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EFFECT OF PENETRATION DEPTH ON THE BEHAVIOUR OF WALLING BEAM SHEET PILES USING FINITE ELEMENT METHOD

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Abstract

In the present work, a continuous waler beam is designed to retain two types of sheet piles a cantilever sheet piles and an anchored sheet piles with different penetration depths (24, 26, 28 and 30 meter length) in a 400m length port. The analysis of the waler beam as well as sheet piles under the effect of active and passive pressure was extended by using finite element method with two dimensional plain strain analysis. The structural behavior of the continuous waler beam connected to the sheet piles is studied using a software Autodesk FEM ROBOT 2019. Bending moments and displacements of the sheet piles were reviewed. The effect of the penetration depths on the behavior of the continuous waler beam is studied, analyzed and compared for each depth with a specific soil properties.

Keywords: Penetration depth, Sheet piles, Waler beam, Finite element method

1. Introduction

A parametric study is performed to investigate the effect of different wall penetration depths (D) on the behavior of continuous waler beam for cantilever and anchored sheet piles. The wall penetration depths analyzed ranged from the depths calculated by the finite element methods of sheet piles to the points where increasing the wall penetration depth after these points had no effect on the waler behavior. The sheet piles penetration depths are measured from the end of the required excavation (dredge line) to the butt of the sheet piles. The width and depth of each model boundaries were fixed as wall penetration depth increasing. The bending moment and displacements for both cantilever and anchored sheet piles were discussed in the current study.

The anchored sheet piles connected to a continuous waler beam. The waler beam consists of two back to back channels riveted by bolts. The bolts were passed through the channels as well as through the sheet piles. For anchored sheet piles the waler beam is connected to tie rods. The design of the waler beam as well as the analysis of the soil continuum is analyzed using Autodesk ROBOT 2019 program by using a 16 node triangular element in order to simulate the stress concentration acted on the waler beam.

Many references were made to many papers that have discussed different penetration depths for the anchored and cantilever sheet piles, for example, Ammar Almoswi, (2019) [1] David Baxter, (2016) [4], Hathem A. Amer (2014) [6], Franklin, S.O. and Olopade (2013), Leila Eskandari (2011), and Škrabl, S. (2006).

2. Case study and model simulation

A sheet piles of different lengths (24, 26, 28 and 30m), are analyzed using finite element method in order to investigate:

• The required penetration depth for cantilever and anchored sheet piles with respect to the applied active and passive loads.

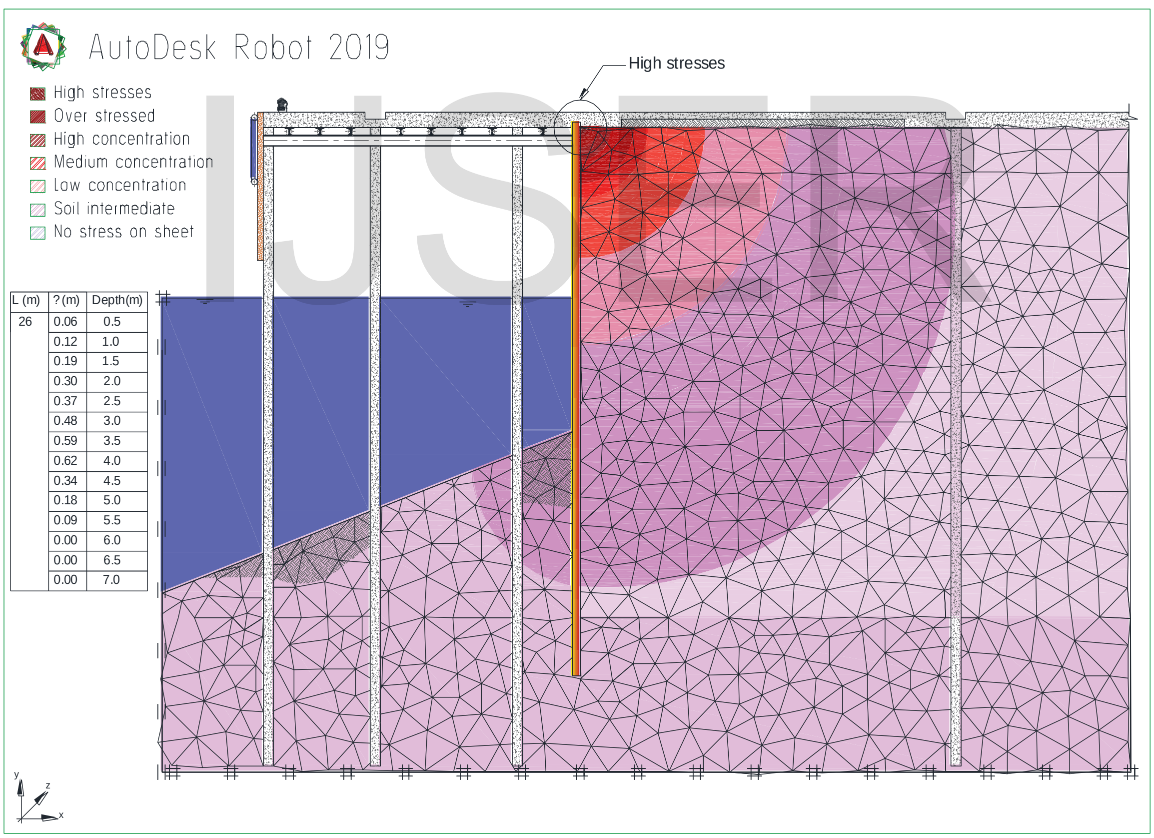
• The ideal coordinates and location of the waler beam and the minimum required numbers of walers needed.

