STABILITY OF DOUBLE-ROW SHEET PILES QUAY WALLS

I.A.Ebeido, B.A. El-Sharnouby and A.M. Sobhy
Transportation Engineering Department
Faculty of Engineering,
Alexandria University,
Alexandria, Egypt

ABSTRACT

Double-row sheet pile quay walls are usually used to retain virgin soil, back filling or water. This type of structure has to resist a large magnitude of earth pressure developed on its two sides. Laboratory tests were performed on a double-row sheet pile model and results are presented and analyzed. The experimental earth pressure distribution curves exerted on the front and back sides are compared with the theoretical analysis and the comparison showed a significant difference. the experimental date showed also that the width between the two sides as an important factor affecting the shape and magnitude of earth pressure developed on both sides and an optimum design may be obtained at a width equal or close to the height of the wall.

INTRODUCTION

The common types of sheet pile walls include the cantilever type, the anchored walls, the cellular type, and double-row sheet pile. The so-called double-row sheet pile quay wall is used primarily as a retaining structure of a considerable height and usually formed of two roes of sheet piles driven parallel to each other and tied together with anchors and wales.

The design of the double row sheet pile walls generally follows the traditional theories of earth pressure and the procedure is somewhat similar to that used for the design of cellular sheet pile. Double-row sheet pile resting on rock was analyzed first as a gravity retaining walls specially with respect to its resistance to overturning and sliding along its base. Then, several theories have been introduced for better analysis considering failure mechanism, tilting of the walls, slippage along vertical planes and slippage along horizontal surfaces, and still connecting bars.

Among the approaches were those obtained by Rimstad (1940), Hansen (1940). Terzaghi (1945), White and Parentis (1950), Chumming (1960) and Dunham (1962). Although, these studies have contributed pioneerly to the analysis of the doubled-walled sheet pile, they have not provided a solid data the distribution of the earth pressure exerted on its sides and the various factors affecting the stability of the structure.

The objective of this research is to experimentally determine the lateral earth pressure distribution on the two sides of a double-row sheet pile quay wall model. A parametric study was carried out in order to find out the effect of the width of the wall, relative density of the filling sand, wall movement, and number of tie rods connecting the two sides, on thee stability of structure. The experimental data are presented, and analyzed and compared with theoretical predictions based on Coulomb's theory.

EXPERIMENTAL APPARATUS

A model of a double-row sheet pile quay wall has been developed. The apparatus, Figure 1, was constructed of rectangular steel container with two movable vertical walls tied together by tie rods placed inside it. The two inner vertical walls simulate the front and back sides of the double-row sheet pile wall with allowance made for a translatory movement through a screw jack. The internal dimensions of the apparatus were 290×80×80 cms; Length, width and height respectively. The two sides of the container are formed of hard glass to allow a clear vision of the soil profile, so that the rupture planes of the filling sand can be observed. Each side of the two inner walls was formed of twenty horizontal steel slices mounted on two vertical beams (Figures 2, 3). The two vertical beams were tied together by two horizontal tie rods, one at top and the other at bottom.

Each beam was rested on rollers to allow for horizontal motion. Two vertical plates and vertical rods were bolted and welded respectively in order to provide two guiding channels and support for the slices. The horizontal distance between the vertical rods was 55 mm which represented the effective span of the slices. The motion was transfered to the front side through a horizontal beam welded to the vertical beams, this motion was controlled by the screw jack. Slips of card board papers used to fill the space between the slices and the flange of the channel to hold the slices in its places. Strips of rubber were used as sealing between the guiding channel and the glass walls. Strain gages were fixed at midpoints of the slices (570×30×6 mm each slice). These gages were calibrated and pressure-strain relations were experimentally developed for each slice. To prevent friction and interlocking effects between slices on measurements, ball bearings ($\Phi = 10$ mm) were placed in between each two successive slices.

EXPERIMENTAL SET-UP AND TEST PROCEDURE

The front and back sides were connected together by the upper tie rod for the first group of tests and by the upper and lower ties for the second group of tests. The strain gages fixed on the selected slices were connected to the starin indicator. An initial-set of readings of strain indicator was always taken. The second set was taken after placing the filling sand in the container at rest condition, (displacement=0.0).

The final sets of readings were taken while moving the wall outward at a constant rate of displacement.

From these sets of readings, the magnitudes of strain, corresponding to any case of pressure, were calculated by subtracting the initial readings recorded at this case pressure.

