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Experimental Study for the Behavior of Anchored Sheet Pile Subjected to Cyclic Load in Sandy Soil

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Keywords:
Anchored sheet pile; Cyclic load; Sandy soil; Experimental study.

Highlights:
- *Stability of anchored sheet pile wall against cyclic load.*
- *The lateral displacement of sheet pile induced from strip footing and cyclic load.*
- *Lateral resistance of anchored sheet pile wall against periodic load.*

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Abstract: Excavation deeper than about six meters is restricted by the application of sheet pile walls with anchors. This paper examined the effects of different parameters on anchored sheet pile walls under a lateral cyclic load ratio (CLR) of 10% and several cycles equal to 100. It was fixed by two anchored piles horizontally and embedded in sandy soil. The ratio of the spacing between anchored to the free head of sheet pile wall (S/H= 1/3, 2/3, and 1) and the ratio of anchored length to the free head of sheet pile wall (L/H= 1, 4/3, and 5/3) under the influence of two–way cyclic lateral load at 0.2 Hz environmental frequency. The research aims to ascertain the rod's impact spacing and length anchored on the lateral and vertical displacement of the sheet pile, as well as the vertical displacement of surcharge (line load) applied to the surface. The wale for sheet pile decreased the lateral displacement of a sheet pile to 66% compared to lateral displacement without wale. Also, the results of the length rod to the free height of the sheet pile wall (L/H= 1) increased the anchored sheet pile wall's lateral displacement by about 55% from the cantilever sheet pile wall's lateral displacement with wale because it was near the active failure zone. The ratio of length to free head of sheet pile wall (L/H= 5/3) reduced the anchor sheet pile's lateral displacement wale by about 51% compared to the cantilever sheet pile's lateral displacement with wale. The ratio of length anchored to the free head of the sheet pile wall (L/H= 4/3) decreased the anchored sheet pile's lateral displacement to 49% compared to the cantilever sheet pile's lateral displacement with wale. Both reductions for two lengths with the spacing ratio between the anchors rod to the free head of the sheet pile wall was (S/H= 1/3).

دراسة مختبرية لسلوك الركائز اللوحية المثبتة المعرضة للحمل الدوري في التربة الرملية

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الخلاصة
عمق الحفر اكثر من ٦ امتار تقريبا محدد باستخدام جدران من الركائز اللوحية المثبتة.تم في هذا البحث دراسة تأثير عوامل مختلفة على الركائز اللوحية تحت نسبة حمل دوري جانبي ١٠٪ واستخدام عدد دورات يساوي ١٠٠ تم تثبيتها بواسطة قضبان بشكل افقي ومثبتة في التربة الرملية. نسبة التباعد بين القضبان الى الارتفاع الحر للركائز اللوحية (S/H=1/3, 2/3, and 1)، ونسبة طول القضبان الى الارتفاع الحر للركائز اللوحية (L/H=1, 4/3, and 5/3) تحت تأثير الحمل الجانبي الدوري ثنائي الاتجاه عند التردد ٠,٢ هيرتز. الهدف من البحث تحديد تأثير تباعد القضبان و طول القضبان على الازاحة الافقية والرأسية للركائز اللوحية تحت الحمل الدوري الجانبي وكذلك الازاحة الرأسية للتحميل الاضافي. عند استخدام احزمة للركائز اللوحية انخفضت الازاحة الجانبية الى 66% من قيم الازاحة الجانبية بدون احزمة. كما ان نسبة طول القضبان الى الارتفاع الحر للركائز اللوحية (L/H= 1) كان قريب من خط الفشل حيث ادت تلك القضبان الى زيادة الازاحة الجانبية الى حوالي 55% من قيم الازاحة الجانبية مع الاحزمة. اما نسبه طول القضبان الى الارتفاع الحر للركائز اللوحية(L/H=5/3) ادى الى تقليل الازاحة الجانبية الى 51% من قيم الازاحة مع الاحزمة. و نسبة طول القضبان الى الارتفاع الحر للركائز اللوحية (L/H= 4/3) ادى الى تقليل الازاحة الجانبية الى ٤٩٪. كلا التقليل للطولين كان لنسبة التباعد الى الارتفاع الحر للركائز اللوحية (S/H= 1/3).

الكلمات الدالة: الركائز اللوحية المثبتة، حمل دوري، تربة رملية، دراسة مختبرية.

