Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

EXPERIMENTAL STUDY OF STABILITY OF CELLULAR RETAINING STRUCTURE FOR SATURETED SOILS

Asst.Prof .Dr. Kareem R. Al-Murshde
Dep. of Civil Engineering
Engineering College
Kufa University

Asst.Prof.Dr.Kadhim N. Kadhim
Dep. of Civil Engineering
Engineering College
Babylon University

Eng.Hana'a M.Alkassar
Dep. of Civil Engineering

Received: 19/ 6 / 2011; Accepted: 12 / 6 /2013

Abstract

Series of laboratory tests have been carried out on one (single) circular and diaphragm cells of different width to height ratio (0.75, 1.00), to study the stability of cellular retaining structures in saturation soils. The tests include the following factors, such as the effect of berm ratios (back fill of cell) (0.2H, 0.4H) , embedment depth ratios (0.2H, 0.4H), other factors such as cell width and soil type were studied too.

Three types of soils are used subbase, sand passing sieve No.4 and river sand. Where used models statistically to find out relationship between the berm, embedment depth, and horizontal displacement after applying failure load .

Keywords: Cellular Cofferdams, Sheet Pile Wall, Lateral Resistance, Earth Pressure, Saturation Soils.

دراسة مختبرية لاستقرارية المنشأت الخلوية في الترب الرطبة

ا.م.د.كريم راضي ألمرشدي
جامعةالكوفة/كلية الهندسة

ا.م.د.كاظم نايف كاظم
جامعة بابل/كلية الهندسة

مهندسة.هناء محمود كسار
المعهد التقني/النجف

الخلاصة

أجريت سلسلة من الفحوصات المختبرية على خلايا دائرية وحجابيه بنسب عرض إلى ارتفاع مختلفة (0.75, 1.0) لدراسة استقرارية المنشآت الحاجزة الخلوية في الترب المشبعة. الفحوص تتضمن العوامل التالية, أثر نسب الإملاء خلف الخلية (0.2H, 0.4H) , نسب عمق الدفن (0.2H, 0.4H) , وعوامل أخرى كعرض الخلية وخواص التربة.

استخدم ثلاثة أنواع من الترب الحصو الخابط , رمل مار على منخل رقم 4 و رمل النهر. حيث استخدمت موديلات إحصائية لإيجاد العلاقة بين الإملاء, عمق الدفن والإزاحة الأفقية بعد تسليط حمل الفشل.

1. Introduction

Cellular cofferdams are a gravity retaining structures consisting of a series of interconnected soil material or rock filled cells to stabilize them, and resting on a soil or rock foundation, both acting as one unit. These cells and the connecting arcs constructed of interlocking steel sheet piling arranged in a variety of geometric shapes. The interconnection provides water-tightness and self-stability against the lateral pressure of water and earth [Bowles, (1997)].

The purpose of the cofferdam is to retain a hydrostatic head of water as well as the dynamic forces due to currents and waves, ice forces, seismic loads and accidental loads or to provide a lateral support to the mass of soil behind it. However, the cofferdam is subjected to unbalanced lateral forces acting at different heights. These unbalanced forces will tend to produce a resultant moment which tends to overturn the cofferdam or to produce a resultant force which tends to slide the cofferdam on its base. The resisting forces and moments against the sliding and overturning vary in magnitude from soil to soil depending on the unit weight, the coefficient of friction of the soil, Young's Modulus of elasticity, poison's ratio, and cohesion [Nemati, (2007)].

Al-Taee, (1990) studied the design and construction of cellular cofferdams through test models to observe their stability. Series of laboratory tests have been carried out on one, two, and three diaphragm cells of different width to depth ratios, as well as a rectangular and an isolated circular cell. The tests included the study of the following factors: effect of height, width, length, embedment depth, and loading height. Additional tests were carried out on an instrumented diaphragm cell to determine the distribution of the bending moments and hoop tensions. Many conclusions had been drawn from this study. Among these are the embedment depth is greatly affected the stability of cells.

Mohammod et al., (2001) behavior of double sheet pile wall cofferdam on sandy soil subjected to high water through a series of centrifuge model tests was studied. Model ground and fill of the cofferdam were made by fine silica sand in a rectangular model container. The model double sheet pile wall cofferdam consisted of two aluminum sheet pile walls, tie rods at the top and also at ground level. Various factors affecting stability of the cofferdam were examined. Under 70g, water was fed into the upstream of the cofferdam to simulate high floodwater until the water level reached nearly to the top of the cofferdam or large deflection of the cofferdam was observed. Test results imply that: (i) the shear deformation of the fill dominates the failure mechanism of the cofferdam, (ii) as the width of the cofferdam increase, the water height at failure increases and(iii) the sheet pile wall at the downstream is subjected to higher stresses than the sheet pile wall at the upstream.

Mohammod et al., (2006) studied behavior of double sheet pile wall cofferdam on a thick clay deposit subject to flash flood through a series of centrifuge model tests and test results: the degree of consolidation of the clay foundation affect of the stability of the cofferdam though degree of consolidation was simulated after construction of the cofferdam.