The magnitudes of pressure intensities were obtained from the stress-strain calibration curves. The lateral earth pressure diagrams were then plotted for the different cases.

To determine the distribution and magnitude of earth pressure on the front and back sides of double-row sheet pile quay wall, 19 tests were carried out. Twelve of them were performed with the two sides of the wall tied together at the top and the others were performed with the walls tied at the top and bottom. The spacing between the sheets, B, in the tests was varied as well as the relative density of the filling material (sand), D_r, within and behind the walls.

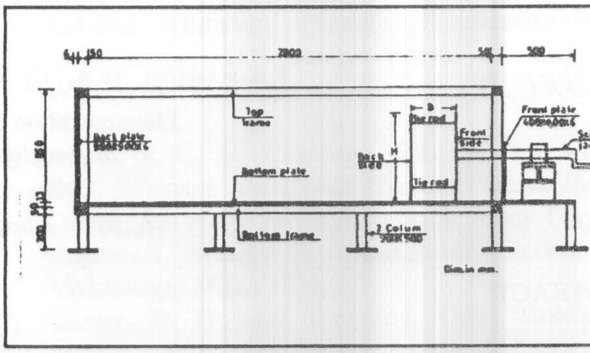

Figure 1. Test apparatus of double-row sheet pile wall.

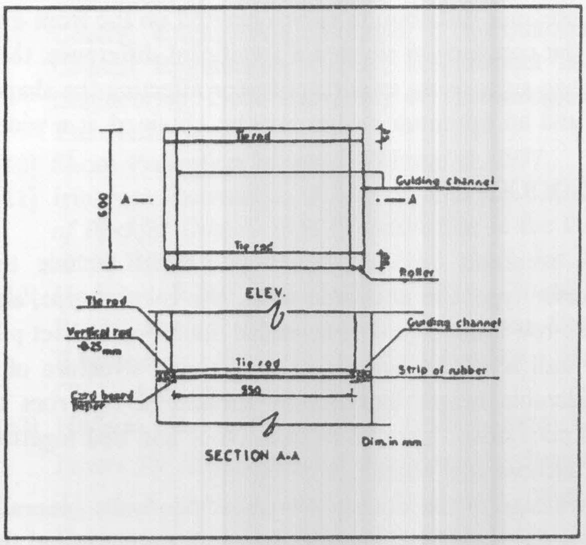

Figure 2. Slices supporting system (front wall).

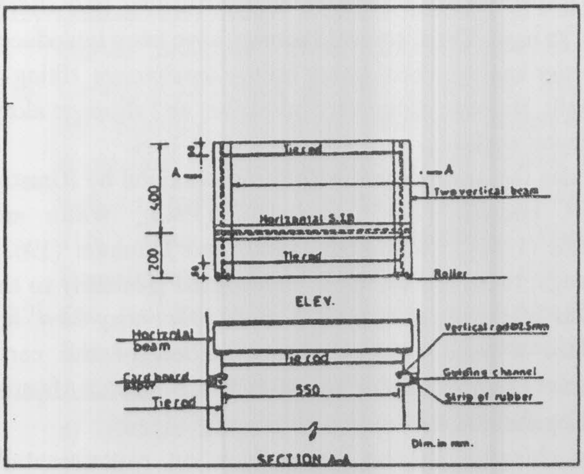

Figure 3. Slices supporting system (back wall).

The distribution curves of earth pressure acting on the front and back sides were developed for various wall width to height ratios, B/H, and different wall displacement ratio, Δ/H where H is wall height. The experimental results were compared with theoretical results based on Coulomp's theory of earth pressure.

The earth pressure diagrams were constructed by hand fitting using 6 points for each experiment. The pressure at four of them was actually measured, and the pressure at top and bottom points was assumed to one zero. The assumption of zero pressure at the bottom is not justified, because of the difficulty of measuring the strain at the bottom of the wall.

WALLS TIED AT TOP ONLY

A total of 12 tests were performed. The distances between the front and back sides was normalized as a ratio of the wall height. Four ratios were considered(B= 0.5 H, 0.75 H, H and 2 H). For each ratio the test was repeated using three different relative densities of the filling material(minimum density, 40% D_r and 70% D_r). The intensities of earth peruser at 4 different points at both the front and back sides were determined and the corresponding diagrams were plotted. For each test, the readings were recorded for different displacement ratios of the front wall(Δ/H = 0.0, 0.00083, 0.0016, 0.0025, 0.00416, 0.0083, 0.0125 and 0.016).

