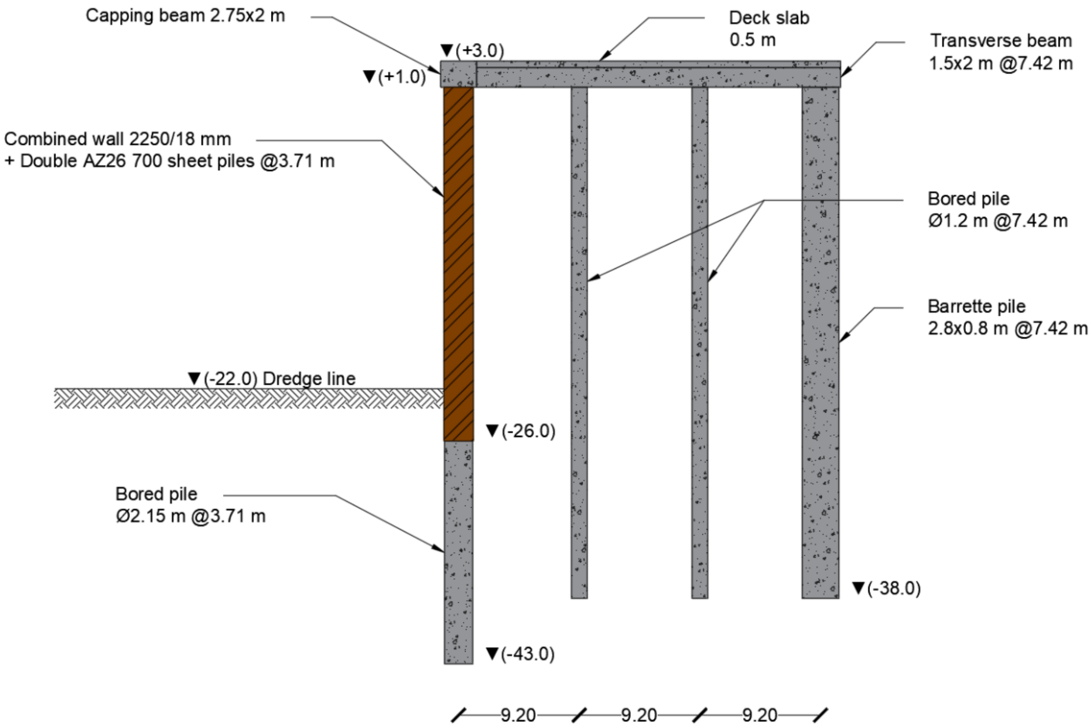


Figure 1: 22 m draft container terminal quay wall

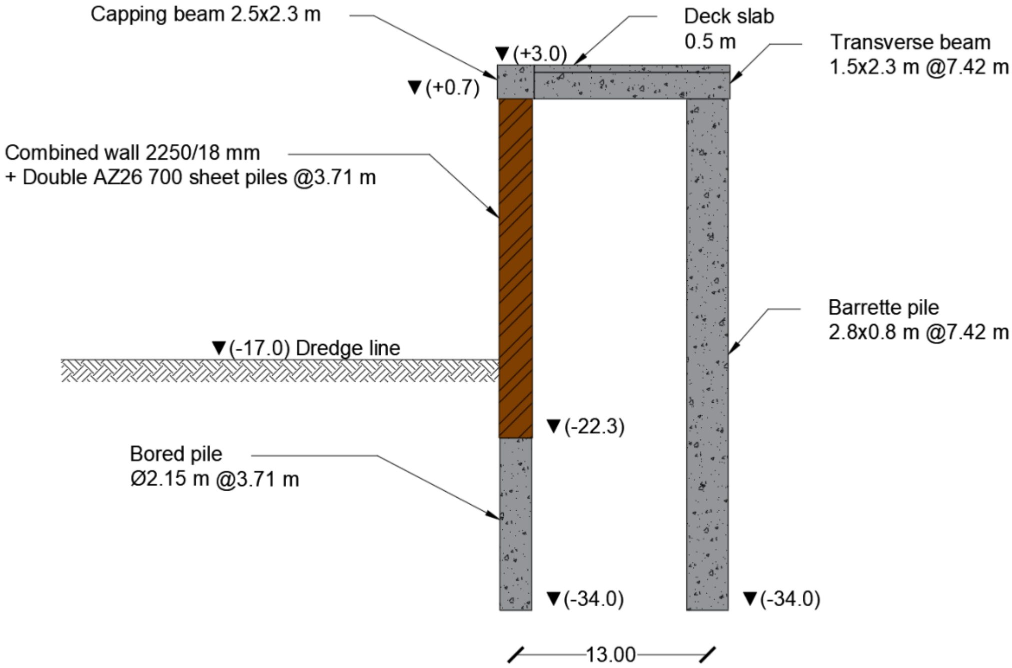


Figure 2: 17 m draft multipurpose terminal quay wall

4. GEOTECHNICAL DATA

The soil stratigraphy for the 17 m quay wall was presented by (Kamel, et al. 2025) [8] as shown in **Table 4**, the stratigraphy is comprised of reclaimed sand, followed by silty sand then clay and silt. The stratigraphy for the 22 m quay wall is shown in **Table 5** where it is comprised of reclaimed sand, silty sand, and then clay.

Table 4. Soil stratigraphy for the 17 m quay wall

Soil layers	*Top level (m)*	*Bottom level (m)*
Reclaimed sand 1	3.0	-5.0
Reclaimed sand 2	-5.0	-10
Reclaimed sand 3	-10	-15
Silty sand	-15	-36
Silt	-36	-38.5
Clay	-38.5	-42
Silty sand	-42	-43.5
Silt	-43.5	-60

Table 5. Soil stratigraphy for the 22 m quay wall

Soil layers	*Top level (m)*	*Bottom level (m)*
Reclaimed sand 1	3.0	-5
Reclaimed sand 2	-5.0	-14
Upper sand	-14	-24
Lower sand	-24	-34
Clay	-34	-60

5. OPERATIONAL LOADS

The operational loads acting on both quay walls are shown in **Table 6**. The 17 m quay wall will serve as a multipurpose terminal therefore no crane loads are present, while the 22 m quay wall will serve as a container terminal with crane loads acting on the capping beam.

Table 6. Operational loads

Quay wall	*Uniformly distributed live load (kPa)*	*Mooring load (kN)*	*Crane load (kN/m)*
17 m	60	480	-
22 m	60	480	900

6. METHOD OF ANALYSIS

The analysis was performed using PLAXIS 3D V21. PLAXIS 3D is a powerful geotechnical software used for modelling soil/structure interaction using the finite element method (Bently Systems, Incorporated 2025) [1]. Both quay walls were modelled with the same structural material properties and the same stages of construction. The straining actions and deformations for the structural elements were extracted and the structural performance was evaluated.

7. NUMERICAL MODELLING

7.1 Boundary Conditions

Boundary conditions of the 22 m quay wall were determined after (Hugel, Henke and Kinzler 2008) [6] as shown in **Figure 3** where the top of capping beam elevation was +3.0 m and the toe of the front wall elevation was -43.0 m, this gives a total of 45 m retaining height. This distance was doubled below the toe of the front wall giving a Z_{min} boundary -90 m. This distance was set as for the maximum and minimum longitudinal boundaries (X_{max} and X_{min}) and approximated to 100 m.

The lateral width of the model was determined as 22.26 m, due to modelling two cranes adjacent to each other, each with a 7 m roller length. For the 17 m quay wall, the same boundary conditions were determined except for the lateral boundary which was set at 14.84 m which corresponds to the bollard spacing. The model geometry was built in a symmetric manor.

