Effect of Pile and Load Inclination on the Pile Resistance In both Compression and Tension

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Abstract:

According to this theoretical study which was about loading of piles under different condition of loading (compression and up-lift forces) and for deferent pile installation (vertical and inclined pile) by which it called (positive batter pile) when the inclination of the load and pile is in the same direction and called (negative batter pile) when the inclination of load is opposite to the pile inclination, and from studying these cases the results of analysis can be summarize in the flowing points:

1-Variation of load inclination on piles affects on the bearing capacity and uplift resistance. It was found that bearing capacity of the piles increase with increasing of load inclination up to the inclination angle (37.5°) which represents the maximum bearing capacity and then the bearing capacity decrease with increasing of load inclination.

2- Variation of batter pile affects the bearing capacity of the pile and up-lift resistance. by which equivalent angle will be used as result between the load and piles inclination and this angle will be used in calculation of piles resistance .

3- It was noticed the shape of soil failure is highly affected by the inclination of pile. The shape of failure for the soil which is in contact with pile and this include (vertical and batter piles) is highly affected by the angle of inclination.

تأثير ميلان الركيزة والأحمال على مقاومة الركيزة للأحمال في حالتي قوى الضغط والسحب

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الخلاصة :

تم من خلال البحث دراسة حالات مختلفة لتحميل الركائز (قوى إنضغاطية أو قوى سحب) نظرياً للركائز العمودية والمائلة والتي إما أن تكون باتجاه الحمل وتسمى ركائز مائلة موجبة أو أن تكون بعكس اتجاه الحمل وتسمى ركائز سالبة ومن خلال تحليل النتائج تم التوصل إلى النقاط التالية :

1 . إن تغيير زاوية تسليط الحمل يؤثر على قابلية تحمل الركيزة للأثقال وقابلية تحمل الشد حيث تزداد وتقل حسب الميلان .

2. إن تغيير زاوية ميلان الركيزة يؤثر على قابلية الركيزة لتحمل الأحمال الانضغاطية وعلى قابلية تحمل الركيزة لقوى الشد.

3. إن تغيير مستوى فشل التربة المحيطة بالركيزة يتأثر بشكل كبير بزاوية ميلان الركيزة والحمل ،حيث إن مخططات فشل التربة الملامسة للركيزة تتأثر بهذا الميلان وهذا يشمل (الركيزة المفردة العمودية والركائز المائلة الموجبة والسالبة) وإن إتجاه ميل الحمل والركيزة بتغيير مع تغيير زاوية الميلان .

Introduction:

The rapid increase in size and number of civil engineering structures has passed the problem of safe efficient and economic design of foundation ,it is important where the bearing capacity of upper layer of foundation not able to carry these heavy load so the use of pile is the clear choice to solve this important issue in civil engineering,[4]and [7]. A pile foundation may be subjected to various loading condition (vertical load ,horizontal load or combination of vertical and horizontal load) which resulting in inclined load ,and this depends on the condition of pile ,vertical piles are usually used as foundation where these are subjected to vertical loads and inclined piles used when the structures subjected to the horizontal or lateral loads, Batter piles in combination with vertical piles are used when large horizontal load are applied. The design of many foundations like television and transmission towers required the proper evaluation of resistance of soil to uplifting loads in addition of the resistance of compression load, the pile groups and due to eccentric load are subjected to the compression and uplift loads.[1],[3]and[7].

A- Experimental Studies:

1- Piles under compressive load:

Properly due to the complexity of the problem of pile under inclined load or pile with inclination angle (β) with the vertical, many attempt have been made to study the affect of load inclination and pile inclination on the behavior of pile in both tension and compression forces, and in order to review the results for these studies and make our study results more accurate we present some of the studies. [1], [2] and [9].

Petrosove & Awad (**1968**) reported field tests in which many piles were tested under a constant vertical load and increase of horizontal load he fixed that the bearing capacity decrease with increasing of load inclination , he made tests on vertical piles under inclined loads subjected above ground surface , the results shows that the highest loading resistance of vertical pile accrued under a force inclined with angle (α) equal to (22.5) , the bearing capacity was greater than about (35%) from the vertical load capacity . [13].

Meyrhof & Ranjan (1972) studied the bearing capacity of single pile under inclined load at ground surface. The pile pushed in the sand at a constant rate of penetration , they found that the bearing capacity of vertical and batter piles decreased with increasing in the inclination of load with the vertical , their result also indicated that for small inclination of load with the vertical, positive batter pile (+β) show higher ultimate load with the vertical , as compare with the negative batter pile (-β) , while in the large

Inclination of load with the vertical the trend was changed and at horizontal load negative batter pile show higher ultimate load than positive batter pile. [9]. And they carried out test on inclined piles axially loaded the results showed that for the same depth and soil condition and given inclination of pull ,the uplift resistance of axially loaded inclined pile was more than that for axially loaded vertical piles, more ever while uplift resistance of such axially loaded inclined piles, generally the uplift resistance increase as the inclination increase, and the corresponding uplift capacity of vertical piles increased as the inclination of pull from the vertical increase. [10].

Meyrhof & Ranjan(1973) conducted tests on single rigid vertical and batter pile. It was found that the reduction of the ultimate bearing capacity with increasing of the load inclination from the pile axis and it is depend on the relative density of the sand layer and upper layer thickness ratio.[11].

Chari & Meyrhof (1983) used a large model of pile, they found that the inclination of applied load reduce the ultimate capacity of pile, and the reduction was nearly (30%) at (α=30), and about (50%) at (α=60). [5].

Meyrhof & Chosh (1989) made tests on single and group of timber piles and flexible pile in loose sand under various eccentricities and inclination of loads, the results indicated that the ultimate bearing capacity generally decreased with increasing of the inclination of load with the pile axis. [12].

2- Piles under up lift load:

Meyrhof & Ranjan (1972): made tests on the vertical and batter pile with different embedded length, the results indicated that at increasing of pull inclination the uplift failure load increases with the maximum at (α=90),(for both vertical and positive batter pile) , the negative batter pile has greater uplift failure than that for vertical and positive batter pile for the same embedded length and diameter. [10].

B-Theoretical studies:
1- Piles under compressive load:

Several attempts to analysis single vertical and batter pile under inclined loads.
Meyrhof & Ranjan(1972) extended the analysis of block footing under an eccentric inclined load to that of pile group with batter and vertical piles ,the analysis was based on elastic theory , the equation given by Metrhof were modified for generally loaded piles group as mentioned by Meyrhof. [10].