Al-Rmmahi, (2009) studied the design and construction of cellular cofferdams through test models to observe their stability. Series of laboratory tests had been carried out on two diaphragm cells of different width to height ratios (0.75, 0.85, 1.00). The tests include the

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

following factors, the effect of width of cell, width to height ratio, properties of soil and embedment depth to height ratios (0.15, 0.3, 0.45). Four type of soil are used. These types are subbase, sand passing sieve No.4, sand river and clay soil. Then analysis of cellular cofferdam by software which is known PLAXIS is used to compute deformations, stresses, and strain in the body of cofferdam and foundation. And comparison the results between laboratory tests and the software PLAXIS Reliability of results that obtained from experimental tests by statistical analysis to formulation these results by four functions are created to computes the deformations.

AL-Humairi, (2010) Series of laboratory tests carried out on one (single) diaphragm and circular cells of different width to height ratios were studied. The tests include factors of the effect of berm ratios (back fill of cell) (0.2H ,0.3H ,0.4H) ,embedment depth ratios (0.2H, 0.3H, 0.4H) for cells of different width to height ratio and the effect at placed with (berm and embedment depth)for cell (b/h=0.75) with ratios (0.2H ,0.3H ,0.4H) from height of cell ,other factors effect of width of cell and properties of soil ,three type of soils were used,(subbase, sand passing on No. 4, river sand).

2. Experimental Work

In present paper, effects of berm and embedment depth on stability of cofferdams in saturation soils have been studied. Series of laboratory tests carried out on one (single) circular and diaphragm cells with different width to height ratio. In this study, used the trapezoidal berm by slope (1V:3H) where (V:vertical H:horiztal) with ratios(0.2, 0.4) from height of cell and compared with embedment depth case for ratios (0.2, 0.4) from height of cell, for three types of soils (subbase, sand passing on No. 4, river sand), so that provide properties of soil that free-draining and a high angle of internal friction, Øº. Table 1 explained types and properties of the soils used in the cell fill and foundation.

Table 1 The Properties of the Soils Used in the Cells Fill.

Type of soil	Dry density (γ)	Max. Dry density(γ_{max}) (kN/m^3)	Optimum water content (%)	Total unit weight (γ_t) (kN/m^3)	Angle of friction (ø)º
Subbase	17.7	21	10	18.5	38º
Sand passing on No.4	16.5	18.41	13.75	16.75	34º
River sand	14.35	15.55	17.1	14.55	32º

In all tests the soil bed on wooden box of (25cm) height, placed by means of raining technique. The raining technique has been used successfully in providing uniformly dense soil bed for model studies, a height of (50cm) was kept between the sieve that was used in the raining technique and the top surface of the soil.

After that, water was added to foundation soil by pipes, supported at four sides until saturation of soil was reached. The cells then were placed in the middle width of soil box at (10cm) distance from the support of dial gages.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

Standard Proctor Test and Direct Shear Test were executed for all soil types for finding maximum dry density and optimum water content. Then the field dry density was calculated by (80%) of the maximum dry density. Later, the wetting unit weight was found . The second test tries to find the angle of internal friction (Ø)^{o}, the models are then filled with wet soil at three layers and compacted.

The cell level was checked by handy level, the loading system and dial gages were adjusted. Then, the load is applied incrementally and continued until a failure in the model was occurred(overturning of the cell). At the end of each load increment, the dial gages recorded. The horizontal displacements of the cell, at each load level and increment can be calculated. In all tests the same soil type was used in the cell fill and foundation.

The test program consists of three cases and for each case three stages(subbase, sand passing on sieve No. 4, river sand) of tests have been conducted. In the first cases for all stages the cells were put on the ground surface and tested for two circular and two diaphragm cells with different (b/H) ratio (0.75, 1.0).The subbase was used for filling and as foundation for these cells.

At the other stages of tests, the same cells were used in tests but with different type of soils, where in the second stage the sand was sieved on No.4 for filling and as foundation and at the last stage the river sand was used in the test for filling and as foundation.

These tests were repeated with other two cases. On each of these cells, the load was applied at one third of height (10 cm), so that the difference between sliding and overturning failure can easily be clarified. The second case trapezoidal berm with slope (1V:3H) in the backside of the cells and with ratios (0.2H, 0.4H) from height of the cells. At the last case, the cells were driven into the soil (embedment depth) for two depth to height ratios (D/H=0.2 and 0.4). Figure1 illustrates testing apparatus.

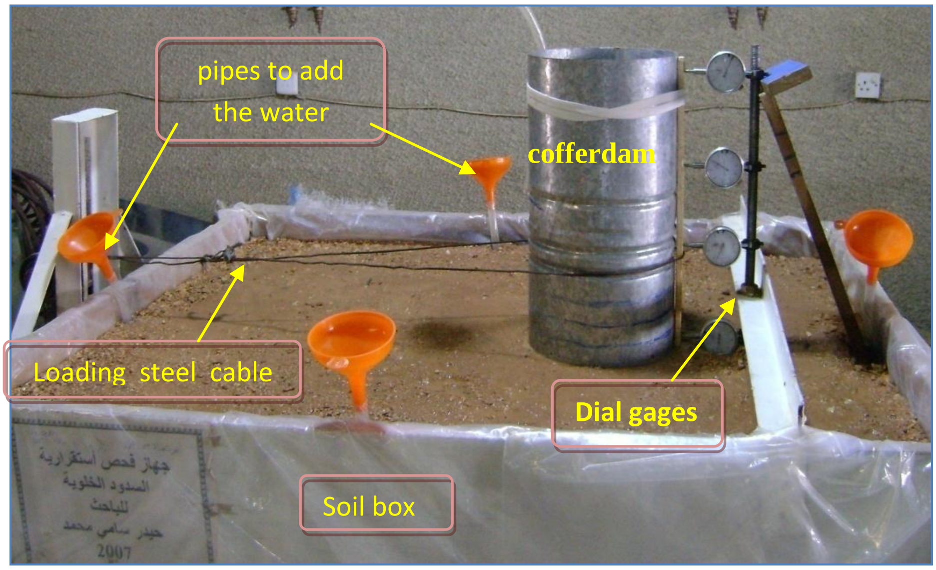


Fig.1 Circular Cofferdam Test for Subbase Soil.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