The sheet piles were chosen to meet the specifications of (AZ 22-800), the yield strength of the steel sheet piles was taken (365 N/mm²) of grade (S275G). The soil parameters and the cam clay model were constant for the soil in all depths. In order to investigate the behavior of the waler beam with respect to the penetration depth of the sheet four cases were reviewed and discussed as follows:

2.1 Case No.1

Cantilever sheet piles that have the properties of (AZ 22-800) with a total length of (24m) without anchoring. The parameters of the soil and the soil layers were constant for all cases. Although the sheet piles were enclosed by a reinforced concrete deck from the sheet piles tip by about (200mm from the total mooring deck thickness) and retained by a several layers of compacted subbase from the face of the active side but the concrete doesn't provide the required anchoring system to the sheet piles because an observed displacement of (760mm) occurred at a distance of (-3.489m). Figure (5) and Figure (6).

High stresses occurred at the tip of the cantilever sheet piles. Figure (1) shows the stress concentration on the sheet piles. A large displacements (760mm) observed at a depth of (-3.489m).



L (m)	? (m)	Depth(m)
26	0.06	0.5
	0.12	1.0
	0.19	1.5
	0.30	2.0
	0.37	2.5
	0.48	3.0
	0.59	3.5
	0.62	4.0
	0.34	4.5
	0.18	5.0
	0.09	5.5
	0.00	6.0
	0.00	6.5
	0.00	7.0

Figure (1) Section in the port shows the stress concentration at the cantilever sheet pile

2.2 Case No.2

Increasing the depth of the cantilever sheet piles with same input data and soil parameters in order to investigate the effect of penetration length without anchoring. Sheet piles that have the properties of (AZ 22-800) with a total length of (26m) without anchoring were analyzed with an increase in depth by (2m) than in case one. It was observed that as the penetration depth increased; the displacement decreased with a small amount but still large displacement observed at depth (-3.78m) which was (634mm). Although the displacement decreased but it is still considered large and unacceptable as well as the stresses on the tip of the sheet piles remain high. In order to overcome the effects of high stresses and displacements; the sheet piles were anchored in case three. Figure (7) and Figure (8)

2.3 Case No.3

Sheet piles of the same properties as in case one and two, (AZ 22-800). The total length was increased to (28m). The sheet piles were anchored with a continuous waler beam connected by tie rods at specified distances each (4.0m) in (z-direction). The waler beam has been located at a depth (-3.5m) from top because it represents the critical distance at which the highest displacement observed in the analysis of the mentioned two cases. The tie rods were connected to a circular reinforced concrete pile. In the analysis of case three a small displacement observed. In this case the largest displacement occurred at a depth (-4.7m) which was (76mm). The amount of displacement gives an indication of the importance of presence of the waler beam compared to case one and two. Figure (9) and Figure (10)

2.4 Case No.4

The length of the sheet piles increased to a total length of (30m) with the same properties (AZ 22-800) and same soil parameters. With the existence of the anchor with a continuous waler beam connected by a tie rods at a specified distances each (3.3m) in (z-direction). In this case the depth of waler beam was located at several coordinates (-3.50m, -3.75m, -4.00m).