Meyrhof & Ranjan(1973) gave good detail about the behavior of vertical pile under inclined load they considered vertical pile subjected to a central foundation load inclined at angle (α) the load (Puα) is shared by base (Qb) making angle (¥) with the vertical and by shift load (Qs) making angle (£) with the horizontal ,as the inclination of load (α) increase the load base decrease and (£) increase also when (α) equal to (90) the base load is (o) and (£)equal to (90) , the greater inclination of load increase the shaft load rabidly , the shaft load (Qs) is the result of the passive and active loads developed below and above the sides of shaft . [11].

For small inclination of load the base resistance decreases but the shaft start taking more loads under full mobilization of friction, under large inclination of load when horizontal resistance govern failure,the angle of friction between the shaft and the soil start decreasing as function of inclination of load (α) until at (α= 90).[13].The load on the shaft is all normal as shown in figure (7).

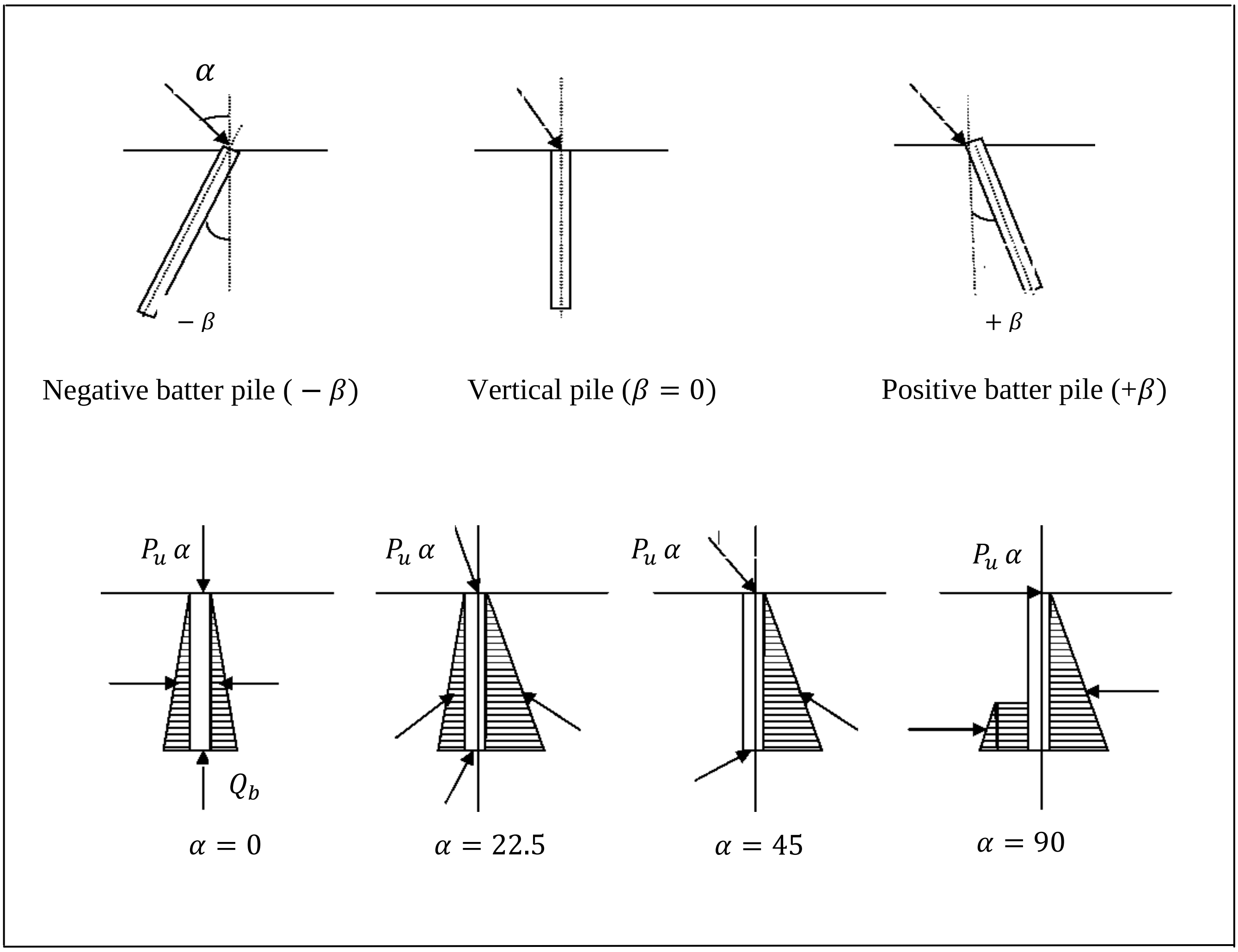

Figure (1): Type of batter pile [5].

The parameter selected here are:

1- (α) is angle of load inclination with the vertical , (α=0) vertical load to (α=90) horizontal load.

2- (β) is angle of pile inclination with the vertical , the value of (β) = from (-30) to (+30).

3- ($P_u\alpha$) is inclined load subjected on the pile.

4- (Q_b) base bearing capacity (end bearing of the pile base).

5- (Q_s) shift resistance (shift friction resistance).

6- (¥) angle of (Q_b) with the vertical.

7- (£) angle of shift resistance (Q_s) with the vertical.

The objective of this research:

The objective of this research is to determine the ultimate compression and uplift loads resistance for single vertical and batter piles under various load conditions. A pile is called negative batter pile **(+β)** when it inclination with the vertical is on the opposite side of the loading, and a pile is called positive batter pile **(+β)** when the inclination of the load with vertical is on the same side

A- Experimental studies:

In order to support theoretical studies which are illustrate above and to make our conclusion with high rang of accuracy we had make many calculations for deferent cases of loading and piles inclination using Chare & Meyrhof (1983),[5],equation:

$[P_u \cos \alpha / P_{uo}] + [P_u \sin \alpha / P_{uo}] = 1$

Where:

$P_{u\alpha}$= ultimate bearing capacity of vertical pile subjected to inclined compressive load at angle (α)with the pile axis.
P_{uo}= the ultimate capacity of an axially pile using Meyrhof equation:

$P_{uo} = {}_{\gamma}\, D\, [N_q A_b + K_s (\tan \mu)\, A_s / 2]$

Where:

γ =unit Wight of soil.
D= length of pile (depth of embedment).
A_b & A_s = base bearing capacity.
N_q = bearing capacity factor.
μ= angle of (pile –soil) skin friction
α= angle of load inclination, ϕ= equivalent angle (α-β).

Vertical pile:

Table (1): The results of inclination of load (V_S) compressive load for vertical pile at β =Zero.