WALLS TIED AT TOP AND BOTTOM

This group of tests was performed with sand being placed at minimum relative density for the same ratios of wall width to height(B/H = 0.5, 0.775, 1.0 and 2.0), and with sand placed at 40% relative density for only three B/H ratios of 0.5, 0.75 and 1.0. Each test was also repeated for different wall displacements.

TEST RESULTS AND ANALYSIS

1- Effect of width, B,on earth pressure distribution:

For B/H = 0.5, 00.75, 1.0 and 2.0 and /H = 0.125 and D_r = 40%, Figures (4-7) show the earth pressure distribution developed on both the front and back sides of wall. From Figure 4 (B/H = 0.5), it can be seen that the earth pressure distribution curves developed on the front side are almost parabolic. Also, the magnitude of the active earth pressure acting on that side is significantly smaller than the theoretical one based on Coulomb's theory. This is because the back side of the wall intercepts the natural and rupture planes of the filling developed on the front side.

Also, the rupture planes of active and passive earth pressure, developed within the wall on the front and back side respectively, were intersected developing a small zone of earth filling to act on the front side as an active and another small zone to act on the inner face of the back side as a passive. It's worth mentioning that the resultant of earth pressure developed on the front wall is almost equal to 18%, 16% and 15% of the active earth pressure computed by Coulomb's theory for minimum, 40% and 70% relative densities respectively. These resultants lie at vertical distances, y, measured from the bottom equal to 0.45, 0.47 and 0.5 of the total height, H.

The resultant of the net earth pressure acting on the back wall was found to be equal 5.7 times the earth pressure exerted on the front side in case of minimum density and 6 times in case of 40% and 70% D_r. These resultants represent also 103%, 96% and 95% the active earth pressure computed by Coulomb's theory and lie at 0.35, 0.375 and 0.4 of the height measured from the bottom for the three cases of relative density respectively. The close agreement, between the experimental earth pressure distribution developed on the back wall and the theoretical one based on Coulomb, shows that for small distance, B, between the two sides, the back side acts as a single sheet pile. This is due to the very small zone of passive earth pressure acting against this side which is confirmed also by the very small earth pressure carried by the front wall. The main contradiction between the theoretical and experimental curves is located at the lower part of the curve where the pressure at the most bottom points was not measured but rather assumed to be zero. Peck and Terzaghi [1,2] suggested that for dense sand, the earth pressure at the bottom of the shuttering structure may be equal to zero and it takes a non-zero value in case of loose sand.

When the distance, B. between the two sheet piles was increased to 0.75 of the height, H, the earth pressure distribution on both front and back side was changed as shown in Figure 5. From this figure, it can be concluded that as a subsequent result to increasing the distance B between the two sides, the pressure exerted on the front side was increased while the net pressure on the back side decreased. This may be due to the increase of the effective zones of active and passive earth pressure acting on the

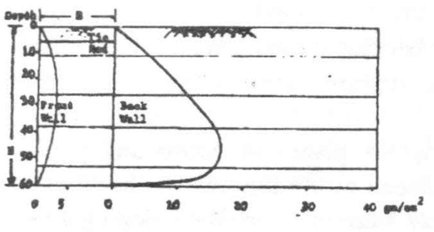

Figure 4. Earth pressure distribuution on front and back walls (B=0.5H,Δ/H= 0.0125, D_r=40%, tie rod at top only).

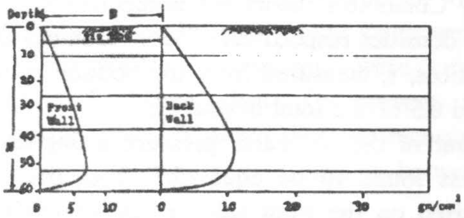

Figure 5. Earth pressure distribution on front and walls (B=0.75 H,Δ/H=0.0125, D_r=40%, tie rod at top only).

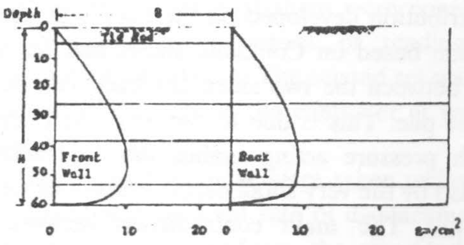

Figure 6. Earth pressure distribution on front and back walls (B=H,Δ/H=0.0125, D_r=40%, tie rod at top only).