1.INTRODUCTION

Anchored sheet pile walls are utilized as temporary or permanent structures to retain water-filled soil for constructing flood barriers, erosion protection, cutoff walls, under dams, waterfront structures, cofferdams, and excavation support systems. The sheet pile is embedded in soil on the opposite side of the wall to support the backfill material under horizontal pressure. The pile segments that continuously interlock make up a sheet pile structure. The present study used a cantilever sheet pile with two horizontal anchored rods embedded in sandy soil under cyclic load. There are two types of earth support methods: fixed and free. In general, sheet piles come in two types: the cantilever type, which is completely supported by the surrounding land, and the anchored type, which is supported by one or more mechanical anchors as well as interactions between the surrounding soils [1]. According to the working theory, one of the types is the most popular cantilever steel sheet pile, which is applied at heights of six meters or less from the drilling line due to its strength, ease of handling, and simplicity of construction [2]. The soil's passive pressure balance and the component materials' stiffness support the sheet pile walls. The lateral force imparted to the sheet pile walls is increased by pressure changes below the walls due to an external load, like construction work or moving objects. This behavior could help cause settlement and deflections, two essential elements in determining the stability of sheet pile walls [3]. Sheet pile walls are becoming increasingly common in urban settings because of their easy installation and capacity to reduce the negative effects of excavation on neighboring infrastructure. Evaluation of lateral earth pressure using the traditional sheet pile wall design method. The relationship between sheet pile walls or retaining wall systems and the soil is a critical component that has piqued the interest of researchers and engineers in this sector. Cantilever sheet pile walls without a backfill surcharge have been the subject of numerous research for flexural moment and earth pressure [4–9]. Surcharges of all kinds occur on the field quite frequently. Very little research has been done on surcharges that are close to the location of the excavation and sustained by the structure of a retaining wall. These surcharges create an extra strain that could alter the sheet pile's behavior, leading to further deflection and settling with fees [10]. Motta's generalized Coulomb theory for active earth pressure with an infinite uniform surcharge existing at a distance [11]. A test of model sheet pile walls was conducted in the sand to determine how surcharge strip loads affected wall behavior. The best predictions came from the straightforward (45 load distribution) [12]. One of the key factors influencing how the sheet pile wall behaves is the distance of the model footing from the excavation face. Ground settlements account for approximately 18% of the maximum excavation depth when the footing is positioned 200 mm from the excavation face; however, only 2.7% of the maximum excavation depth when the footing is positioned 800 mm from the excavation face. The sheet pile wall's corresponding deflections are roughly 30% and 19% of the maximum excavation depth [13]. A study by [14] showed little variations in the horizontal earth pressure on a sheet pile wall before and after the earthquake. Ref. [15] studied the cyclic load effect on batter anchored pile group in dry sand with three types of piles: a pile with one helix. A pile with two helices and a pile without a helices showed that the screw piles with two helix give resistance to the lateral cyclic load more than single and conventional piles. A study by [16] on lateral resistance of inclined pile group in sandy soil with slope degrees (5°, 10°, and 15°) showed that the group piles of pattern (1x2) was better than those of (2x1) in resisting periodic loads. This investigation's experimental work was conducted to understand the actions of lateral and vertical displacement of anchored sheet pile subject to the horizontal two-way cyclic load and also to understand the behavior of vertical displacement of surcharge (line load) near the sheet pile wall.

2.TESTING WORK

2.1.Soil Type

The location of a sandy soil sample from Karabala Governorate is depicted in Fig. 1. Numerous studies have been conducted to ascertain the samples qualities, as displayed in Table 1, and the distribution of grains sizes (ASTM D422) is displayed in Fig. 2. The chemical properties of sandy soil were conducted at national center for construction Laboratories and Research (NCCLR) according to BS 1377 (1990), part 3 standard specification as tabulated in Table 2.

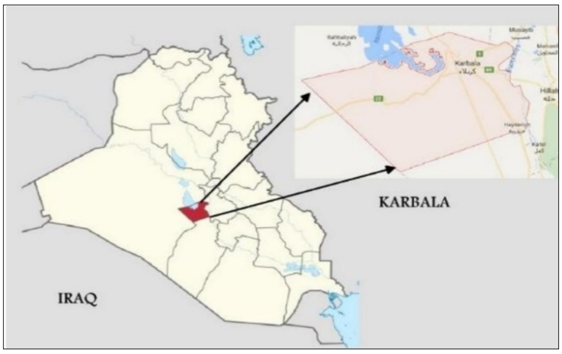

Fig. 1 A Site from Which the Sample Was Taken.

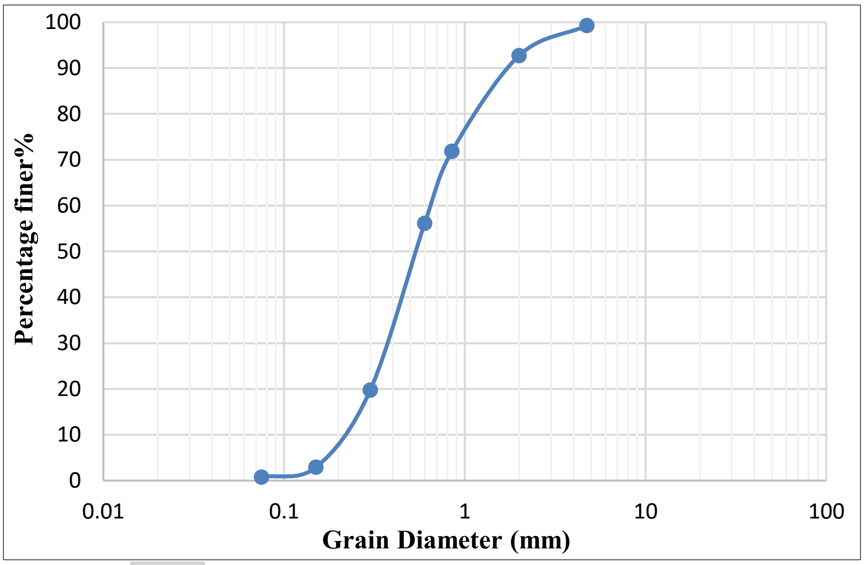

Fig. 2 Distribution of Grain Sizes in the Sandy Soil.

Table 1 Geotechnical Characteristics of Sand Soil.

Characteristics	Values	Standards
The effective size, D_{10} in mm	0.21	ASTM D 422 and ASTM D 2487 (2006)
D_{30} in mm	0.38	
Mean size, D_{50} in mm	0.48	
D_{60} in mm	0.66	
Sand, %	98	
Silt + clay, %	2	
Coefficient of uniformity	3.14	
Coefficient of curvature	1.04	
Classification, (USCS)	SP	
Specific Gravity	2.65	ASTM D 854- (2006)
Angle of Internal Friction	36	ASTM D3040-04-(2006)
γd (max.) (kN /m^3)	18.36	ASTM D 4253 - (2006)
γd min (kN /m^3)	14.98	ASTM D 4254 - (2006)
Maximum void ratio	0.8	………
Minimum void ratio	0.52	………
Field dry unit weight (kN/m^3)	17.08	……….
Relative density, %	67	……….

Table 2 Chemical Properties of Sandy Soil.