α	0	7.5	15	22.5	30	45	60	90
ϕ	0	7.5	15	22.5	30	45	60	90
P_ϕ 1	1446	1459	1497	1565	1670	2045	2892	1400
P_ϕ 2		5274	2660	1799	1377	974	795	688
P_ϕ 1	1446	1459	1497	1565	1377	974	795	688
$\frac{P_\phi}{P_{uo}}$ %	100	100.8	103.5	108.5	95.2	67.5	55	48

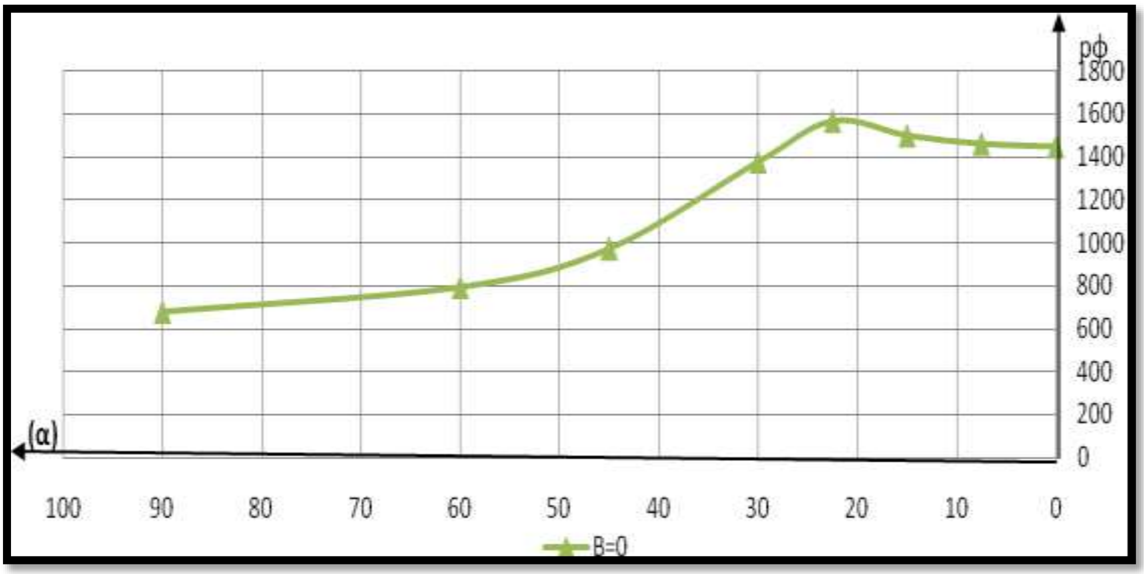

Figure (2): Inclination of load (V_S) compressive load for vertical pile with deferent pile inclination (β).

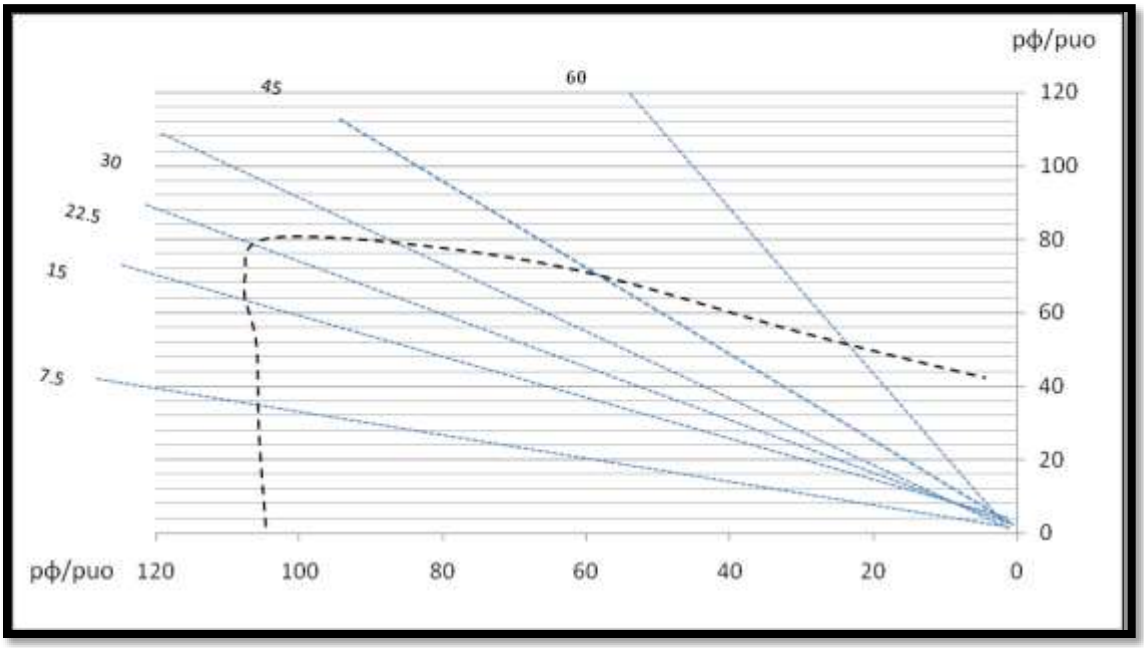

Figure (3): Relative bearing capacity (V_S) inclination of load (α) vertical pile.

2-Positive batter pile:

Table (2): The results of inclinations of load (V_S) compressive load for positive batter pile with deferent pile inclination (β).

***β* =0**								
α	0	7.5	15	22.5	30	45	60	90
¥	0	7.5	15	22.5	30	45	60	90
P ¥ 1	1446	1459	1497	1565	1670	2045	2892	1400
P ¥ 2		5274	2660	1799	1377	974	795	688
P ¥	1446	1459	1497	1565	1377	974	795	688
P ¥ / P uo %	100	100.8	103.5	108.5	95.2	67.5	55	48
***β* =+7.5**								
α	0	7.5	15	22.5	30	45	60	90
¥	-7.5	0	7.5	15	22.5	37.5	52.5	82.5
P ¥ 1	1458	1446	1458	1497	1566	1670	2045	2892
P ¥ 2	5247	5247	5247	2660	1800	1131	866	694
P ¥	1458	1446	1458	1497	1566	1131	866	694
P ¥ / P uo %	100	100.8	103.5	108.5	95.2	67.5	55	48
***β* =+15**								
α	0	7.5	15	22.5	30	45	60	90
¥	-15	-7.5	0	7.5	15	22.5	37.5	52.5
P ¥ 1	1497	1459	1446	1458	1497	1970	2045	5587
P ¥ 2	2660	5274		5274	2660	1377	973	712
P ¥	1446	1459	1497	1458	1497	1377	973	712
P ¥ / P uo %	103.5	100.8	100	100.8	104	95	67	50
β=+30								
α	0	7.5	15	22.5	30	45	60	90
¥	-30	-22.5	-15	-7.5	0	15	30	60
P ¥ 1	1670	1565	1497	1458	1464	1497	1670	2892
P ¥ 2	1377	1799	2660	5247		2660	1377	795
P ¥	1377	1565	1497	1458	1446	1497	1377	795
P ¥ / P uo %	95.5	109	103.5	100.8	100	103.5	95.5	55