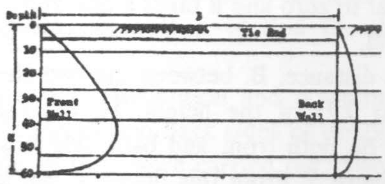

Figure 7. Earth pressure distribution on front and walls (B=2H,Δ/H=0.0125, D_r=40%, tie rod at top only).

front and back sides within the wall respectively as thee distance B increased. However, the magnitudes of the earth pressure exerted on the front side still quite less than the theoretical values based on coulomb. The resultants of the pressure diagrams representing the active earth pressure are about 48.1%, 45% and 42 % of the active earth pressure forces computed by Coulomp's theory and these resultants lie at 0.35, 0.36 and 0.42 of the height from the bottom for the three cases of minimum relative density, 40% D_r and 70% D_r respectively.

The area of the net earth pressure exerted on the back side was reduced to a value almost equal to 1.75 times the area of the earth pressure exerted on the front side. These values represent 75% 74% and 71% of the earth pressure computed by Coulomb for minimum, 40% and 70% relative densities respectively.

When the distance B between the two sides was further increased to be equal to the height H, the developed earth pressure was increased on the front side and decreased on back side to be almost of equal magnitudes (Figure 6). The resultant of earth pressure diagram exerted on the front side varied between 65% and 60% of the theoretical one based on Coulomb's theory at locations 0.37, 0.4 and 0.41 of the height H, for minimum, 40% and 70% relative densities respectively. The distribution of the net earth pressure developed on the back side for all cases of different relative densities was found almost similar to the earth pressure on the front side. These observations shown that selecting a width B, equal to the height H, is quite useful in case of constructing both sides of wall using the same modulus section of sheet pile. Also, this case clearly shows the advantage of using the double row sheet pile quay wall over the single sheet pile where the earth pressure on both sides was reduced to almost 60% of that pressure normally developing on a typical single sheet pile.

Figure 7 shows the earth pressures distribution for a distance B=2H, D_r=40% and Δ/H=0.0125. It can be seen that the excessive increase in the width of the double-row sheet pile walls alleviates the advantage of using this structure. The resultant forces exerted on front side are equal to 95%, 88% and 85% of the corresponding magnitude theoretically computed by coulomb's theory for single sheet pile for minimum 40% and 70% relative densities respectively.

The net resultant acting on the back side represents 0.25 of the resultant acting on the front side. This case shows that the front side in a double-row sheet pile walls with a quite long distance(B $\geq$ 2H) tend to behave as a single sheet pile, and the back side may act as an anchor.

It can be concluded that the relative width B/H, has a significant effect on the earth pressure distribution on both sides of the wall. For small distance B, the front side may be subjected to a quite small earth pressure while earth pressure as large as that produced by Coulomb's theory was developed on the back side. When the width B is increased the pressure on the front side is increased while that on the back side is decreased. For B=H both earth pressure distributions on front and back sides become almost similar as B is excessively increased(b=2H), the front side behaves as a single pile while the back side carries a minimum pressure.

2- Effect of Rod

Figures (8-10) show the earth pressure distribution on the front and back sides of the walls tied with two rods; One near the top and the other near the bottom. Similar observations and remarks about the effect of width can be made for this case as those made for the case of walls tied at top only. However, the existing of the lower tie rod leads to moderately decreasing the earth pressure on both front and back sides. The resultant forces due to earth pressures developed on the front and back sides with ties at top only, and ties at top and bottom for different width over height ratio, B/H, are listed in Table (1).

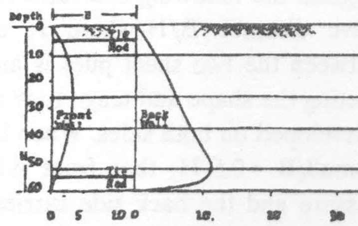

Figure 8. Earth pressure distribution on front and back walls ($B=0.5$ H,$\Delta/H=0.0125$, $D_r=40\%$, two tie rods).

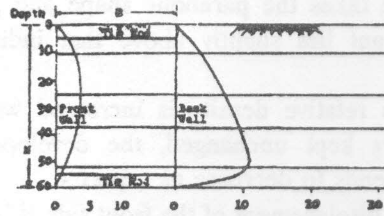

Figure 9. Earth pressure distribution on front and back walls ($B=0.75$ H,$\Delta/H=0.0125$, $D_r=40\%$, two tie rods).