Chemical Properties	Values	Standards
Organic Matters Content, (%)	0.034	(BS 1377: 1990 part 3)
Gypsum Content, (%)	0.12	
Total Soluble Salts Content, (%)	0.39	
Sulphate Content (SO3), (%)	0.05	
Chlorides, (%)	0.192	
pH	8.34	

2.2.Sheet Pile Wall and Deadman

The sheet pile model is made domestically from steel with the exact dimensions as the actual dimensions (6m length, 0.5m wide, and 0.012m thickness) by using ratio and proportion. The dimensions of the cantilever sheet pile model (500mm long, 495mm wide, and 5mm thickness) and in the middle of the sheet pile wall cantilever put a plate for apply the lateral cyclic load on the center of the plate and place the wale under the plate, as shown in Fig. 3. The dimensions of a deadman (70 × 70 × 70) mm with the concrete proportion of mix (1:1:1.5). The present study used two deadman with two rods, the diameter of rods 5mm, as shown in Fig. 4. The properties of sheet pile and deadman are displayed in Table 3.

2.3.Laboratory Testing Devices

Different devices were used in this study, as follows:

1- Raining device, as shown in Fig. 5.
2- Loading device, as shown in Fig. 6, consisted of the following components:
-Motor _Gearbox system
-The Board of Electricity
-Load cell
-Data logging device
-Linear Variation Displacement Transducer (LVDT),
-Two dial gauges.

Fig. 3 Sheet Pile Model With Plate and Wale.

Fig. 4 Deadman and Rod.

Table 3 Properties of Sheet Pile and Deadman.

	Length (mm)	Width (mm)	Thickness (mm)	Type of material	Unit weight (kN/m^3)
Sheet pile	500	495	5.00	steel	78
Deadman	70	70	70	concrete	24

Fig. 5 Raining Device.

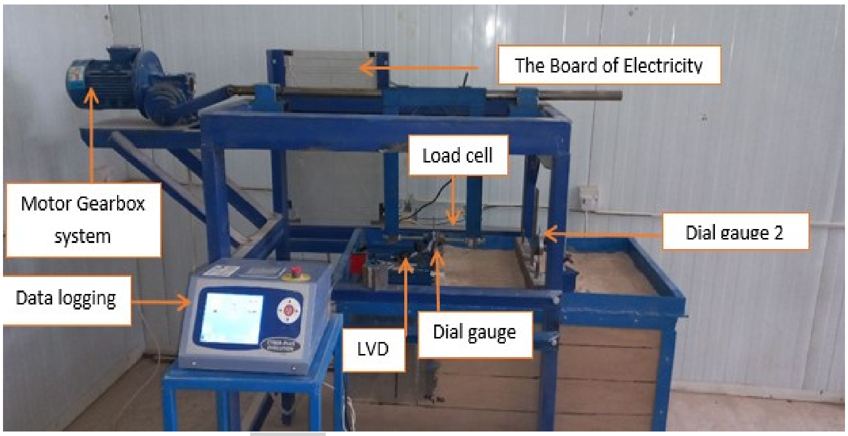

Fig. 6 Cyclic Loading Device.

2.4.Preparation of Sandy Soil and Test Procedure

The soil is placed inside a steel container with dimensions of (1000mm length, 500mm wide, and 650mm height). The container was filled with soil in horizontal layers; each layer depth was 10cm using the raining method, in which the sandy soil was prepared at a relative density of 67%. After that, the container was pushed to the loading device. The passive zone is 30cm from the container, and the sheet pile was placed. The excavation depth was 300mm, and the embedded depth was 150mm and placed the two rods with the deadman on location 10cm from the top of the soil surface, as shown in Fig.7, and put the surcharge (line load) on the distance 30cm from the wall of the sheet pile, the magnitude of this line load was 5 kPa after that put the dial gauge on the sheet pile wall to record the vertical displacement and put LVDT to document the sheet pile wall's lateral displacement reading. Also, the last dial gauge recorded the reading of the vertical displacement of the surcharge. A cyclic load from 1 to 100 cycles with frequency 0.2Hz and a period of test 8 minutes and 33 seconds was applied on the plate location atop the sheet pile wall, as depicted in Fig. 8.

Fig. 7 Container Filled with Sandy Soil.

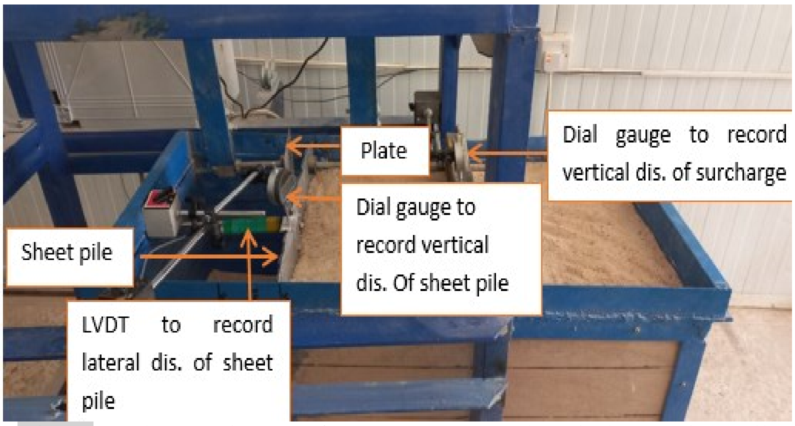

Fig. 8 Cyclic Load Test After Preparing Soil and Sheet Pile Wall.

3.RESULTS AND DISCUSSION

This study investigated different parameters: 1-wale plate existence, 2-Length of rod, and 3-Spacing between rods. Three spaces and lengths were tested in this study. A surcharge of 5kPa was located on the surface of the ground and outside 300mm from the sheet pile. Also, a reference model of a sheet pile wall cantilever using wale was used to compare the results of all models with this reference model. The active failure was 0.002H, which was 0.60mm, and H represents the sheet pile wall's free height.