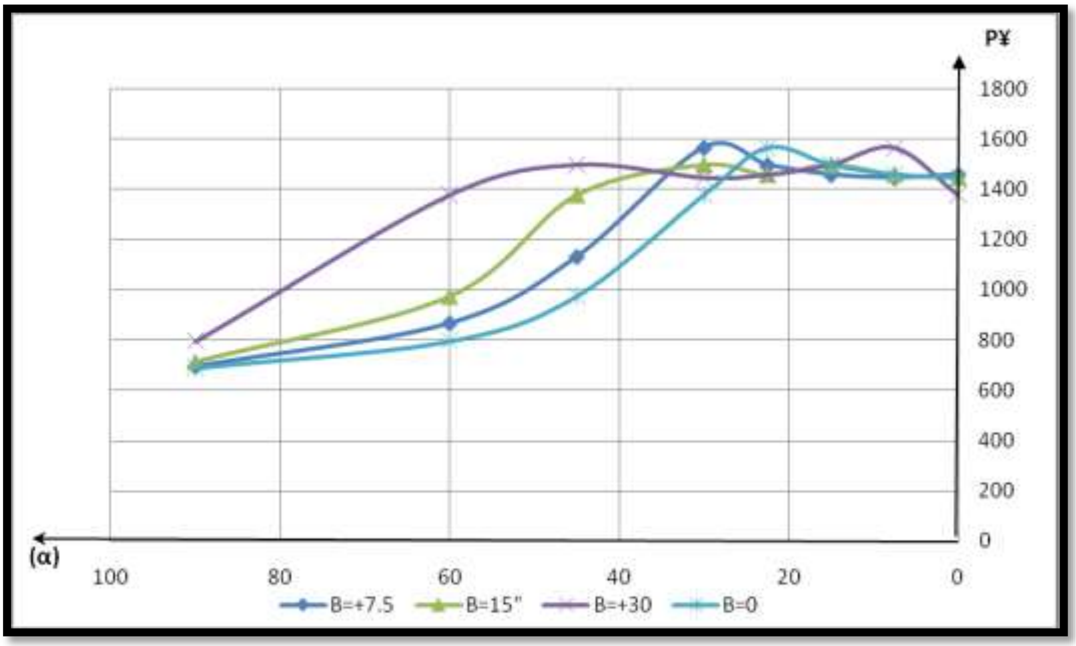

Figure (4): Inclination of load (V_S) compressive load for positive batter pile with deferent pile inclination+ (β)

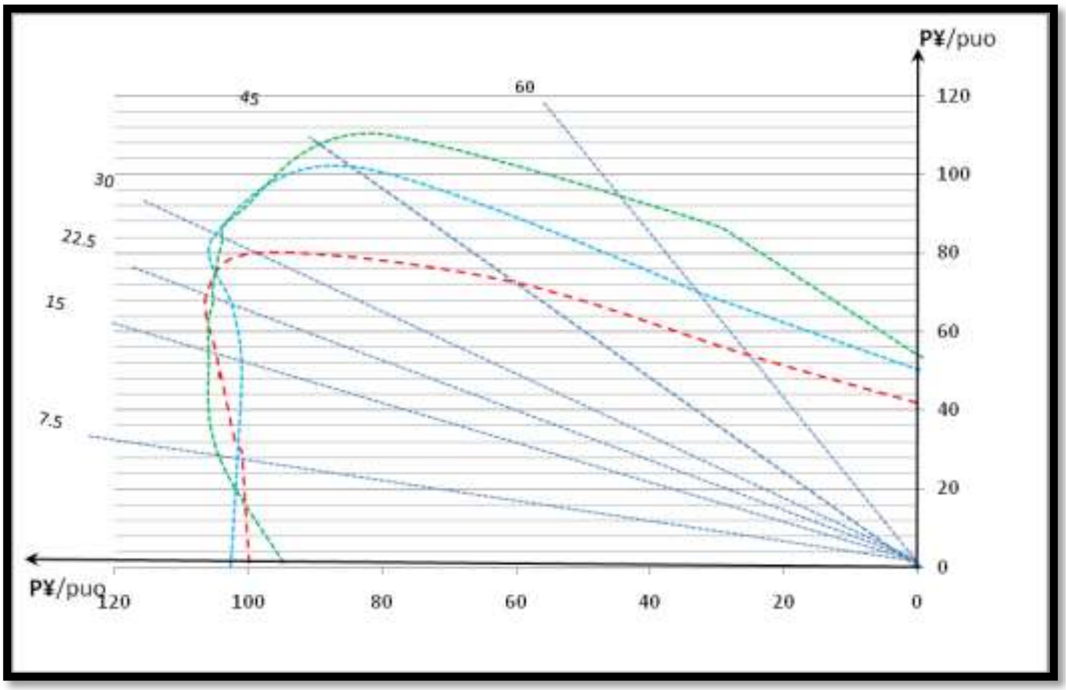

Figure (5): Relative bearing capacity (V_S) inclination of load (α) for Positive batter pile (+β).

2-Negative batter pile:

Table (3): The results of inclinations of load (V_S) compressive load for negative batter pile with deferent pile inclination (β).

				***β*=0**				
α	0	7.5	15	22.5	30	45	60	90
¥	0	7.5	15	22.5	30	45	60	90
P ¥ 1	1446	1459	1497	1565	1670	2045	2892	1400
P ¥ 2	1446	5274	2660	1799	1377	974	795	688
P ¥	1446	1459	1497	1565	1377	974	795	688
$\frac{P¥}{Puo}$ %	100	100.8	103.5	108.5	95.2	67.5	55	48
				***β*=-7.5**				
α	0	7.5	15	22.5	30	45	60	90
¥	7.5	15	22.5	30	37.5	52.5	67.5	97.5
P ¥ 1	1458	1497	1565	1670	1822	2381	3788	1180
P ¥ 2	5247	2660	1799	1377	1131	866	745	694
P ¥	1458	1497	1565	1377	1131	866	745	694
$\frac{P¥}{Puo}$ %	100.8	103.5	108.5	95.5	78	60	51	48
				***β*=-15**				
α	0	7.5	15	22.5	30	45	60	90
¥	15	22.5	30	37.5	45	60	75	105
P ¥ 1	1497	1565	1670	1822	2045	2892	5587	5587
P ¥ 2	2660	1799	1377	1131	974	795	712	712
P ¥	1497	1556	1377	1131	974	795	712	712
$\frac{P¥}{Puo}$ %	103.5	108.5	92.5	78.2	67.5	55	59.3	49.3
				***β*=-30**				
α	0	7.5	15	22.5	30	45	60	90
¥	30	37.5	45	52.5	60	75	90	120
P ¥ 1	1670	1822	2045	2381	2892	5587	0	2892
P ¥ 2	1377	1131	973	866	795	712	688	795
P ¥	1377	1131	973	866	795	712	688	795
$\frac{P¥}{P uo}$ %	95.2	78.2	67.3	60	55	49.3	47.6	45