3. Study cases

Case 1 as shown in Fig. 2

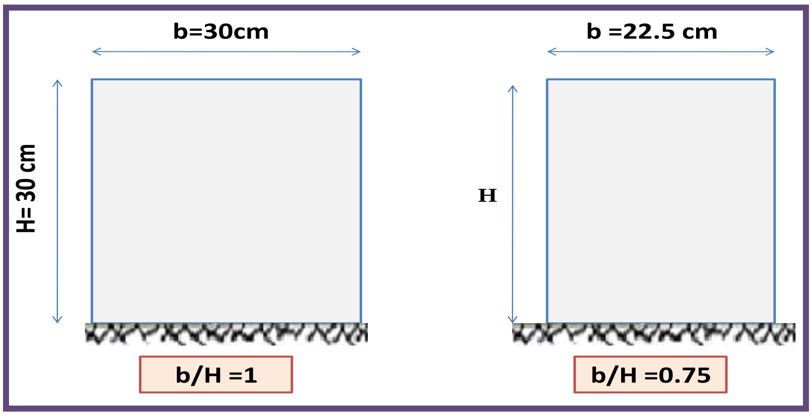


Fig. 2 Cellular Cofferdam Placed on Ground Surface.

Case 2 as shown in Fig. 3

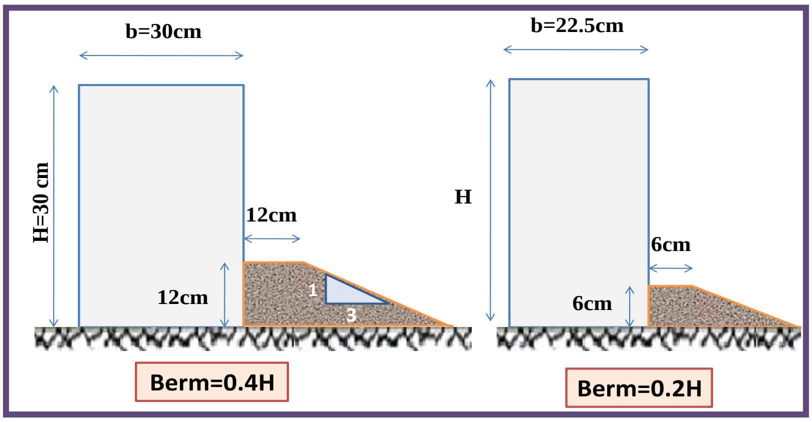


Fig. 3 Cellular Cofferdam with a Back Side Berm.

Case 3 as shown in Fig. 4

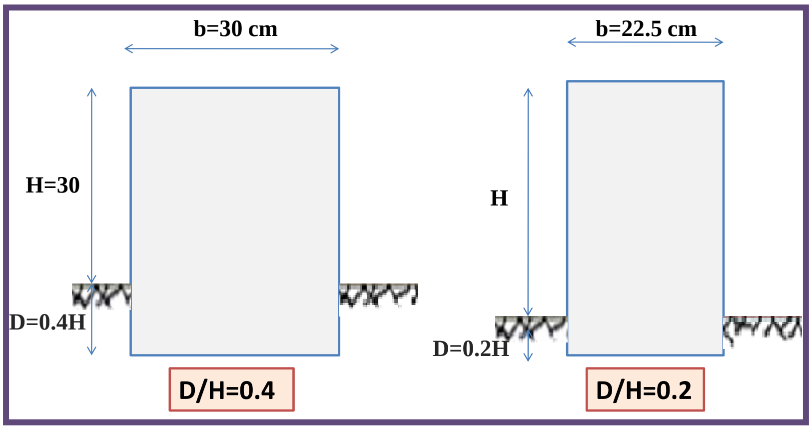


Fig. 4 Cellular Cofferdam Embeded into the Soil.

4. Analysis of Experimental Results

4.1 Comparison The Results with Triangular Berm in Dry Soil

Comparing the results with (Al-Humairi, 2010)when used (single) circular and diaphragm cellular retaining structures with triangular berm in dry soil, with (single) circular and diaphragm cell with trapezoidal berm in saturation soil have resistance and stability greater than previous cell(Al-Humairi)because cross section of area for trapezoidal berm greater than the area of triangular berm as well as wet unit weight of berm and cell soil and adhesive between wet soil and sheet pile is high.

Table 2. Differences in Resistances Between *Trapezoidal Berm* in Saturation Soils and *Triangular Berm in Dry Soils* for Circular Cell.