3.1.Sheet Pile Wall's Lateral Displacement

Firstly, the effect of using wale in cantilever sheet pile was investigated, as displayed in Fig. 9. It is clear from Fig. 9 that using wale reduced the lateral displacement to 66% at cyclic number 100 compared to lateral displacement of sheet pile wall without wale. Using wale gave more lateral resistance to cyclic load and increased the stiffness of the sheet pile wall. In two models of Fig. 9, the sheet pile wall's lateral displacement exceeded the active failure. Figure 10 shows a lateral displacement of the anchored sheet pile wall of rod length 30cm. It is evident from Fig. 10 that a lateral displacement increased with reduced spacing between rods. The values of lateral displacement for all lengths were high and exceeded the active failure due to small anchorage resistance between soil and rod. Also, the small lateral resistance is that the ratio of length to the free head of sheet pile wall of (L/H= 1) was near away from the active failure wedge. Figures 11 and 12 depict the results of lateral displacement of anchored sheet pile wall for ratios of the length of rods to free head of sheet pile wall (L/H= 4/3 and 5/3), respectively. The rod length increase slightly increased lateral resistance. The reduction in lateral displacement of anchored sheet pile wall, compared to the reference model for cantilever, was (22%, 33%, and 51%) and (26%, 44%, and 52%) for ratios of rod length to free head of sheet pile wall (L/H= 4/3, and 5/3) and ratios of spacing to free heads of sheet pile wall (S/H= 1, 2/3, and 1/3), respectively. It is evident that spacing significantly impacted lateral displacement compared to rod length. The small spacing between rods gave more resistance to lateral displacement of cyclic load applied to a sheet pile wall. This behavior is attributed to the cyclic load concentrated on the center of the sheet pile wall, meaning that a close spacing between rods caused high resistance to cyclic load.

3.2.Vertical Displacement of Sheet Pile Wall

Figure 13 displays the vertical cantilever sheet pile wall displacement (reference model) with/ without using wale. Using wale reduced the sheet pile wall's vertical displacement to 76% at cyclic number 100. Figures 14 to 16 display the vertical displacement of sheet pile wall for ratios of spacing between rods to free head of sheet pile wall (S/H= 1/3, 2/3, and 1) and ratios of length rods to free head of sheet pile wall (L/H= 1, 4/3, and 5/3), respectively. In general, the vertical displacement for all rod lengths and spacing between them was small. The reduction in vertical displacement compared to the reference model of cantilever using wale was (75%, 78%, and 83.33%), (67%, 69.44%, and 72.22%), and (39%, 44.44%, and 61.11%) for ratios of spacing between rods to free head of sheet pile wall (S/H=1/3, 2/3, and 1) and ratios of length rods to free head of sheet pile wall (L/H= 1, 4/3, and 5/3), respectively. The rod model, with a ratio of length to the free head of the sheet pile wall (L/H= 1), caused vertical displacement with higher resistance compared to the models of the cantilever sheet pile wall.

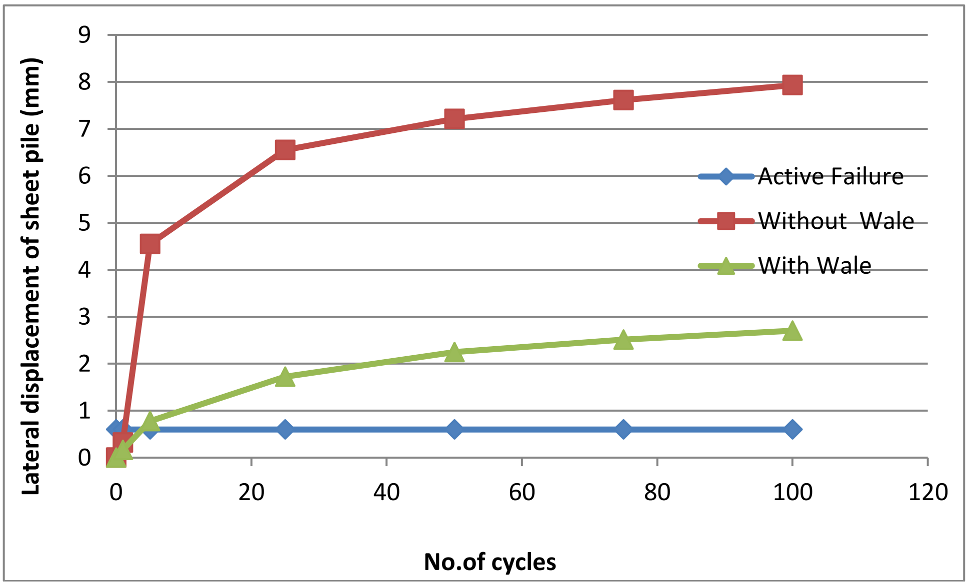

Fig. 9 Cantilever Sheet Pile Wall's Lateral Displacement.

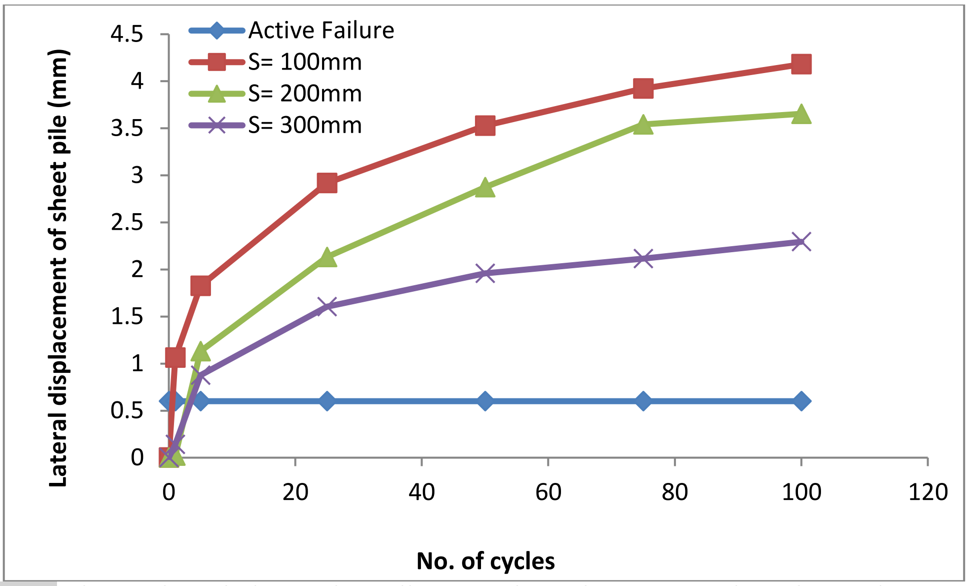

Fig. 10 The Anchored Sheet Pile Wall's Lateral Displacement with Rod Length 300mm.