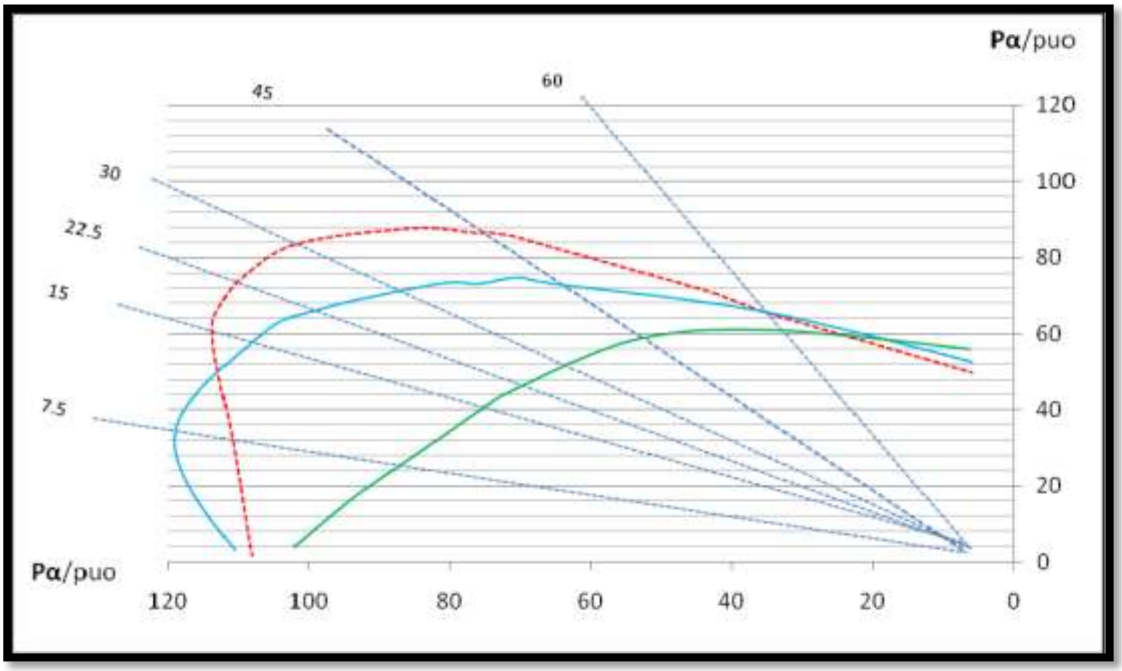

Figure (6).Relative bearing capacity (Vs) inclination of compressive load (α) for negative batter pile (-β)

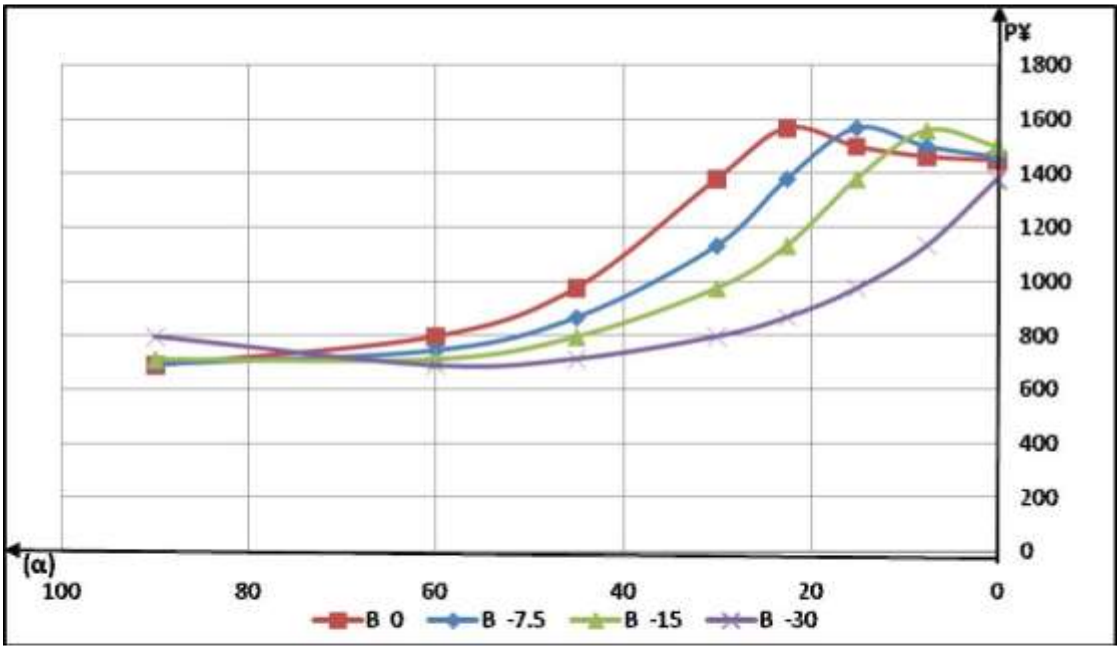

Figure (7).Inclination of load (α) (Vs) compressive load for negative batter pile with deferent pile inclination (-β)

1- Piles under uplift load:

Chari & Meyrhof (1983) Drive theory for vertical and inclined pile subjected to oblique pull and theory was modified it is used to vertical piles using simplifying assume hones shape factor,[4]. The ultimate load on rigid pile may express by semi – empirical equation:

P_u= [C K_cD+ γ Dk_b/2] B+ W cos α.

Where:

P_u= ultimate uplift load on vertical pile.
C= unit cohesion
D= depth of pile base
γ= unit weight of soil.
K_c& K_b = uplift coefficient.

The uplift coefficient (K_c) for cohesive soil (Ø=0) and is equal to (2) for (α=0) and (1) for (α=90), the uplift coefficient (K_b) for vertical rough circular piles.
Meyrhof (1973) expressed the pullout resistance for inclined piles axially loaded in term of uplift skin friction (ignoring pile weight).

P_u= [C_a+ P_o $K_u$tanØ] A_S .

Where:

P_u= ultimate uplift load for axially loaded pile.
A_S= embedded pile surface area.
P_o=average effective over burden pressure .
C&Ø= skin friction parameter of soil to pile.
K_u= uplift coefficient.