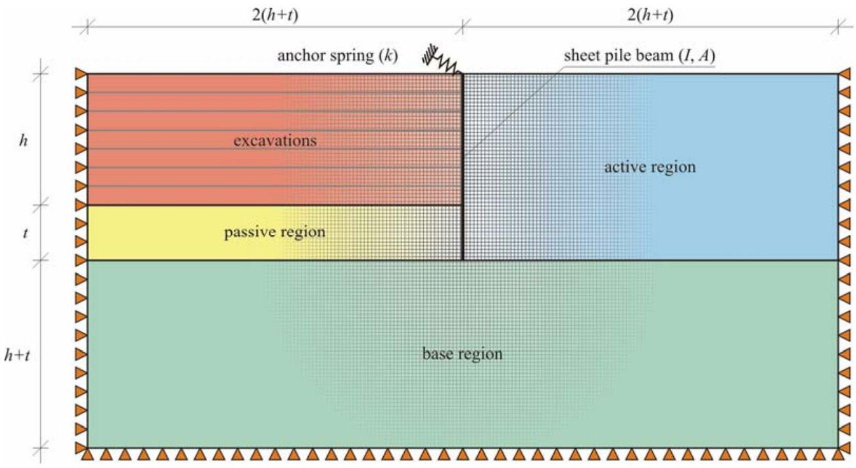


Figure 3: 17 m draft multipurpose terminal quay wall

Table 7. Boundary conditions

Boundary	*Length (m) (22 m quay wall)*	*Length (m) (17 m quay wall)*	*Fixity*
X_{max}	+100	+100	Normally fixed
X_{min}	-100	-100	Normally fixed
Y_{max}	11.13	7.42	Normally fixed
Y_{min}	-11.13	-7.42	Normally fixed
Z_{max}	+3.0	+3.0	Free
Z_{min}	-90	-90	Fully fixed

7.2 Soil input

Soil was modelled using the Mohr-Coulomb failure criteria, **Table 8** shows the soil parameters for the 22 m quay wall and **Table 9** shows the soil parameters for the 17 m quay wall after (Kamel, et al. 2025) [8].

Table 8. 22 m quay wall soil parameters

Soil layers	*Material model*	*Drainage*	*γ unsat/sat (kN/m³)*	*E (MPa)*	*v*	*C (kN/m²)*	*φ (°)*	*ψ*
Reclaimed sand 1	Mohr-Coulomb	Drained	18/18	$10 + 1.5\, z_0$ [a]	0.33	-	31	1
Reclaimed sand 2	Mohr-Coulomb	Drained	18/18	$10 + 1.5\, z_0$ [a]	0.33	-	34	4
Upper sand	Mohr-Coulomb	Drained	17/17	$35 + 1\, z_1$ [b]	0.33	-	36	6
Lower sand	Mohr-Coulomb	Drained	18/18	45	0.33	-	36	6
Clay	Mohr-Coulomb	Undrained	18/18	75	0.3	150	-	-

[a] z_0 is the depth below ground level
[b] z_1 is the depth below natural seabed level

Table 9. 17 m quay wall soil parameters

Soil layers	*Material model*	*Drainage*	*γ unsat/sat (kN/m³)*	*E (MPa)*	*v*	*C (kN/m²)*	*φ (°)*	*ψ*
Reclaimed sand 1	Mohr-Coulomb	Drained	18/20	$20 + 1.5\, z_0$ [a]	0.33	-	31	1
Reclaimed sand 2	Mohr-Coulomb	Drained	18/20	$20 + 1.5\, z_0$ [a]	0.33	-	34	4
Reclaimed sand 3	Mohr-Coulomb	Drained	18/20	$20 + 1.5\, z_0$ [a]	0.33	-	38	8
Silty sand	Mohr-Coulomb	Drained	18/20	$50 + 2\, z_1$ [b]	0.3	-	38	8
Silt	Mohr-Coulomb	Drained	17/17	50	0.3	-	34	4
Clay	Mohr-Coulomb	Drained	18/18	50	0.3	-	21	0