At depth (-3.5m) the maximum displacement was (28mm). The stresses on the face of sheet piles at the waler beam coordinates were low as clear in. A significant increase in displacement occurred at depth (-3.75m). The maximum displacement record was (54mm). High stress concentration on the face of sheet piles at the waler beam coordinates was observed. Figure (11) and Figure (12)

At depth (-4.00m) an increase in displacement was indicated with high stresses at face of waler beam compared to depth (-3.75m).

The anchoring system of the sheet piles for case No.4 is replaced from a tie rod system to another special type of anchoring called truss anchoring system type making use of the driven piles on the sea part of the port as shown in Figure (2), Figure (3) and Figure (4)

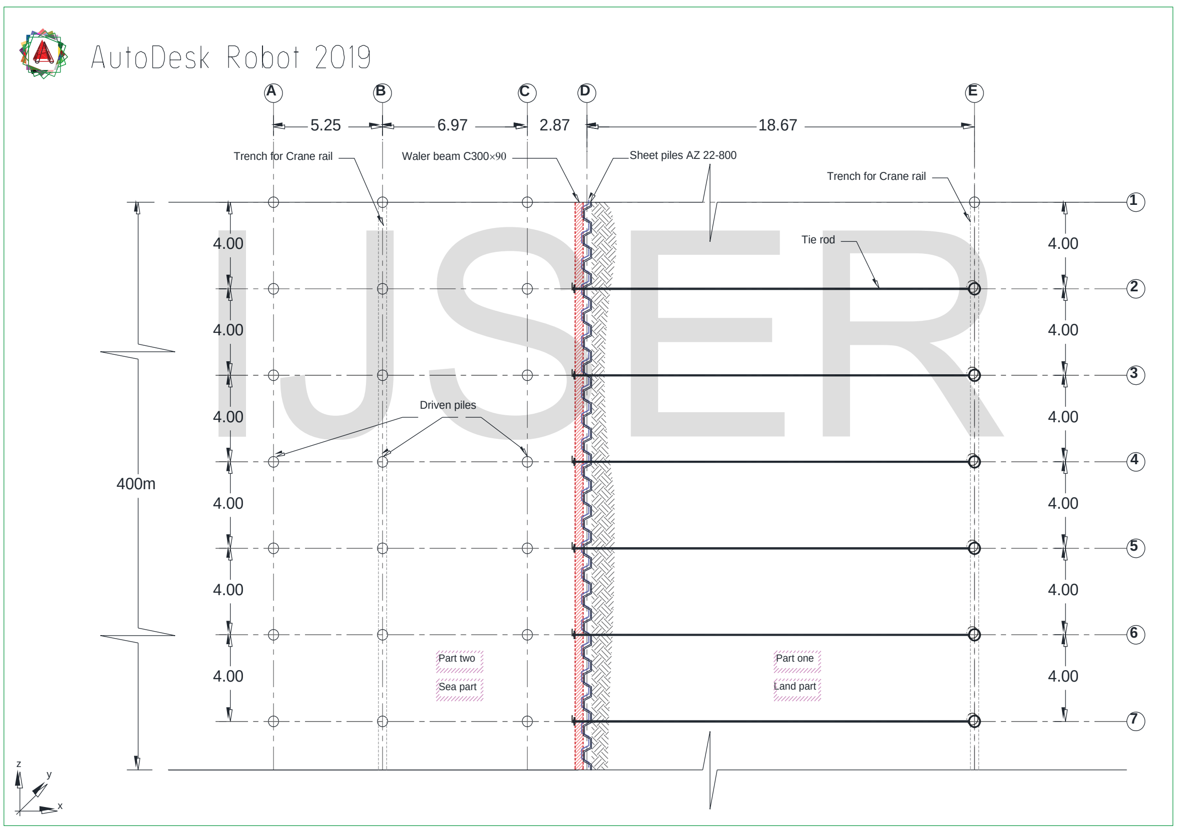


Figure (2) Layout of the anchored sheet piles

Figure (2) shows the layout of the anchoring system of the sheet piles. The distance between each tie rods is 4 meter. The tie rods were connected to the set of piles at the land part which were driven under the crane wheel rail at the land part side. Figure (3) shows the stress concentration of the cantilever sheet piles. The tie rods were connected to the driven piles directly as clear in Figure (3).