1-Vertical pile:

Table (4): Inclination of load (α) (Vs) up-lift loads for vertical pile at $\beta = 0$

α	0	7.5	15	22.5	30	37.5	45	60	90
$P\alpha\,1$	770	778	797	834	889	970	1090	1540	
$P\alpha\,2$	0	5165	2600	1759	1364	1055	952	777	673
$P\alpha$	770	778	797	834	889	970	952	777	673
$\frac{P\alpha\,1}{P_u o}$ %	100	100.8	103.5	108.5	115.4	126	123.6	101	88

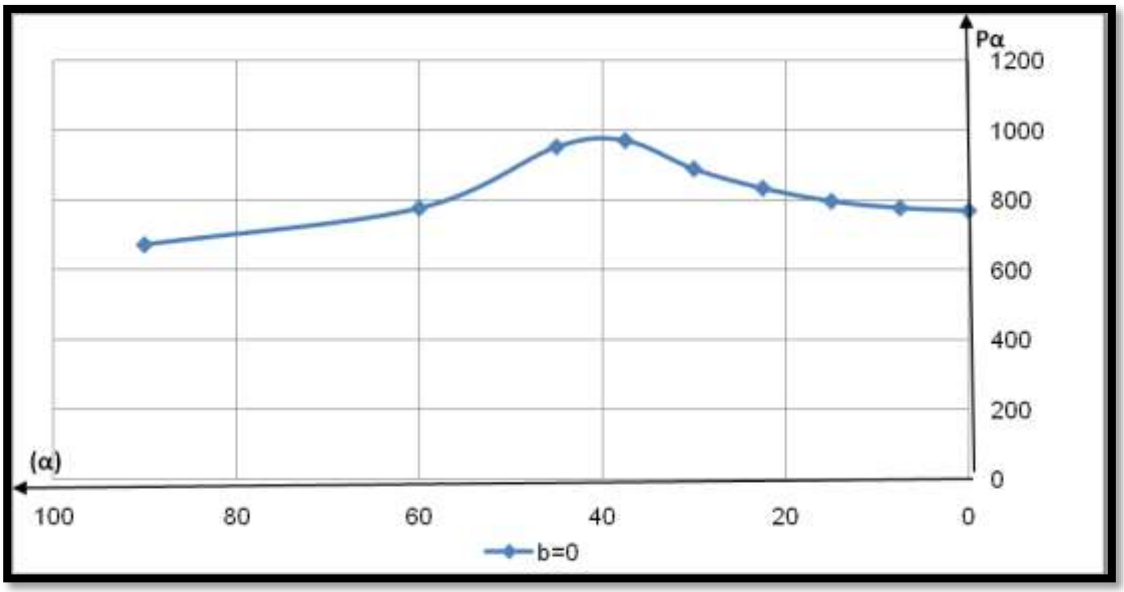

Figure (8).Inclination of load (α) (Vs) up-lift loads for vertical pile

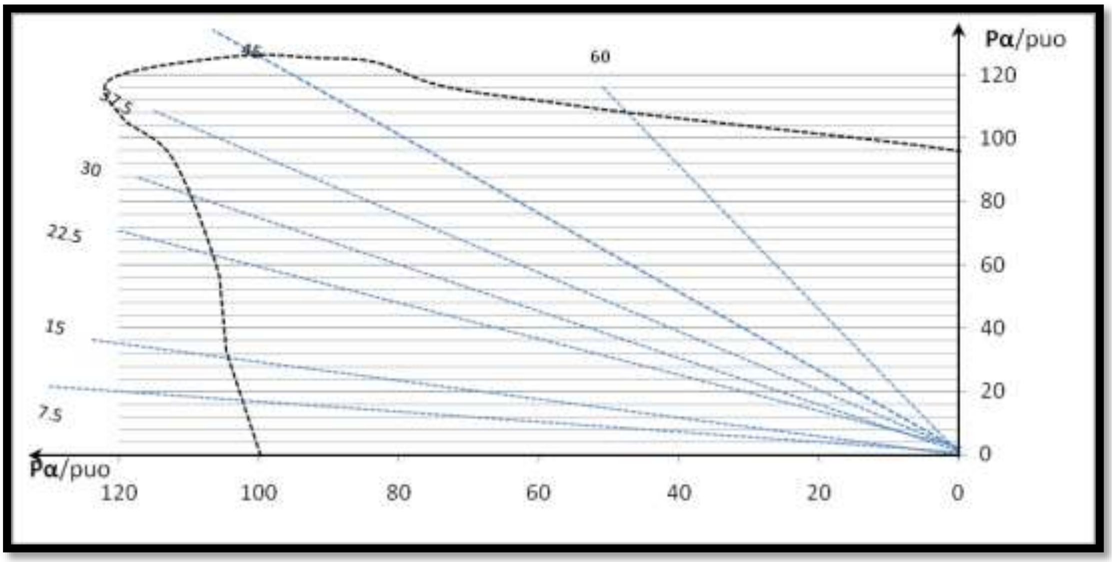

Figure (9). Relative uplift resistance (V_S) inclination of up-lift load (α) for vertical pile.

2- Positive batter pile (+β)

Table (5) Results of inclinations of up-lift load (V_S) uplift resistance for positive batter pile with deferent pile inclination (β)

***β*= 0**									
α	0	7.5	15	22.5	30	37.5	45	60	90
¥	0	7.5	15	22.5	30	45	60	90	90
P ¥ 1	770	777	797	834	889	970	1090	1540	
P ¥ 2		2600	2600	1759	1346	1050	952	777	673
P ¥	770	797	797	834	889	970	952	777	673
$\frac{P¥}{Puo}$ %	100	100.8	103.5	108.5	115.4	126	123.6	100.9	88
***β*= + 7.5**									
α	0	7.5	15	22.5	30	37.5	45	60	90
¥	-7.5	0	7.5	15	22.5	30	37.5	52.5	82.5
P ¥ 1	777	0	777	797	834	889	970	1264	5899
P ¥ 2	5256	0	5256	2600	1759	1346	1050	848	678
P ¥	777	770	777	7976	834	889	970	848	678
$\frac{P¥}{Puo}$ %	100	100	100.8	103.5	108.5	115.4	126	110.2	88
***β*= + 15**									
α	0	7.5	15	22.5	30	37.5	45	60	90
¥	-15	-7.5	0	7.5	15	22.5	30	37.5	52.5
P ¥ 1	797	777	770	776	797	834	889	1090	2975
P ¥ 2	2600	5156	0	5156	2600	1759	1346	952	697
P ¥	797	777	770	776	797	834	889	952	697
$\frac{P¥}{Puo}$ %	103.5	100.8	100	100.8	103.5	108.5	115.4	123.6	90
***β*= + 30**									
A	0	7.5	15	22.5	30	37.5	45	60	90
¥	-30	-22.5	-15	-7.5	0	7.5	15	30	60
P ¥ 1	889	843	797	776	770	776	797	889	1450
P ¥ 2	1347	1759	2600	5156	0	5156	2600	1346	777
P ¥	889	843	797	776	770	776	797	889	777
$\frac{P¥}{Puo}$ %	115.4	100.5	103.5	100.8	100	100.8	103.5	115.4	100.9