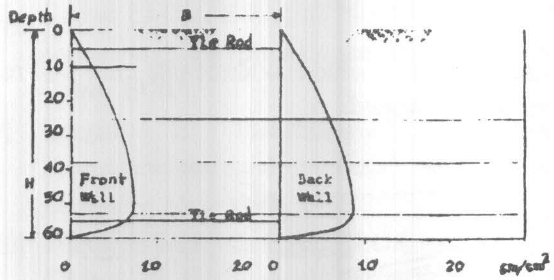

Figure 10. Earth pressure distribution on front and back ($B=H$,$\Delta/H=0.0125$, $D_r=40\%$, two tie rods).

Table 1. Relationship between the relative width B/H and the resultant of the actual earth pressure developed on the two sides as a ratio of the corresponding one based on Coulomb's theory ($\Delta/H=0.0012$, D_r-40%).

Earth pressure Resultant Ratio

B/H	Front side		Back side	
	One tie rod	Two tie rods	One tie rod	Two tie rods
0.50	16%	12%	96%	85%
0.75	45%	35%	74%	74%
1.00	65%	58%	60%	50%
2.00	88%	75%	22%	18%

Table 2. Variation of the location of earth pressure with other parameters for both front and back sides

Y/H

B/H	Relative Density	walls tied at top only		walls tied at top and bottom	
		Front side	Back side	Front side	Back side
	MIN	0.45	0.35	0.50	0.35
0.50	40%	0.46	0.375	0.50	0.36
	70%	0.50	0.40	—	—
	MIN	0.35	0.35	0.55	0.35
0.75	40%	0.36	0.375	0.55	0.38
	70%	0.42	0.40	—	—
	MIN	0.37	0.36	0.40	0.38
1.00	40%	0.40	0.375	0.41	0.39
	70%	0.41	0.40	—	—
	MIN	0.36	0.50	0.38	0.43
2.00	40%	0.40	0.50	—	—
	070%	0.43	0.50	—	—

SUMMARY AND CONCLUSION

Behaviour of the double-row sheet pile quay wall resting on rock is investigated.

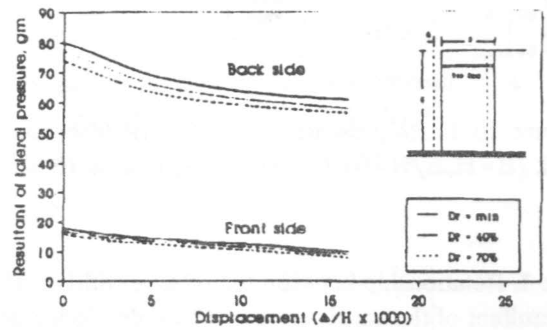

Figure 11. Effect of wall moovement on résultant of lateral earth pressure exerted on front and back sides (B = 0.5 H), one tie rod.

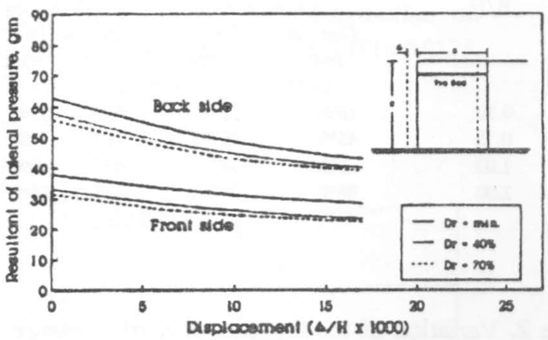

Figure 12. Effect of wall movement on resultant of lateral earth pressure exerted on front and back sides (B = 0.775 H), one tie rod.

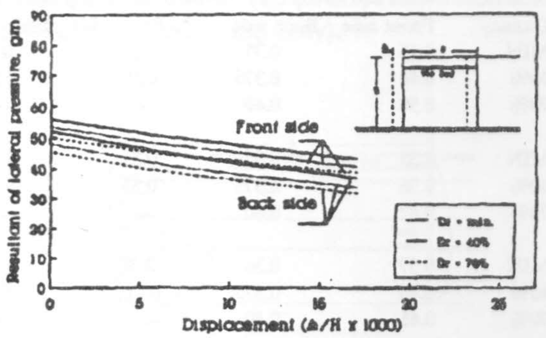

Figure 13. Effect of wall movement on resultant of lateral earth pressure exerted on front and sides (B = H), one tie rod.