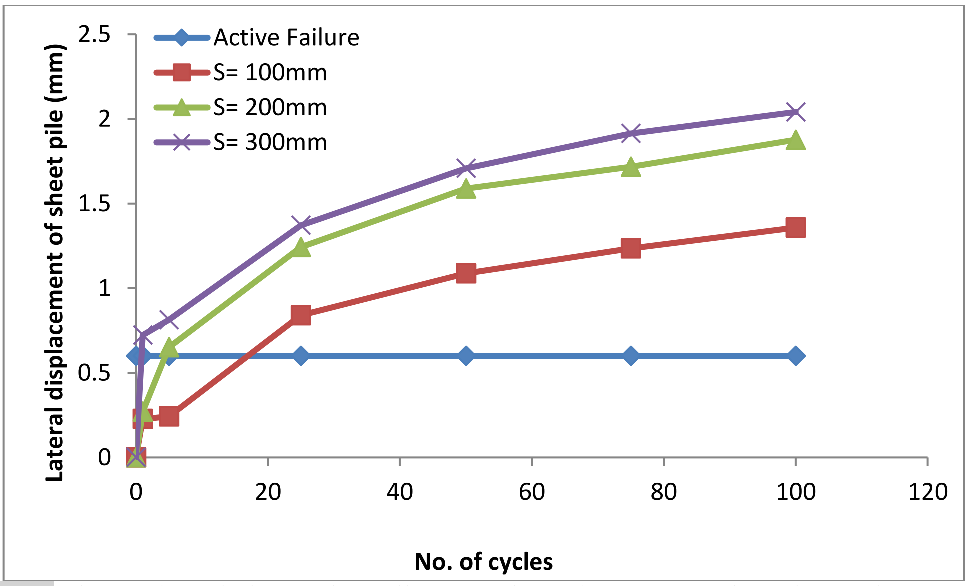

Fig. 11 The Anchored Sheet Pile Wall's Lateral Displacement with Rod Length 400mm.

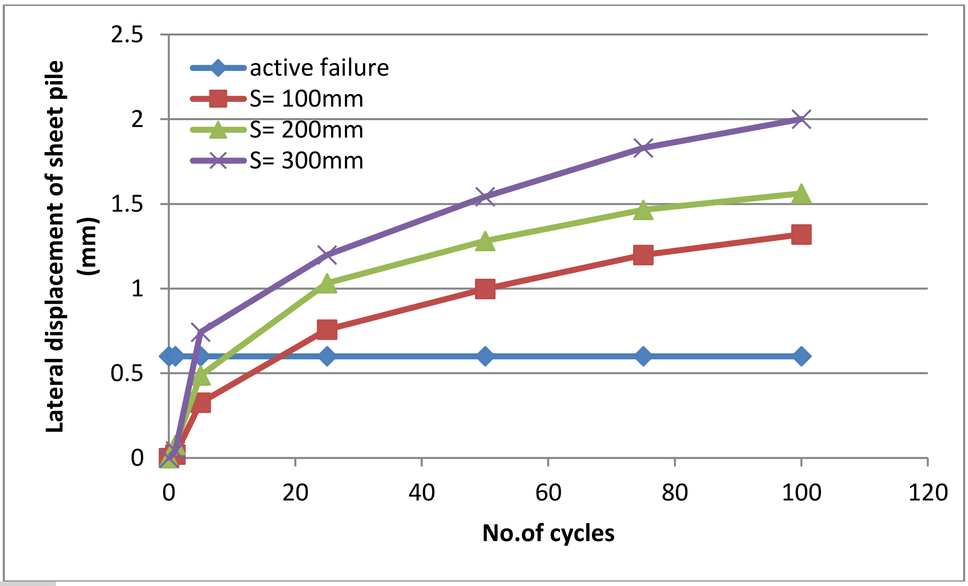

Fig. 12 The Anchored Sheet Pile Wall's Lateral Displacement with Rod Length 500mm.

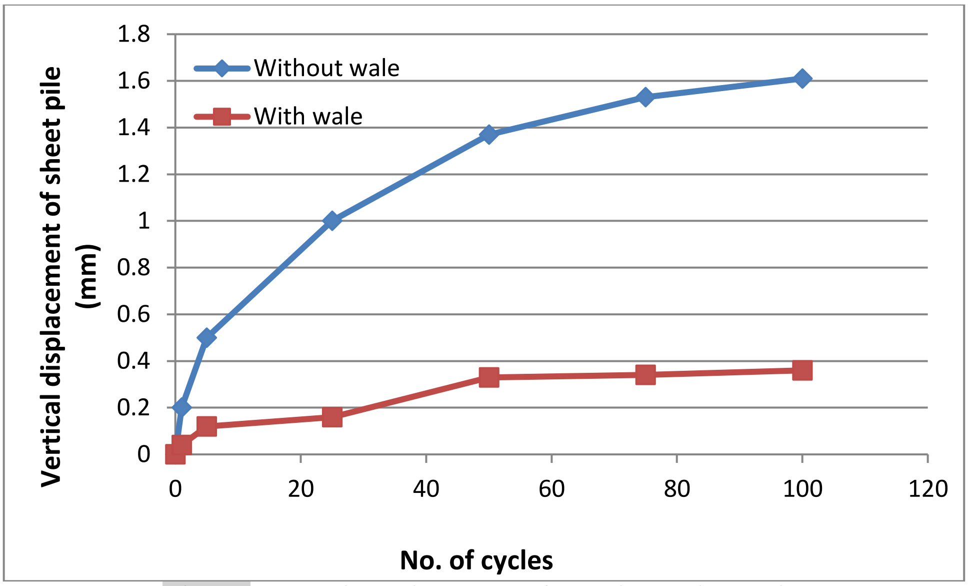

Fig. 13 Vertical Displacement of Cantilever Sheet Pile.