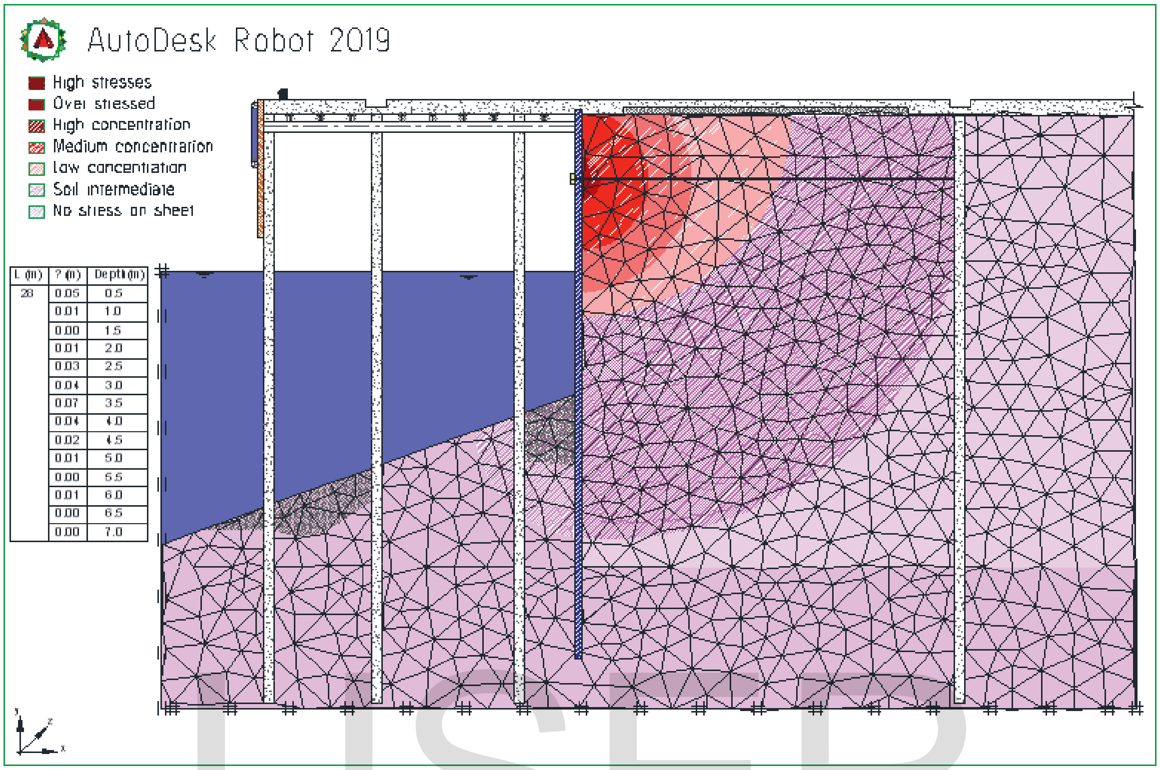


Figure (3) Stress concentration of anchored sheet piles

For cantilever sheet piles Figure (5) the length of the sheet piles is (24m) the maximum bending moment is (683.65Mpa) while the maximum displacement in case number one was (0.77m) at depth (-3.675m) as shown in Figure (6). A cantilever sheet piles with length (26m) as shown Figure (7); for this case a significant decrease in the bending moment observed (591.02Mpa) while the displacement was (0.62m) at depth (-4.0m) for case two as shown in Figure (8). For an anchored sheet piles with length (28m), the maximum bending moment (372.6 Mpa) at depth (-3.54) as shown in Figure (9) while the maximum displacement in this case was (70mm) at depth (-3.545m) as shown in Figure (10). For an anchored sheet piles with length 30m the maximum bending moment (237.67 Mpa), see Figure (11) while the maximum displacement was (20mm) at depth (-3.556m) as clear from Figure (12).