Type of soil	Berm ratios	Resistances(KN/m)		Differences %
		observed data from laboratory for *trapezoidal berm* in saturation soils	observed data from laboratory for *triangular berm* for (*Al-Humairi*) in dry soils	
Subbase	0.4H	1.6	0.707	56
Sand passing no.4	0.2H	0.86	0.403	53
	0.4H	1.2	0.667	44.4
River sand	0.2H	0.73	0.275	63
	0.4H	1.07	0.618	43

Table 3 Differences in Resistances Between Trapezoidal Berm in Saturation Soils and Triangular Derm in Dry Soils for Diaphragm Cell.

Type of soil	Berm ratios	Resistances(KN/m)		Differences %
		observed data from laboratory for trapezoidal berm in saturation soils	observed data from laboratory for triangular berm for (Al-Humairi) in dry soils	
Subbase	0.2H	1.67	0.733	56
	0.4H	2.06	1.258	39
Sand passing no.4	0.2H	1.28	0.667	48
	0.4H	1.5	1.192	21
River sand	0.2H	1.00	0.508	49
	0.4H	1.22	0.967	21

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

4.2 Comparison The Results with Data Fit

Tables 4 and 5 show a comparison between horizontal displacement from laboratory tests and horizontal displacement from data fit software for subbase soil for circular and diaphragm cell.

Table 4. Comparison of the Horizontal Displacement from Experimental and Data Fit for Subbase Soil and Circular Cell.

N0.	b/H	Berm Ratios	Embedment Depth Ratios	Failure load (kN)	Horizontal Displacement From Experimental (mm)	Horizontal Displacement From Data fit (mm)	Difference %
1	0.75	-	-	0.11	5.54	4.42	20
2	0.75	0.2H	-	0.17	10.04	11.14	-9.87
3	0.75	0.4H	-	0.28	8.74	9.4	-7
4	0.75	-	0.2H	0.20	11.72	11.707	0.11
5	0.75	-	0.4H	0.32	16.93	16.08	5
6	1	-	-	0.32	6.73	6.13	8.9
7	1	0.2H	-	0.37	19.47	19.22	1.3
8	1	0.4H	-	0.48	16.85	16.24	3.6
9	1	-	0.2H	0.42	12.3	13.04	-5.7
10	1	-	0.4H	0.54	17.43	17.91	-2.6

Table 5 Comparison of the Horizontal Displacement from Experimental and Data fit for Subbase Soil and Diaphragm Cell.

N0.	*b/H*	*Berm Ratios*	*Embedment Depth Ratios*	*Failure load (kN)*	*Horizontal Displacement From Experimental (mm)*	*Horizontal Displacement From Data fit (mm)*	*Differences %*
1	0.75	-	-	0.75	15.53	17.5	-11.2
2	0.75	0.2H	-	0.24	24.13	23.95	0.74
3	0.75	0.4H	-	0.36	13.34	16.63	-19.8
4	0.75	-	0.2H	0.34	13.03	12.78	1.9
5	0.75	-	0.4H	0.44	21.42	18.35	14.33
6	1	-	-	0.54	31.22	30.7	1.64
7	1	0.2H	-	0.60	41.37	41.98	-1.45
8	1	0.4H	-	0.74	24.86	23.26	6.42
9	1	-	0.2H	0.70	21.05	22.4	-6
10	1	-	0.4H	0.80	29.98	32.17	-6.8

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

Figures 5 to 8 show the relationship between failure load and horizontal displacement for data fit and experimental test.

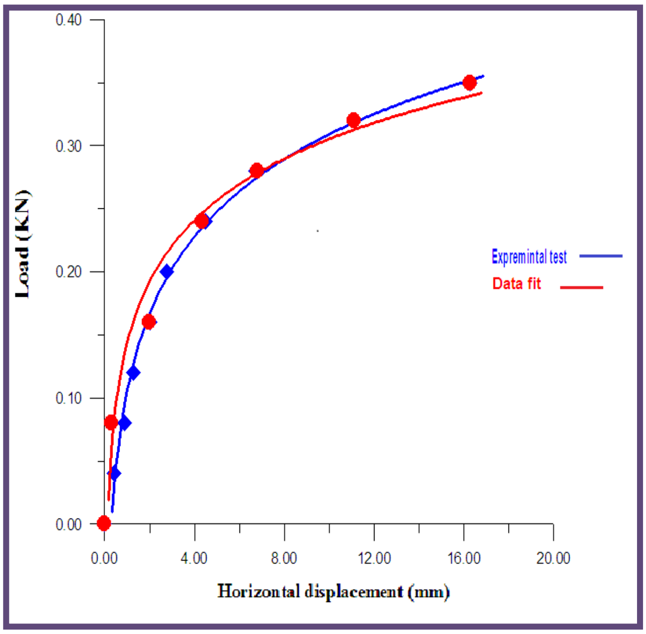


Fig. 5 Load-Horizontal Displacement Curve Comparison for Circular Cell with Berm.