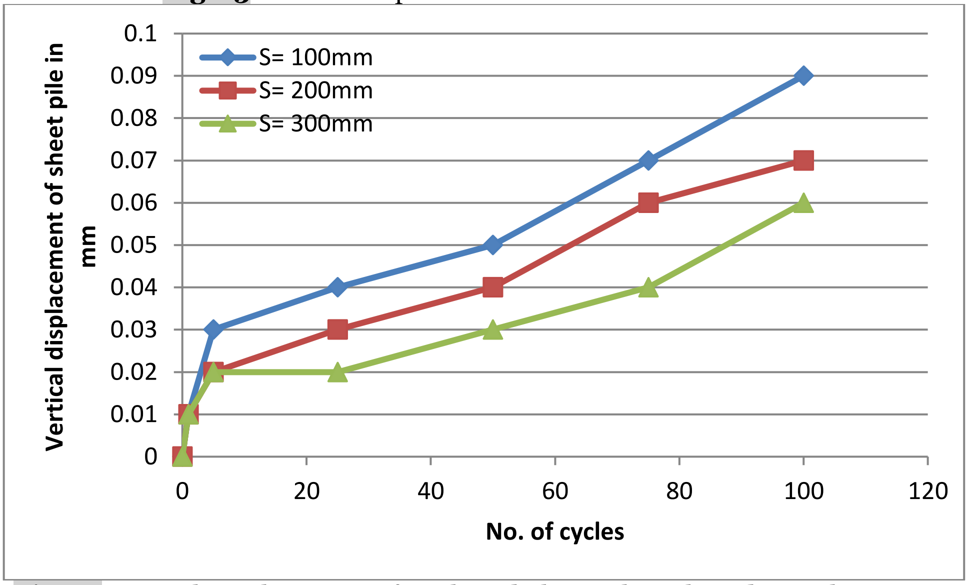

Fig. 14 Vertical Displacement of Anchored Sheet Pile with Rod Length 300mm.

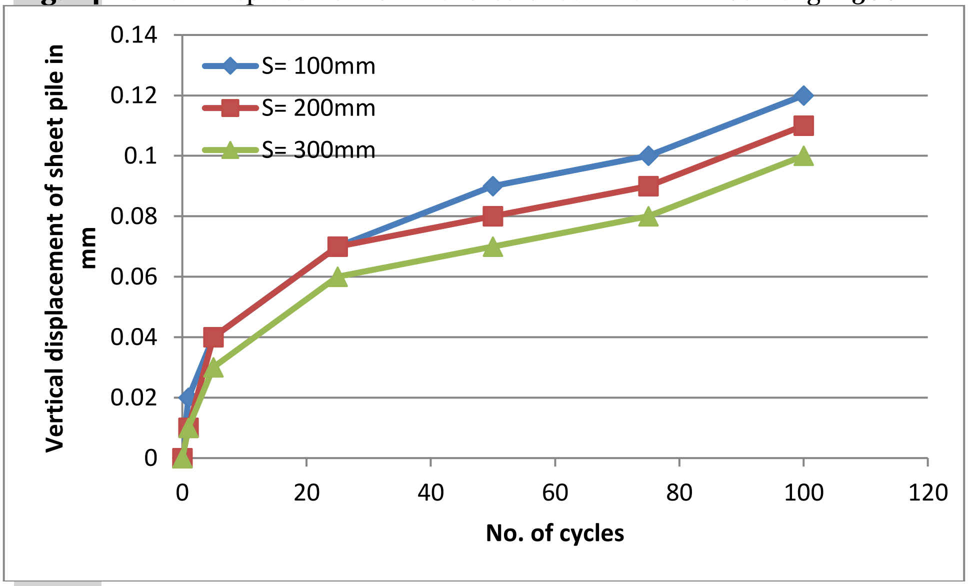

Fig. 15 Vertical Displacement of Anchored Sheet Pile with Rod Length 400mm.