All the cases are discussed in the following paragraph.

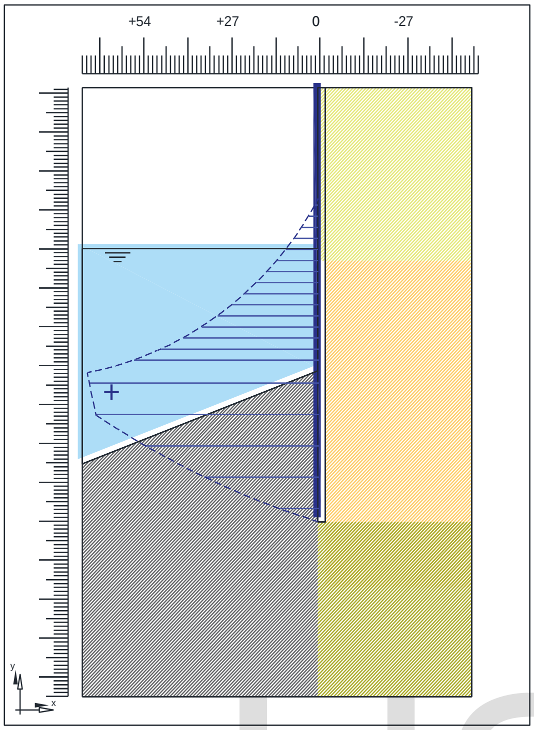


Figure (5) B.M.D for Case No.1

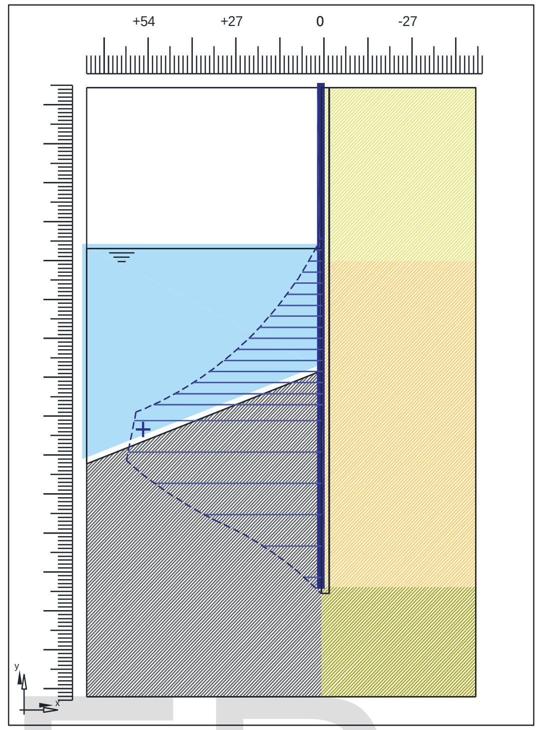


Figure (7) B.M.D for Case No.2

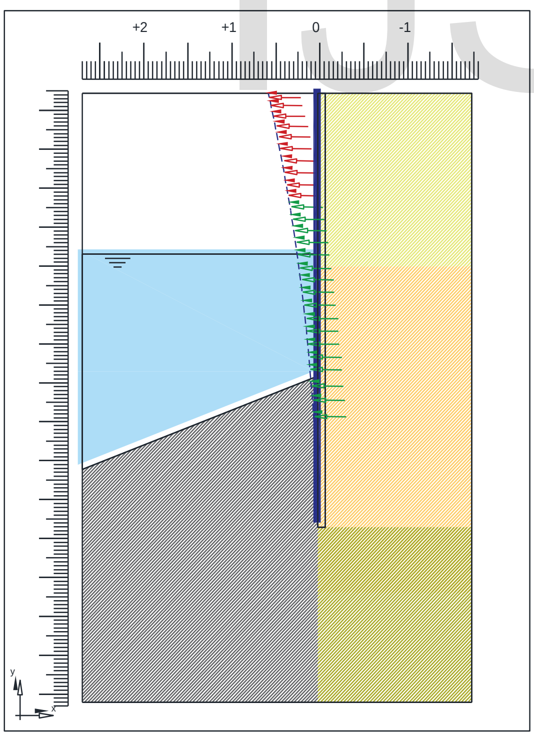


Figure (6) Displacement for Case No.1

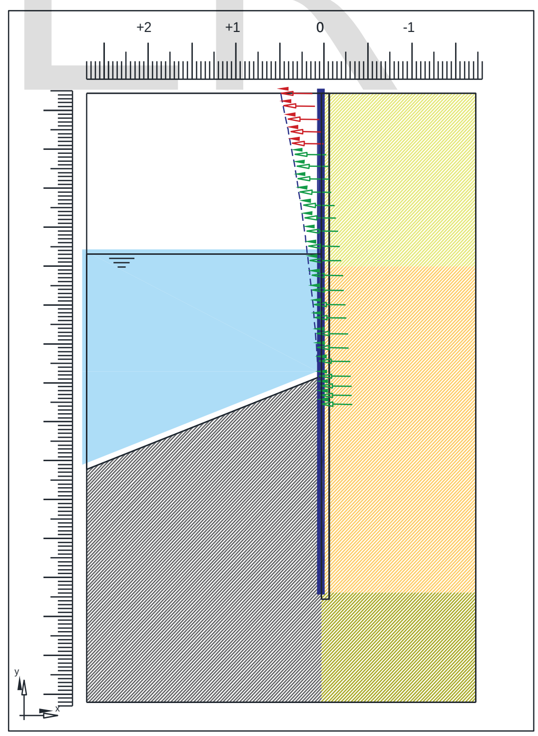


Figure (8) Displacement for Case No.2

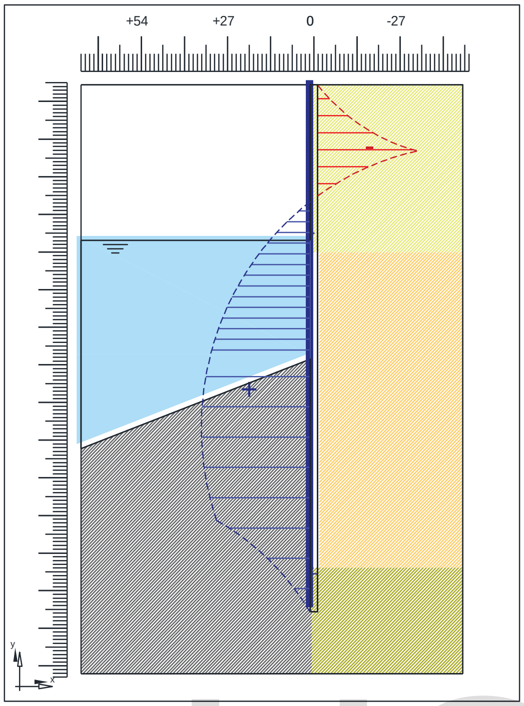


Figure (9) B.M.D for Case No.3

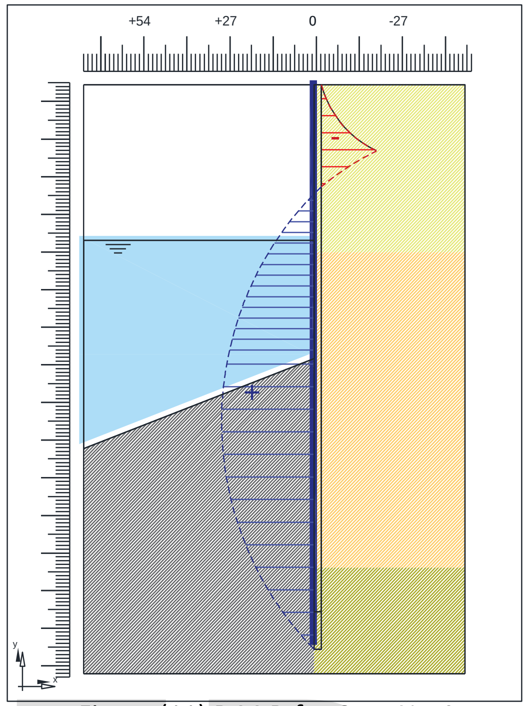


Figure (11) B.M.D for Case No.4