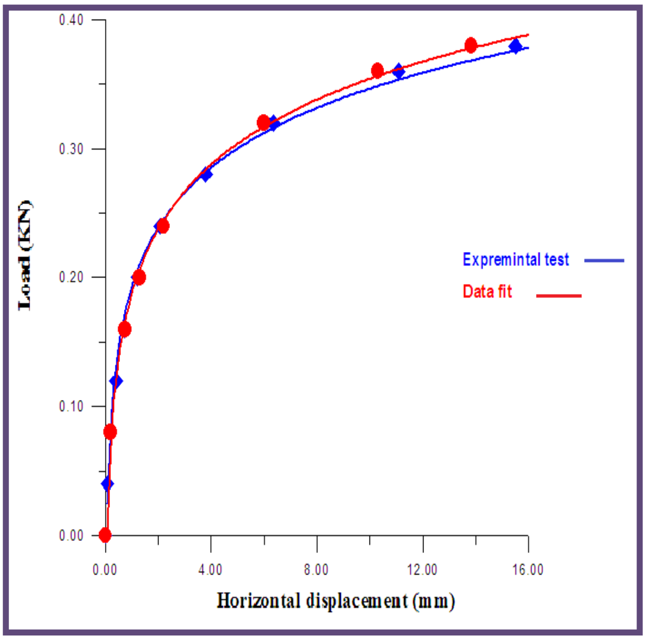


Fig. 6 Load-Horizontal Displacement Curve Comparison for Circular Cell with Embedment Depth.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

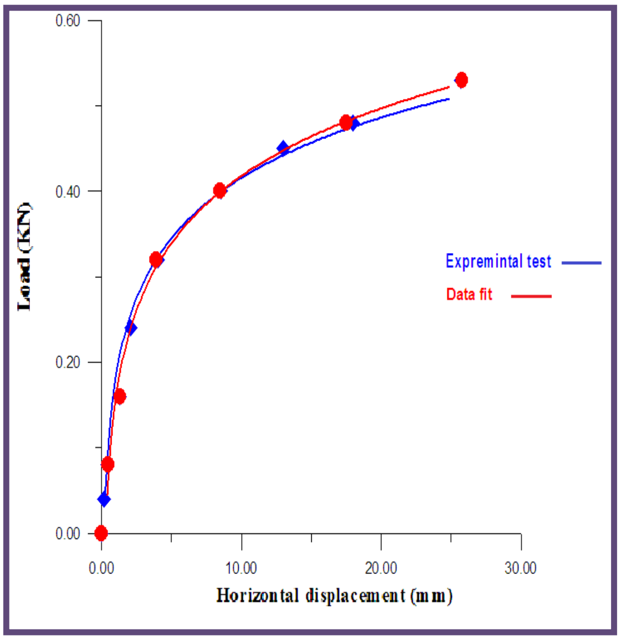


Fig. 7 Load-Horizontal Displacement Curve Comparison for Diaphragm Cell with Berm.

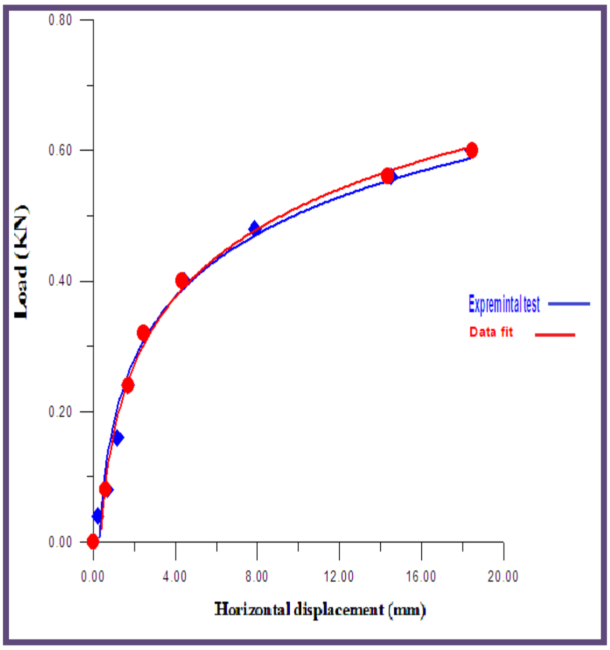


Fig. 8 Load-Horizontal Displacement Curve Comparison for Diaphragm Cell with Embedment Depth.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

4.3 Influence of Parameters

This section includes the analysis of parameters (width to height of cell (b/H), berm ratio(back fill) and embedment depth ratio) on stability of retaining structures (cofferdams) in saturation soils. Effect of embedment depth ratio on stability of cellular retaining structures is higher, then width to height ratio(b/H), and then berm ratio.

4.3.1 Cell Width

Effect of width on the behavior of a cellular retaining structure. Width of circular cell were examined, 22.5cm and 30cm and constant height equal to 30cm, in case the cell was placed (6cm) below the ground surface .The resistance of the (22.5cm) width cell was equal to (0.88 kN/m), it was increased to (1.4 kN/m) when the width increased to (30cm), previous results increase ratio of the resistance equal to (37%). Where the same case for diaphragm cells, the resistance of the (22.5cm) width cell was equal to (1.5 kN/m), it was increased to (1.94 kN/m) when the width increased to (30cm), previous results increase ratio of the resistance equal to (23%). That mean when the width of the cell increase lead to increased in resistance of the cell, the reason for this behavior is believed to be due to the increase in the size of footing area.