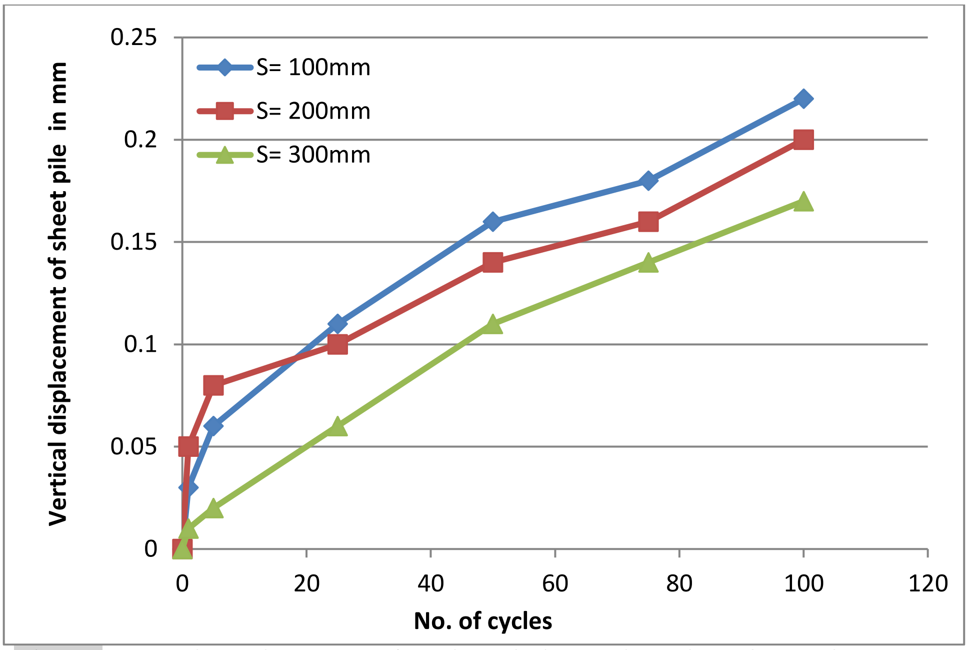

Fig. 16 Vertical Displacement of Anchored Sheet Pile with Rod Length 500mm.

3.3.Vertical Displacement of Surcharge (Line Load)

The surcharge was located 30cm from the sheet pile wall and had a value of this surcharge was 5 kPa. The vertical displacement of the surcharge using wale decreased the vertical displacement by about 65 % compared to without the wale, as shown in Fig.17. Figures 18 to 20 show the vertical displacement of surcharge for models of anchored sheet pile wall with ratios of length anchored rods to the free head of sheet pile wall (L/H= 1, 4/3, and 5/3). In general, the vertical displacement of the surcharge (Line load) was small and did not exceed 0.23mm because the distance of the surcharge from the sheet pile wall was 300mm from the sheet pile wall, so the vertical displacement of the surcharge load was small.

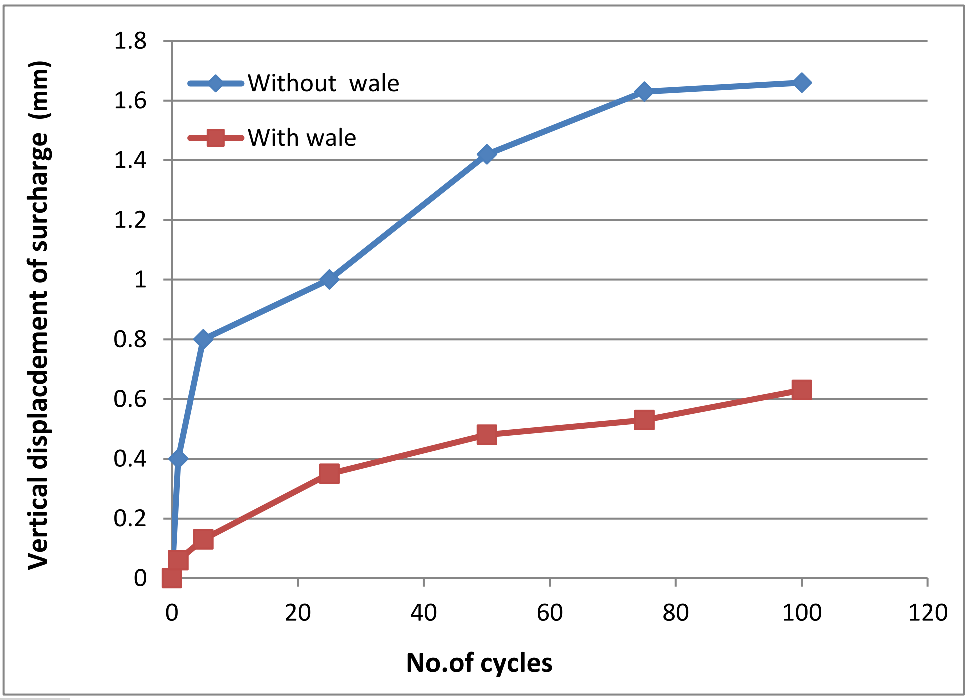

Fig. 17 Vertical Displacement of Surcharge for a Model of Cantilever Sheet Pile Wall.

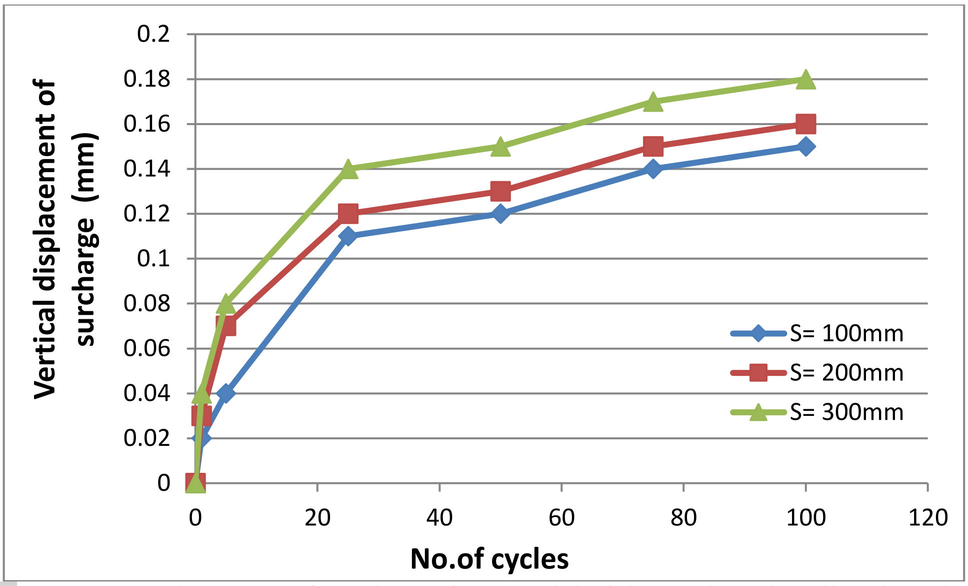

Fig. 18 Vertical Displacement of Surcharge for a Model of the Anchored Wall with Rod Length 300mm.