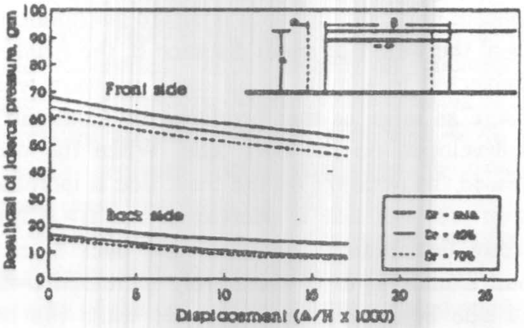

Figure 14. Effect of wall movement on resultant of lateral earth pressure eexterted on front and back sides (B = 2H), one tie rod.

Laboratory tests on a double-row sheet pile model perfovrmed in order to provide data for the distribution of earth pressure on the front and back sides of the wall. The developed earth pressure distribution curves were compared with the theoretical prediction based on Coulomb's theory.

A parametric study was carried out including variable distance between the two sides, B, the relative density, D_r, number of tie rods and magnitude of displacement of the front wall,

The study suggests the following conclusions:

1. The relative distance B/H(where H is the wall height) between the two sheet piles is an important factor affecting the shape and magnitude of the earth pressure developed on both sides. When the distance B is too small(B =0.5 H) thee front side carries a minor pressure and the back side carries the most. and vise versa when the distance between the two sides is too large (B = 2H). The distribution of earth pressure on the two sides is almost similar for the width, B equals to the height of the wall H.
2. The earth pressure distribution curves developed on both sides takes the parabolic shape and generally the resultant lies slightly above that indicated by coulomb.
3. When the relative density is increased with other parameters kept unchanged, the developed earth pressure tends to decrease as expected.
4. When the displacement of the front side is increased, the earth pressure developed on both sides decreased.
5. Using two ties(one near the top and the second near the bottom) alliviates the magnitude of earth

pressure on both sides moderately (10-20%).

6. Recommendation for further research:

The distribution of earth pressure on both sides and the effect of the different parameters needs to be investigated for double-row sheet pile quay wall penetrated into sand.

REFERENCES

[1] Gregory P. Tschebotarioff, *"Foundation retaining and earth structure"*, McGraw-Hill Kocakasha, Ltd., 1973.

[2] Hansen J.B., *"Earth pressure calculation"*, the dansih technical press, 1961.

[3] Joseph E. Bowels, *""Foundation analysis and design"*, McGraw-Hill Kocakasha, Ltd., 1968.

[4] Melvin I. Esring, "Stability of ce;;ular cofferdam against vertical shear",*Asc. E* . vol.96 No, SM6, Nov. 1970.

[5] Hans F. Winterkorn and Hsai-Yang Fang, *""Foundation engineering handbook"*, Van Nostrand Reinhold Company.

[6] Leonards G.A., *"Foundation engineering"*, McGraw-Hill Book Company, New York, 1962.

[7] Minikin R.R., *"Piling for foundation"*, London Crosby Wood & Son, Ltd., 1948.

[8] Gamal El-Din, A.K., *Soil mechanics and foundation engineering"*, Egyptian Organization for Editing pub., Cairo, 1970.

[9] Gregory P. Tschebotarioff, *Soil mechanics, Foundation and earth structurre"*, McGraw-Hill Book Company, New York, 1951.

[10] Tomlison M.J., C. Eng., F.I.C.E., A.M.I. Struct. E., *Foundation Design and Construction"*, 1960.

[11] Alamsingh, *"Soil engimeering in theory and practical fundamentals and general principles"*, Asia Publishing House, 1975.

[12] Whitney Clark Huntington *"Earth pressure and retaining walls"*, 1957.

[13] Wilum Z., and Starzcuski K.,*"Soil mechanics in foundation engineering"*, 1972.

[14] Wayne C. Teng and associates Consulting engineering, Chicago, Illinois, *Foundation design"*, Prentice-Hall of India Private Limited, New Delhi, 1969.

[15] Clarence W. Dunham *"Foundation of Structres"*, McGraw-Hill Book Company, INC.New York, 1962.

[16] Ahmed Sobhy,*Stability of Double-row sheet pilees quay walls"*, Master thesis, Faculty of engineering, Alexandria University, 1986.