4.3.2 Berm Ratio

Effect of berm (back fill) on stability of cofferdams, one circular and one diaphragm cell with different ratios (b/H=0.75, 1.0) and subjected to a load applied at one third of the cell height have been tested. Placed the trapezoidal berm in the back side from the cell for different ratios (0.2, 0.4) from height of cell, used slope of berm(1V:3H). The figures from (9) to (12) show the relationship between load failure and horizontal displacement for berm ratios and for each type of soil for cell (b/H=1).

Resistance of circular cell (b/H=1.0) at berm ratios (0, 0.2, 0.4) is equal to (1.067, 1.23 , 1.6) kN/m respectively for subbase soil, thus at used berm ratio of (0.2H) has increase the cell resistance (13%), when used berm ratio of (0.4H) has increase the cell resistance (33.3%). Resistance of diaphragm cell (b/H=1.00) at berm ratios (0,0.2, 0.4) equal to (1.5, 1.67, 2.06) kN/m respectively ,thus at used berm ratio of (0.2H) has increase in the cell resistance (10.2%), when used berm ratio of (0.4H) has an increase the cell resistance (27.2%).

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

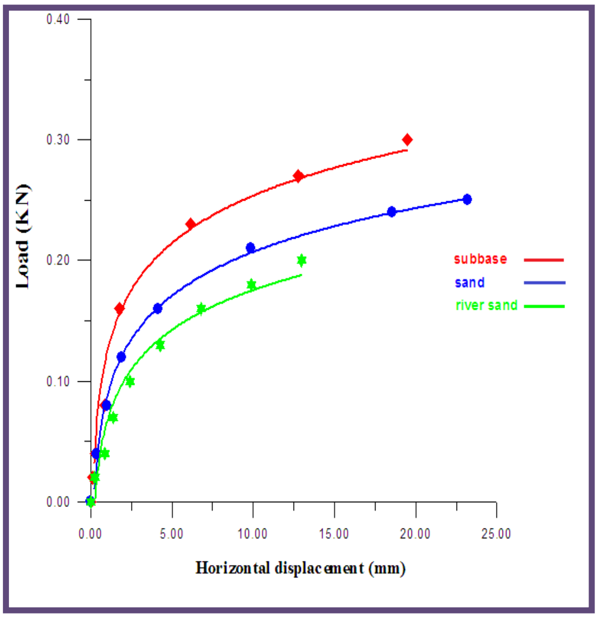


Fig.9 Horizontal Displacement vs. Lateral Load Curve, Circular Cell, $\frac{b}{H}$ =1, Berm=0.2H.

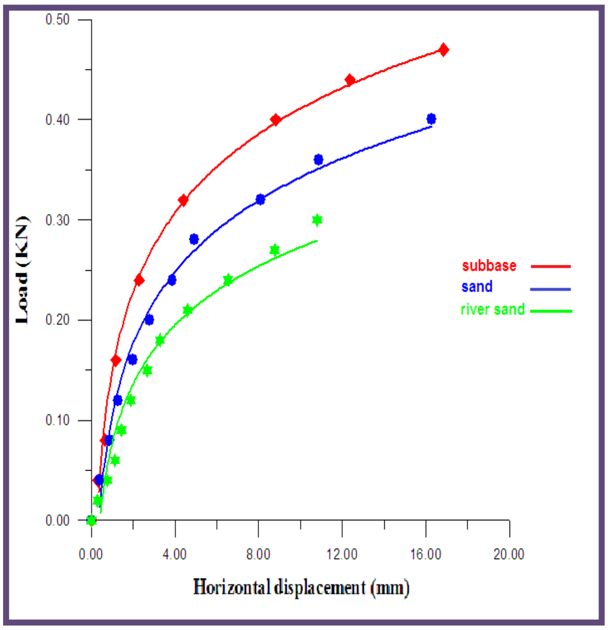


Fig. 10 Horizontal Displacement vs. Lateral Load Curve, Circular Cell, $\frac{b}{H}$ =1, Berm=0.4H.

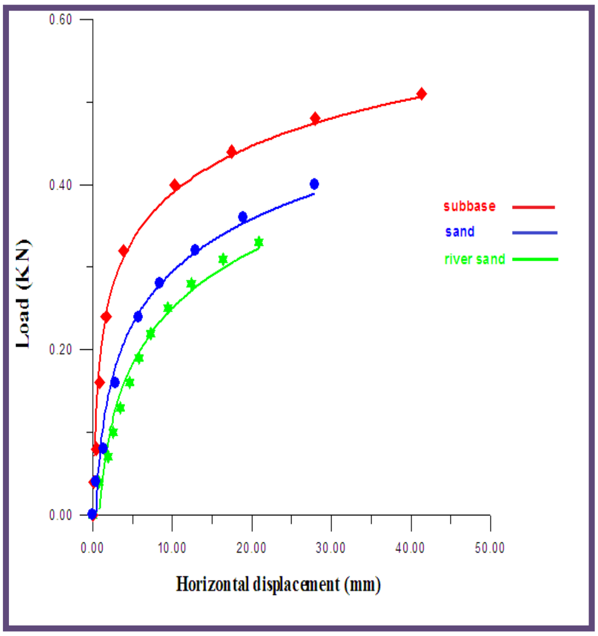


Fig. 11Horizontal Displacement vs.L Load Curve, Diaphragm cell, $\frac{b}{H}$ =1, Berm = 0.2H.