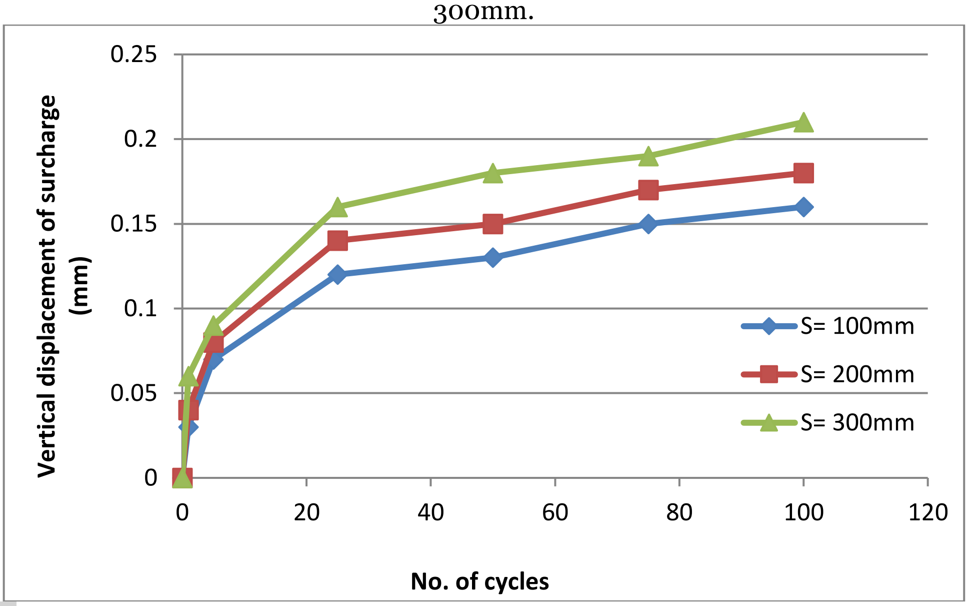

Fig. 19 Vertical Displacement of Surcharge for a Model of the Anchored Wall with Rod Length 400mm.

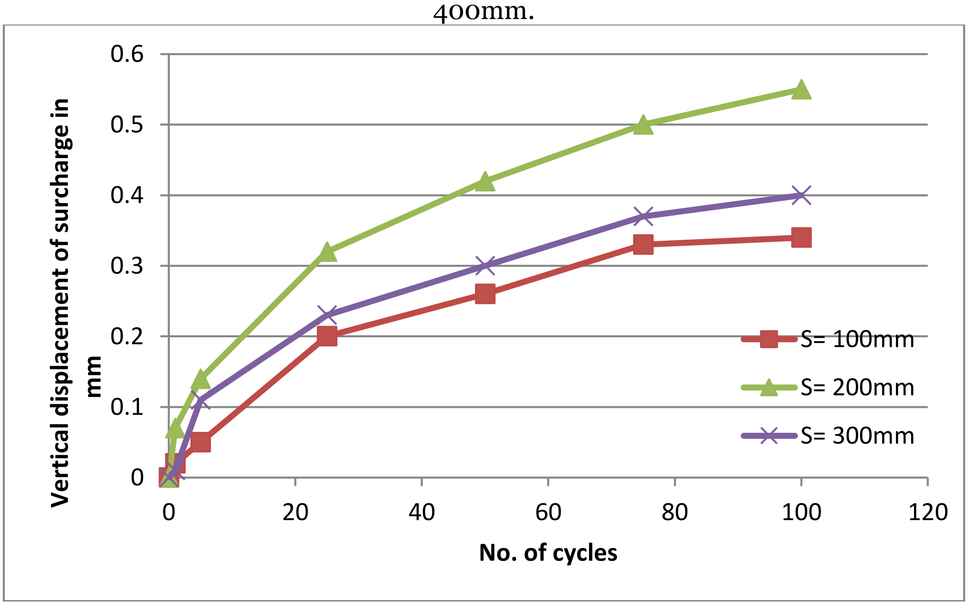

Fig. 20 Vertical Displacement of Surcharge for Anchored Sheet Pile Wall with Rod Length 500mm.

4.CONCLUSIONS

Following examination and assessment of the test findings for the model of a sheet steel pile wall with anchors under the influence of a lateral cyclic load, with and without a wale, as well as anchored in sandy soil. The following are the key findings:

1- When the lateral cyclic load increased in cycles, the lateral displacement of a cantilever sheet pile wall increased as well. In all cases, the lateral displacement increased when the cycle numbers changed from 1 to 100, with and without wale. With more cycles, the anchored sheet pile wall's lateral displacement also increased.
2- Using wale for the sheet pile wall to support the sheet pile wall reduced the cantilever sheet pile wall's lateral displacement to 66% under lateral cyclic load.
3- The ratio of the spacing between rods to the free head of the sheet pile wall equal to 1/3 gave a better percent of 50% in reducing the sheet pile's lateral displacement.
4- The ratio of the length of the anchored rod to the free head of the sheet pile wall equal to (1) increased the sheet pile wall's lateral displacement by about 55% from the values of the cantilever sheet pile wall's lateral displacement with wale for the ratio of the spacing between the anchored to the free head of the sheet pile wall equal to 1/3.
5- The ratios of the length of anchored rods to the free head of the sheet pile wall equal to (4/3 and 5/3) gave the best performance of decreasing the sheet pile wall's lateral displacement by about (49% and 51%), respectively, for the ratio of the spacing between anchored to the free head of sheet pile wall of 1/3.
6- The vertical displacement of the anchored sheet pile wall was insignificant and did not exceed 0.25mm. The vertical displacement of the cantilever sheet pile wall was reduced by 76% using the wale support of the sheet pile wall.
7- When the surcharge was located at a distance equal to the free height of the sheet pile wall, the effect of the surcharge on the sheet pile was insignificant.

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