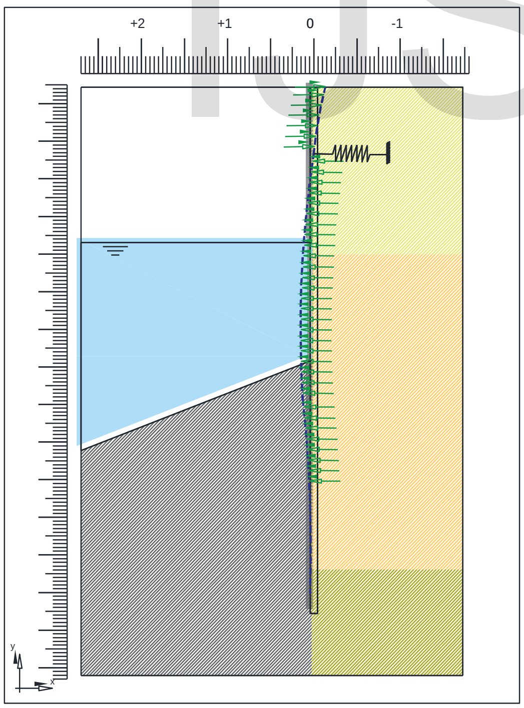


Figure (10) Displacement for Case No.3

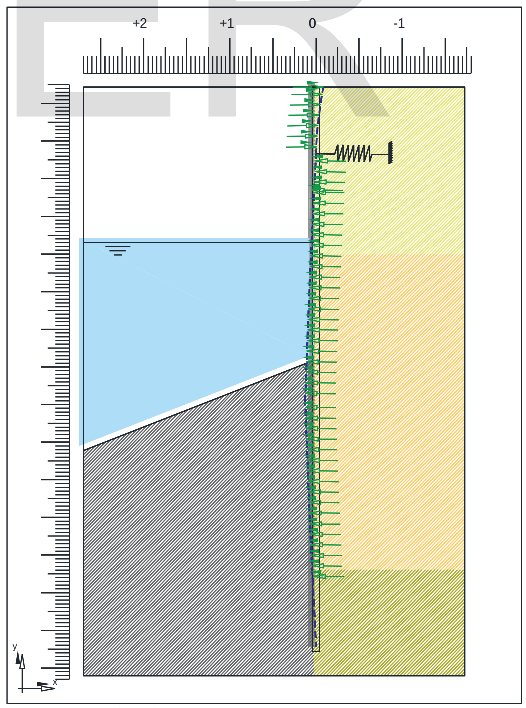


Figure (12) Displacement for Case No.4

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3. Waler beam formulation and methodology

A continuous waler beam is a straight steel element that is primarily subjected to transverse loads that come from the active side pressure. The deformed shape of the continuous waler beam is described by the transverse displacement and slope (rotation) of the beam. Hence, the transverse displacement and rotation at each end of the beam element are treated as the unknown degrees of freedom. For the analysis using finite element method a beam element of one meter length in the (*zy*) plane. The four degrees of freedom in the local (*zy*) coordinate system are indicated as $q_1, q_2, q_3 \, and \, q_4$. Because there are four nodal displacements, we assume a cubic displacement model for $\upsilon(x)$. [3]

$$\upsilon(x) = \alpha_1 + \alpha_2 x + \alpha_3 x^2 + \alpha_4 x^3 \qquad (3.1)$$