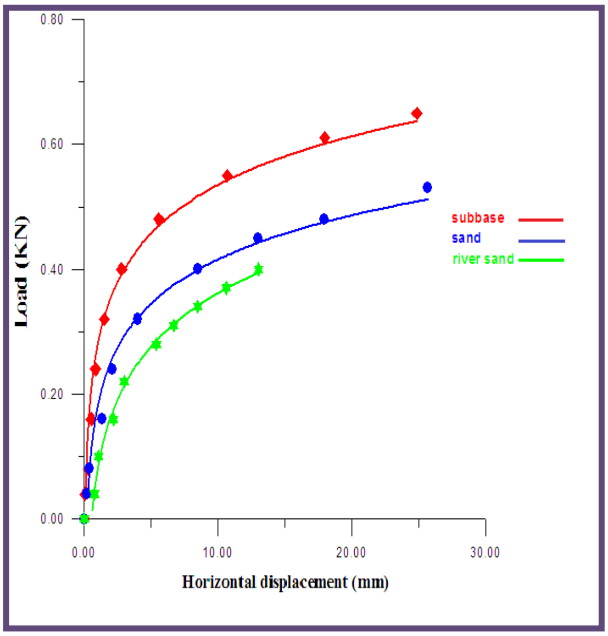


Fig. 12 Horizontal Displacement vs. Lateral Load Curve, Diaphragm cell, $\frac{b}{H}$ =1, Berm = 0.4H.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq

4.3.3 Embedment Depth Ratio

Effects of the embedment depth, one circular cells and one diaphragm cell with different ratios (b/H=0.75, 1.0) and subjected to a load applied at one third of the cell height have been tested. The lower end of the cell considered in study was placed (0.2, 0.4) depth (D) to height (H) ratios below the ground surface. It is noted the curve form vary from cell to others according to the (D/H) ratio,(b/H) ratio and type of soil used in the filling.

Resistance of circular cell (b/H=1.00) at embedment depth ratios (0, 0.2, 0.4) equal to(1.067, 1.4, 1.8) kN/m ,respectively ,thus at used embedment depth ratio of (0.2H) has increase the cell resistance (23.8%), compared with the ratio (0.4H) has increase the cell resistance (40.72%).

Resistance of diaphragm cell (b/H=1.0) at embedment depth ratios (0, 0.2, 0.4) equal to (1.5, 1.94, 2.22) kN/m respectively ,thus at used embedment depth ratio of (0.2H) has increase the cell resistance (22.7%), when used embedment depth ratio of (0.4H) has increase the cell resistance (32.5%).

This increase may be related to the passive resistance of soil that contact the cell, as well as the friction and cohesion between the soil and sheet pile. The figures from (13) to (16) show the relationship between load failure and horizontal displacement for embedment depth ratio, for each type from cellular structure.

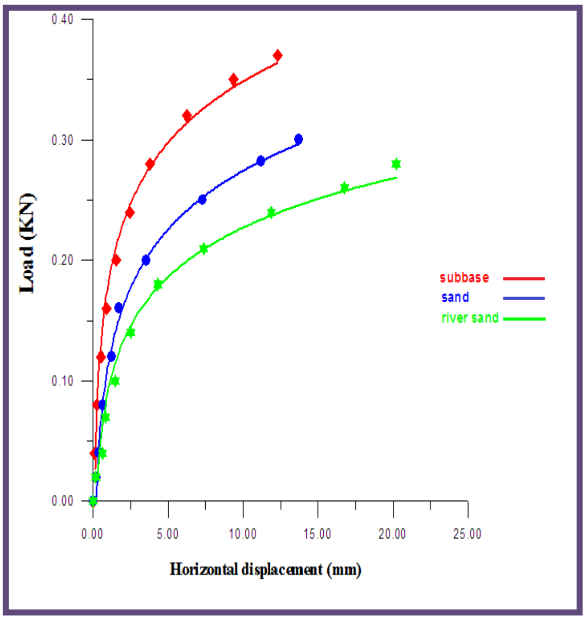


Fig. 13 Horizontal Displacement vs. Lateral Load Curve, Circular Cell, $\frac{b}{H}=1$, Embedment Depth = 0.2 H

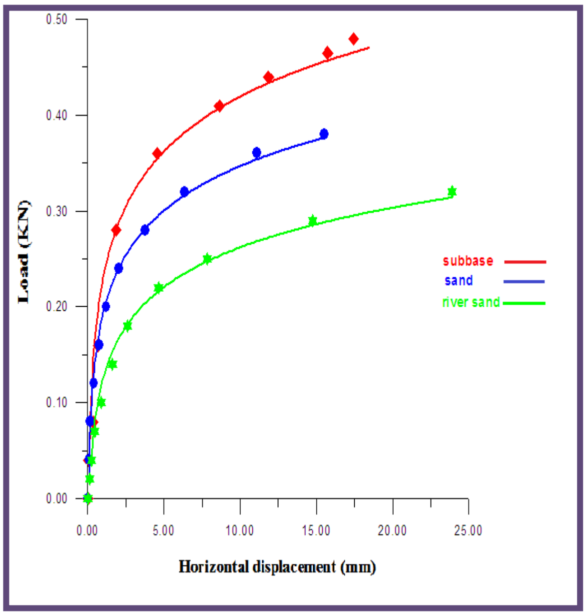
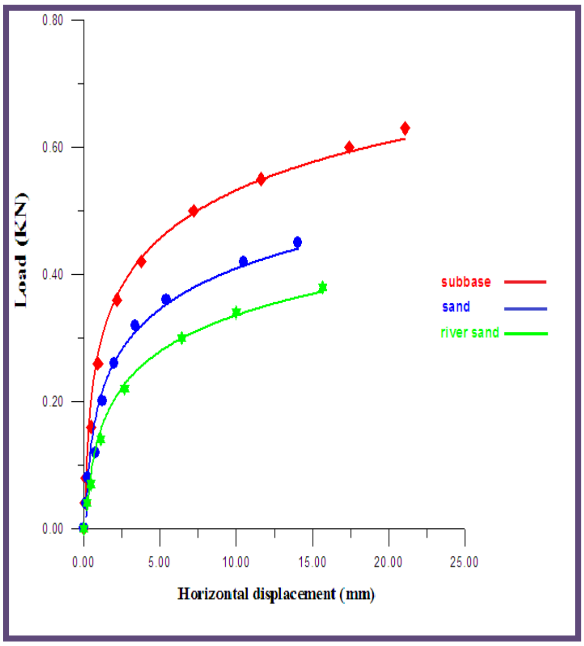