[a] z_0 is the depth below ground level
[b] z_1 is the depth below natural seabed level

7.3 Structure, material modelling, and mesh generation

Volume elements were used for modelling concrete elements while plate elements were used for modelling steel elements. Volume elements are the most practical approach to model a laterally loaded embedded structure (PLAXIS 2021) [11] (Kamel, et al. 2025) [8]. Soil/steel and soil/concrete interface values (R_{inter}) were determined to be 0.67 and 1.0 respectively (BS EN 1997-2 2007) [2] (Kamel, et al. 2025) [8]. Concrete and steel were modelled as linear elastic with the properties shown in Table 10 after (Kamel, et al. 2025) [8].

Mesh was generated using medium element distribution and a coarseness factor of 0.1 was applied to the volume elements from which the results were obtained.

Table 10. Material properties

Material	*Material model*	*γ (kN/m³)*	*E (GPa)*	*ν*
Concrete	Linear elastic	25	31*	0.2
Steel	Linear elastic	78.5	210	0.2

*31 GPa for the 17 m quay wall and 28 GPa for the 22 m quay wall

7.4 Stages of construction

Modelling the stages of construction was performed according to the actual construction process on site which is shown in **Table 11** after (Kamel, et al. 2025) [8].

Table 11. Stages of construction

Construction phase	*Phase description (17 m quay wall)*	*Phase description (22 m quay wall)*
Initial phase	Initial phase (initializing K_0 procedure)	Initial phase (initializing K_0 procedure)
Phase 1	Substructure construction	Substructure construction
Phase 2	Superstructure construction	Superstructure construction
Phase 3	Dredging seaside in front of the quay wall down to -17 m	Dredging seaside in front of the quay wall down to -22 m
Phase 4	Dredging seaside in front of the quay wall down to -19 m	Dredging seaside in front of the quay wall down to -24 m
Phase 5	Installing scour protection	Installing scour protection
Phase 6	Operational loads (60 kN/m² surcharge + 480 kN bollard load)	Operational loads (60 kN/m² surcharge + 480 kN bollard load + 900 kN/m crane wheel load)

7.5 Post processing

Straining actions were extracted from volume elements by integrating a manual centerline along the pile using the "structural forces in volume piles" tool in PLAXIS 3D. Deformations were extracted by implementing "dummy" beams along the pile centerline, these dummy beams have the same dimensions as the main element, a stiffness 1000 times less than the element stiffness, and zero unit weight.

8. RESULTS AND DISCUSSION

8.1 Deformation & bending moment

This section showcases the deformed mesh, horizontal soil deformation and bending moments of both quay walls in terms of serviceability state. The deformed mesh for the 17 m quay and the horizontal soil deformation are shown in **Figure 4** and **Figure 5** respectively after (Kamel, et al. 2025) [8].