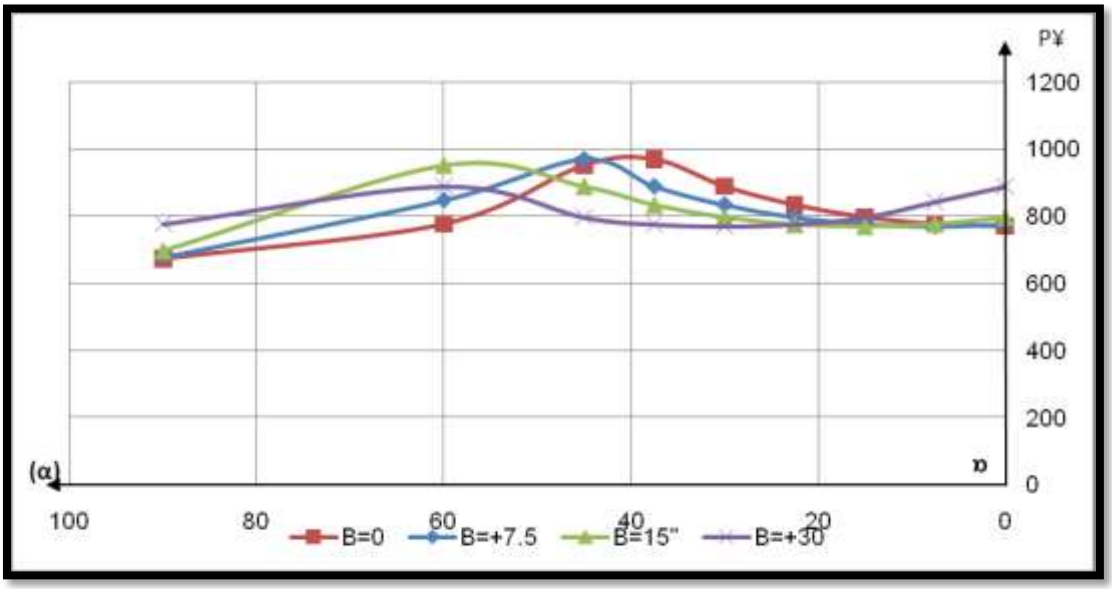

Figure (10): Inclination of Up-lift load (V_S) uplift resistance for positive batter pile with deferent pile inclination (β).

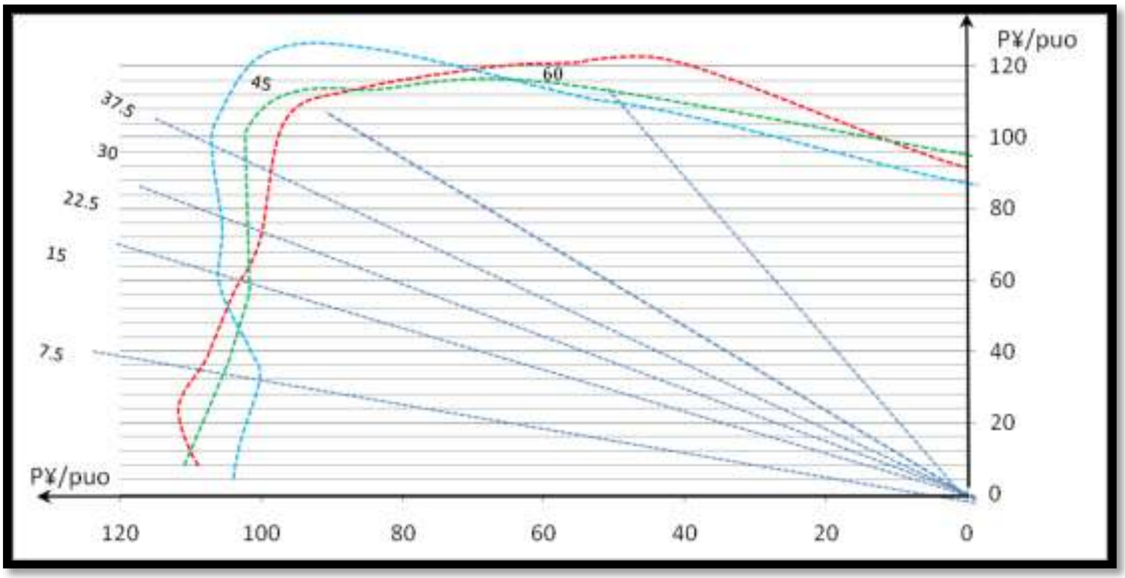

Figure (11): Relative uplift resistance (V_S) inclination of up-lift load (α) for positive batter pile (+β).

3- Negative batter pile (-β)

Table (6): Results of inclination of up-lift load (V_S) uplift resistance for negative batter pile with deferent pile inclination (β)

***β*= 0**									
α	0	7.5	15	22.5	30	37.5	45	60	90
¥	0	7.5	15	22.5	30	37.5	45	60	90
P ¥ 1	770	777	797	834	889	970	1090	1540	
P ¥ 2	0	5156	2600	1759	1346	1059	952	777	673
P ¥	770	777	797	834	889	970	952	777	673
P¥/Puo %	100	100.8	103.5	108.5	115.4	126	123.6	100.9	88
***β*= -7.5**									
α	0	7.5	15	22.5	30	37.5	45	60	90
¥	7.5	15	22.5	30	37.5	45	52.5	67.5	97.5
P ¥ 1	676	797	834	898	970	1090	1265	2012	2975
P ¥ 2	5165	2600	1759	1346	1055	952	848	730	678
P ¥	676	767	834	898	970	952	848	730	678
P¥/Puo %	100.8	103.5	108.5	115.5	126	123	110	95	89
***β*= -15**									
α	0	7.5	15	22.5	30	37.5	45	60	90
P ¥ 1	797	834	899	970	1090	1265	1540	2975	2975
P ¥ 2	2600	1759	1364	1055	952	848	777	696	696
P ¥	797	834	899	970	952	848	777	696	696
P¥/Puo %	103.5	108.5	115.5	126	123.5	110	101	90	90
***β*= -30**									
α	0	7.5	15	22.5	30	37.5	45	60	90
¥	30	37.5	45	52.5	60	67.5	75	90	120
P ¥ 1	899	970	1090	1265	1540	2012	2975	0	1540
P ¥ 2	1346	1055	925	848	777	730	696	673	777
P ¥	899	970	925	848	777	730	696	673	777
P¥/Puo %	115.4	126	123.6	110	101	95	90	87	101