Fig. 14 Horizontal Displacement vs. Lateral Load Curve, Circular Cell, $\frac{b}{H}=1$, Embedment Depth = 0.4H

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 1, Dec., 2013,P.P.113 -126
Printed in Iraq



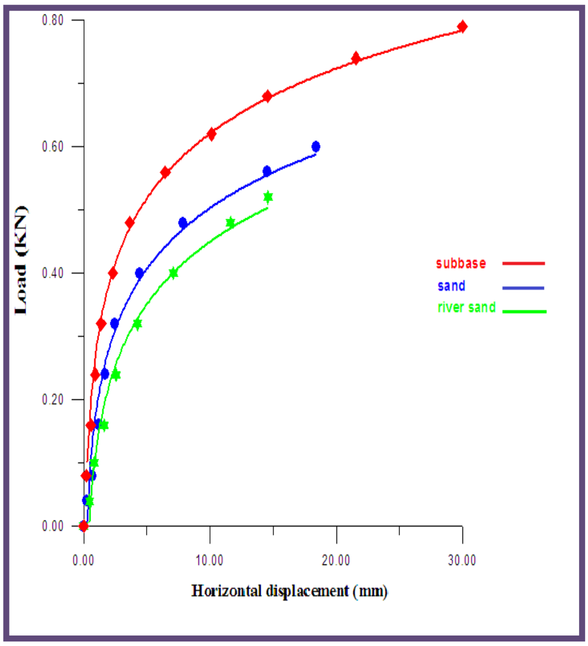


Fig. 15 Horizontal Displacement vs. Lateral Load Curve, Diaphragm Cell, $\frac{b}{H}=1$, Embedment Depth = 0.2H

Fig. 16Horizontal Displacement vs. Lateral Load Curve, Diaphragm Cell, $\frac{b}{H}=1$, Embedment Depth = 0.4H

5.Conclusions

Effect embedment depth ratio on stability of cellular retaining structures is higher, width to height ratio(b/H), and then berm ratio. Resistance of cellular retaining structures with wet soil fill in saturation soils greater than its with dry soil fill in dry soils, where increase of resistance for embedment depth ratio(0.4H) equal to(52%) for circular cell and (30%) for diaphragm cell. While in case of berm, where increase of resistance for berm ratio(0.4H) equal to(56%) for circular cell and (39%) for diaphragm cell.

The (single) cellular cofferdams in case unable executed embedment depth especially in rock foundations. Replaced embedment depth by berm through adopted on embedment depth resistance or load failure of embedment depth to give dimensions of berm, as so as replace trapezoidal berm ratio from (0.4H) to (0.46H).

The statistical models are created to find the relationship between horizontal displacement and width to height ratio (b/H), berm ratio, embedment depth ratio after applied failure load .

References

Al-Rmmahi, S. H. [2009]: "Effect of Width to Depth Ratio on Stability of Cellular Cofferdams". M. Sc. thesis, College of Engineering, University of Babylon.

Al-Humairi, B. A. [2010]: "Effect of Embedment Depth on Stability of Cellular Sheet pile Retaining Structure". M. Sc. thesis, College of Engineering, University of Babylon.

Al-Taee, K. N. [1990]: "Effect of geometry on stability of cellular cofferdams". M. Sc. thesis, College of Engineering, University of Baghdad.

Bowles, J. E. [1997]: "Foundation analysis and design". McGraw-Hill, New York, U.S.A.

Mohammod, R. Amin Khan ,Jiro T., Hiroki, F. and Osamu K. [2001]:"Behavior of double sheet pile wall cofferdam on sand observed in centrifuge tests ".IJPMG- International Journal of Physical Modeling in Geotechnics, Tokyo ,Japan.

Mohammod, R. Amin Khan ,Jiro T., Hiroki F.and Osamu K. [2006]:"Behavior of double sheet pile wall cofferdam on a thick clay observed in centrifuge tests ".IJPMG- International Journal of Physical Modeling in Geotechnics ,Tokyo ,Japan.

Nemati, K.M. [2007]:"Temporary Structure, Cofferdam" Department of Construction Management, University of Washington.