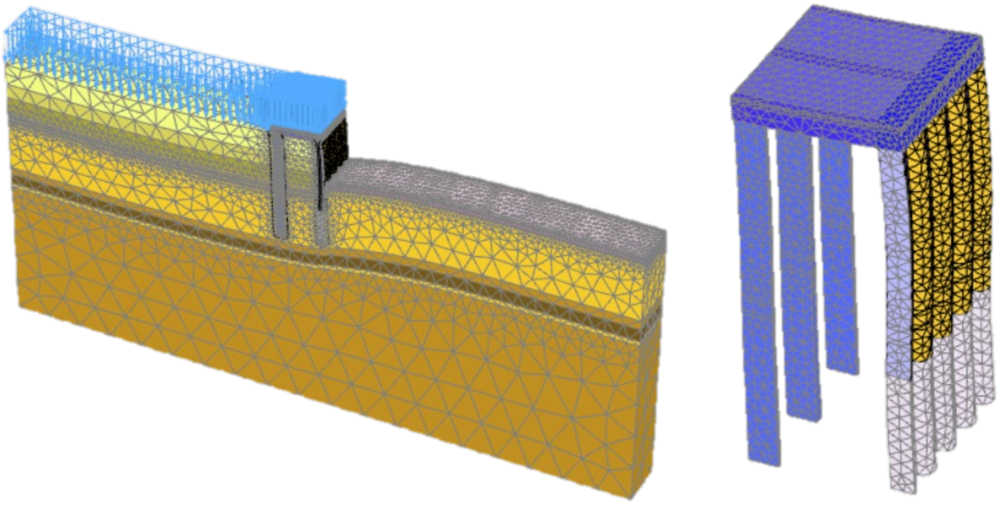


Figure 4: 17 m quay wall deformed mesh due to operational loads

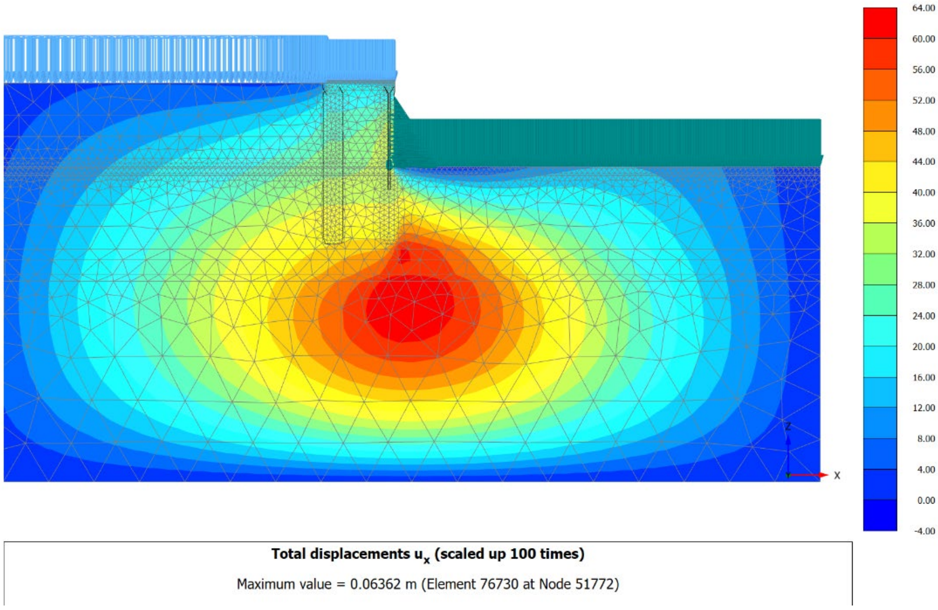


Figure 5: 17 m quay wall horizontal soil deformation

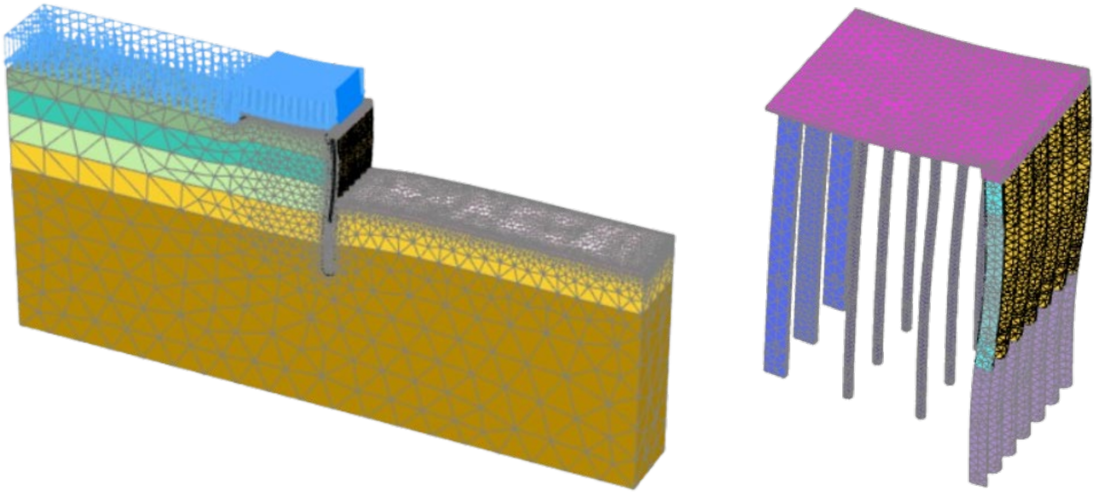
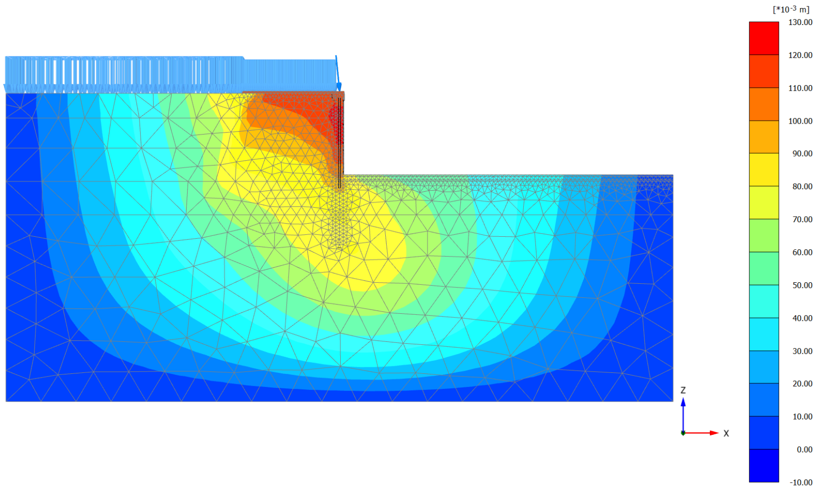


Figure 6: 22 m quay wall deformed mesh due to operational loads



Total displacements u_x (scaled up 50.0 times)
Maximum value = 0.1238 m (Element 35834 at Node 11433)
Minimum value = 0.000 m (Element 9591 at Node 66744)

Figure 7: 22 m quay wall deformed mesh due to operational loads

The maximum horizontal deformation due to the loading stage was 123.6 mm and 44.2 mm for the 22 m and the 17 m quay walls respectively as shown in Figure 8 which is a 64% reduction in the quay wall's horizontal movement. The bending moment value of the front bored pile was nearly unaffected by the change in the structural system while the barrette bending moment increased due to it becoming closer to the front wall as explained by (Kamel, et al. 2025) [8].

The results highlight the need for a cross-section reduction when designing the 17 m quay wall, where the two intermediate bored piles were omitted, the pile tip elevation was shortened to -34.0 m, the barrette was moved closer to the front wall and the steel tube elevation was shortened to -22.3 m.