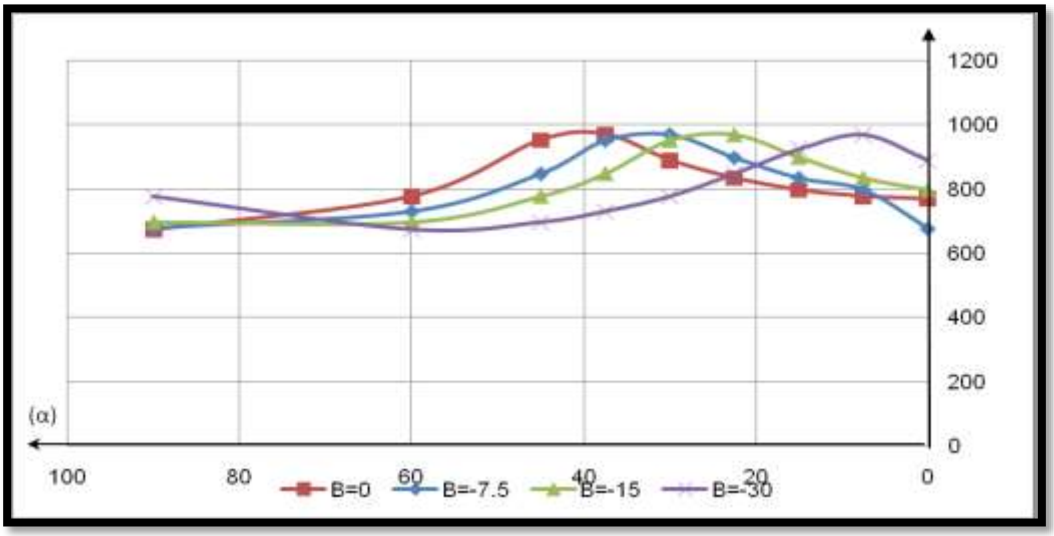

Figure (12): Inclination of up-lift load (V_S) uplift resistance for negative batter pile with deferent pile inclination (β).

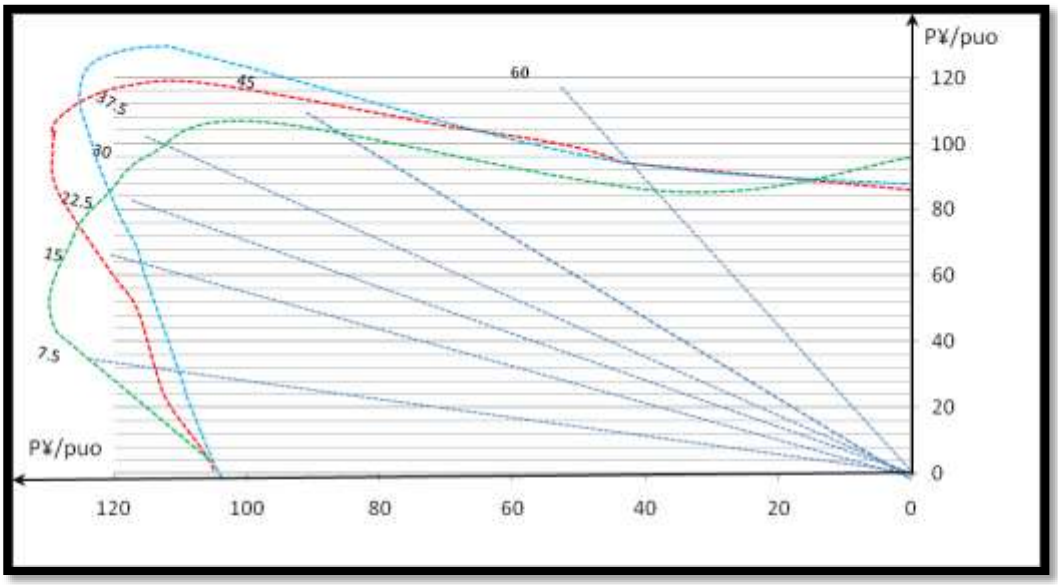

Figure (13): Relative uplift resistance (V_S) inclination of up-lift load (α) negative batter pile (-β).

Conclusion

Based on the objective results collected throughout these studies the following conclusion can be recorded:

a-Piles under compressive load :

1- Figure (1) show the types of pile according to the load and pile inclination condition, the highest ultimate compressive load of vertical single pile accrued at (α=22.5°), and these result is similar to that obtained by (Betrosovit & Award) [5]also as shown in figure(3).
2- For positive batter pile, the height ultimate compressive load accrued at (α=22.5+β).and for the same inclination condition, batter pile decrees the compressive load and that true for small inclination (<22.5) and then the compressive load increase with increasing load inclination (α), and the value of compressive load is greater than values obtained for the vertical pile subjected to compressive load under the same condition of inclination . as shown in figures (4) and (5)
3- For the negative batter piles the highest ultimate compressive load accrued under vertical load and decreased with increasing load inclination. See figure (7), bearing capacity of vertical piles varies as an elliptic shape.
4- The greater axial compressive load accrued at (β=15) see Figure (6) , and At small inclination (α)with the vertical negative batter pile has greater ultimate compressive load than that of positive batter pile, the trend is changed at inclination (>22.5). See Fig (5) & Fig (7).

b- Piles under Up-lift load :

1- The uplift capacity of vertical pile and inclined batter pile under vertical and inclined pulls load increase with increasing the load inclination angle (α) until reaching the maximum value and then the uplift capacity decrees with increasing the inclination of pull. see figure (11) &figure (13).
2- Vertical pile has ultimate load greater than batter pile , that's true for large pull inclination (>37.5)and positive batter pile . See figure (11) &figure (13).
3- The highest ultimate uplift capacity occurred at angle equal to (37.5-β) and that is compatible for all cases of load inclination.
4- Positive batter pile (+β), has smaller uplift capacity as comparing with the negative batter pile under the same condition of pull. , and the highest ultimate capacity occurred at angle equal to (37.5) for vertical pile and at angle equal to (37.5-β) for inclined pile (batter pile) with
angle of inclination with the vertical equal to (β).

Recommendation:

Many factors could be investigated to get clear pictures about the behavior of piles under inclined load and batter pile:
1- The influence of spacing could also be investigated with various combination of vertical and batter pile.

2- The behavior of pile with varying depth embedded.
3- Single flexible piles under inclined load could be studied.
4- Field tests must be carried out in order to compare the model tests results.

Notification:
α= angle of inclination of load with the vertical.
β= angle of inclination of pile with the vertical (pile batter angle).
¥= equivalent angle of load inclination.
D= diameter of pile.
L= length of pile
e = eccentricity above ground level.
Puo= ultimate vertical compressive load of single pile.
Hu = ultimate horizontal load of vertical pile.
Pu¥= ultimate inclined compressive load or up-lift load for batter pile.
Ø = angle of internal friction of soil.
puα/puo= Relative bearing capacity .

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