The constants $\alpha_1, \alpha_2, \alpha_3 \, and \, \alpha_4$ can be found by applying the boundary conditions;

$$at\ x = 0 \ \rightarrow \ \upsilon(x) = q_1$$

$$at\ x = 0 \ \rightarrow \frac{d\upsilon(x)}{dx} = q_2$$

$$at\ x = l \ \rightarrow \ \upsilon(x) = q_3$$

$$at\ x = l \ \rightarrow \frac{d\upsilon(x)}{dx} = q_4$$

Thus the finite element [N] matrix will be: [2]

$$\upsilon(x) = [N] \ \vec{q} \qquad (3.2)$$

Where [N] is given by:

$$[N] = [\, N_1 \quad N_2 \quad N_3 \quad N_4] \qquad (3.3)$$

The deformation of an element for continuous waler beam. The shape functions of the nodal deformations are calculated as follows; [4]

$$N_1(x) = \frac{2x^3 - {}^{3}/_{x^2} + l^3}{l^3} \qquad (3.4)$$

$$N_2(x) = \frac{x^3 - {}^{2}/_{x^2} + l^2 x}{l^2} \qquad (3.5)$$

$$N_3(x) = \frac{-(2x^3 - {}^3/_{x^2})}{l^3} \tag{3.6}$$

$$N_4(x) = \frac{x^3 - lx^2}{l^2} \tag{3.7}$$

The degrees of freedom for the continuous waler beam is represented by the following matrix:

$$\vec{q} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{bmatrix}$$

The finite element method and according to simple beam theory, plane sections of the beam remain plane after deformation and hence the axial displacement (u) due to the transverse displacement (v) can be expressed as it is shown in Figure (13);

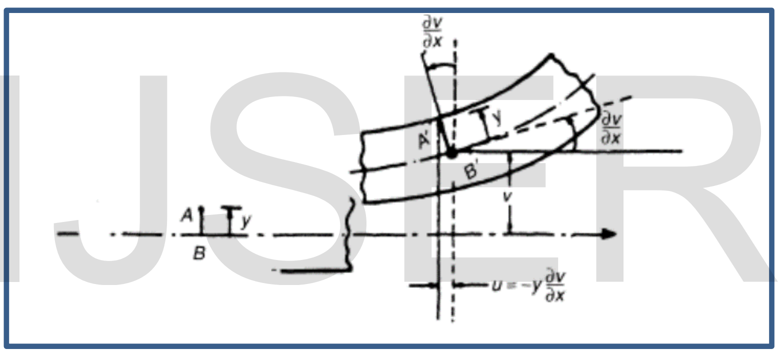

Figure (13) Transverse displacement for continuous waler beam [4]

The transvers displacements of the continuous waler beam could be represents by:

$$u = -y\frac{\partial v}{\partial x} \tag{3.8}$$

The bending moment of continuous waler beam as follows: [5]

$$M = \frac{Wl^2}{ב}$$

Where:
M: is the bending moment
W: is the calculated load to be supplied by the anchorage system (acting as a uniformly distributed load);

P_{ar}: is the tie rod reactions on the sheet pile through waler beam.
Using Table (3.1) to find ב ; [1]

Table (3.1) values of ב with different type of connections:[5]

Support type	ב
Fixed ends	10
Fixed – others	9.4
Simply supported ends	8.6

Conclusions

7.2 Conclusions

Increasing cantilever sheet piles penetration depth in the design can decrease horizontal sheet pile displacements significantly. By increasing penetration depth, about 50 to 60 percent reduction in the horizontal wall displacements are observed. On the other hand, wall bending moments for cantilever sheet pile walls were not affected by increasing the wall penetration depth. The effect of increasing wall penetration depth on the behavior of cantilever and anchored sheet pile continuous waler beam for varying wall heights in different soil types have been studied and presented in the present work. The sheet piles behavior was investigated through the wall displacements, bending moments, and anchor forces. A finite element analysis, using finite element method ROBOT 2019 AUTO desk software, were utilized to perform the parametric analyses. The overall study indicate that increasing wall penetration depth has a significant effect on the structural behavior of sheet pile walls. Increasing wall penetration depth reduced the cantilever wall deformation about (70%) significantly, and this yields a significant decreases in the sheet piles bending moment for anchored sheet pile walls. The results obtained indicate that all necessary information about designing the sheet pile walls; especially, in projects when the lateral sheet pile deformations or bending moment are needed to be restricted for design purposes.

Increasing anchored sheet piles penetration depth is not affecting the total horizontal displacements by increasing penetration depth depending on the anchoring system. The maximum displacement occurred at a total distance equal to 28% from the active part of the total length of the sheet piles as the maximum bending moment observed at these coordinates. A continuous waler beam should be located at maximum displacement.

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