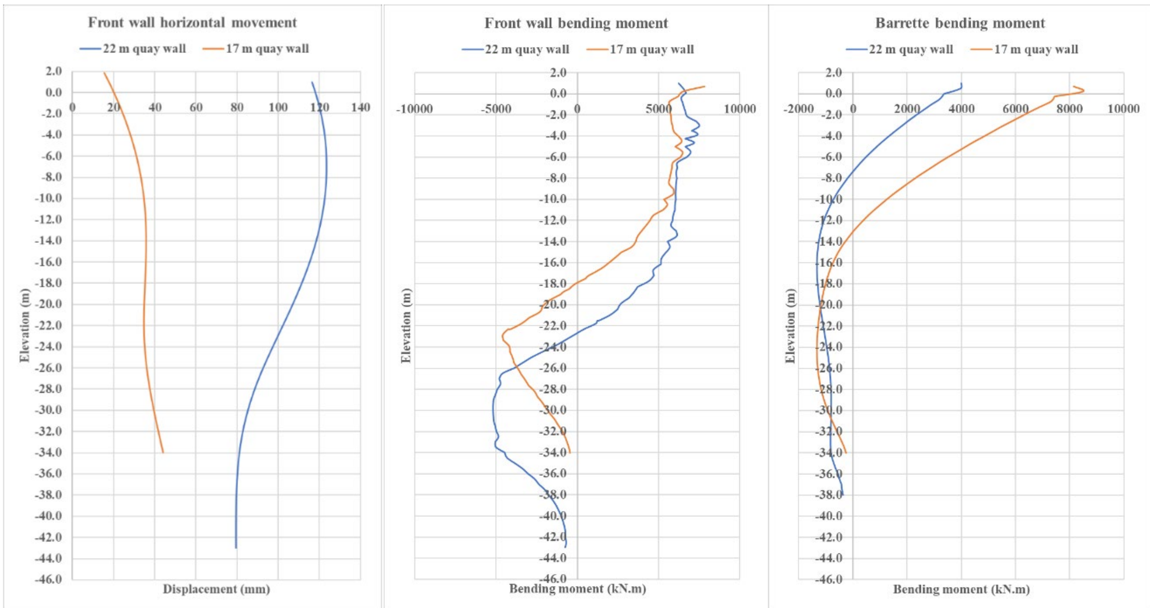


Figure 8: Horizontal deformations and bending moments

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This paper provided a structural comparative analysis focusing on the anticipated performance of the structural systems of a 17 m draft multipurpose terminal and a 22 m draft container terminal. The concept of the structural system adopted for both quay walls was the same, yet the following adjustments were made to the 17 m draft quay wall:

(1) The two intermediate bored piles were omitted.
(2) The pile tip elevation was shortened to -34.0 m.
(3) The barrette was moved closer to the front wall.
(4) The steel tube elevation was shortened to -22.3 m.

The aforementioned changes to the 17 m draft quay wall established a resilient and cost-effective infrastructure.

9.2 Recommendations

The use of numerical modelling programs such as PLAXIS 3D in construction is a much since they allow engineers to perform designs, structural enhancement, and optimization in a relatively short timeframe. Other programs such as FLAC 2D/3D tackle soil and rock mechanics using the finite difference method (ITASCA Software 2025) [6], Abaqus explores the theoretical potential of a method without imposing unnecessary limitation (Dassault Systemes 2025) [3], and GEO5 provides geotechnical design for stability analysis, excavation design and retaining wall design (Fine spol. s r.o. 2025) [4].

Other applications of cost effectives included research by (Francois, et al. 2020) [5] where he developed an automated design procedure for block quay walls optimization where the concrete volume was reduced from 170 m^3/m for a single stage construction to 153.9 m^3/m for 12 stages construction saving approximately 9.5% concrete volume. Using chamfered blocks also reduced the volume of concrete per meter when compared to traditional rectangular blocks by up to 5.1%.

Another research by (Kayabekir, et al. 2020) [9] optimized the design of a L-shaped reinforced concrete retaining walls using the Jaya Algorithm to minimize construction costs while ensuring structural and geotechnical safety. By evaluating 105,000 design cases under varying conditions, including excavation depth, soil friction angle, unit weight, ultimate bearing capacity, and surcharge load, they identified how each factor influences wall sizing and cost. Increasing the soil friction angle from 28° to 38° reduced total material costs by up to 37%, while increasing the ultimate soil bearing capacity from 250 to 350 kPa led to a 15% cost reduction.

10. DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES:

The author(s) declare that no generative AI or AI-assisted tools were used during the preparation of this work.

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