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Effect of Seismic Loading on Variation of Pore Water Pressure During Pile Pull-Out Tests in Sandy Soils

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ABSTRACT

Experimental model was done for pile model of L / D = 25 installed into a laminar shear box contains different saturation soil densities (loose and dense sand) to evaluate the variation of pore water pressure before and after apply seismic loading. Two pore water pressure transducers placed at position near the middle and bottom of pile model to evaluate the pore water pressure during pullout tests. Seismic loading applied by uniaxial shaking table device, while the pullout tests were conducted through pullout device. The results of changing pore water pressure showed that the variation of pore water pressure near the bottom of pile is more than variation near the middle of pile in all tests. The variation of pore water pressure after apply seismic loading is more than the variation before apply seismic loading near the middle of pile and near the bottom of pile and in loose and dense sand. Variation of pore water pressure after apply seismic loading and uplift force is less than the variation after apply seismic loading in loose sand at middle and bottom of pile.

Keywords: Seismic, Pore water pressure, Pull-out test.

تأثير احمال زلزال حلبجة على قابلية تحمل السحب لموديل ركيزة مثبته في تربة رملية مشبعة

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الخلاصة

تم عمل نموذج تجريبي لنموذج ركيزة ذات L/D= 25 مثبته في صندوق القص الطباقي الذي يحتوي على تربة رملية و لكثافات تشبع مختلفة (رمل متخلخل وكثيف) لإيجاد تغيير ضغط ماء المسام قبل وبعد تسليط التحميل الزلزالي. تم وضع اثنين من متحسسات ضغط الماء في موضع بالقرب من منتصف وأسفل نموذج الركيزة لإيجاد ضغط ماء المسام أثناء اختبارات الانسحاب.

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تم تطبيق التحميل الزلزالي بواسطة جهاز المنضدة الهزازة أحادي المحور بينما تم إجراء اختبارات الانسحاب من خلال جهاز السحب.اضهرت نتائج تغيير ضغط ماء المسام أن تباين ضغط الماء المسامي بالقرب من اسفل الركيزة كان اكثر من منتصف الركيزة في جميع الاختبارات. تباين ضغط ماء المسام بعد تسليط التحميل الزلزالي أكثر من التباين قبل تسليط التحميل الزلزالي. تباين ضغط ماء المسام بعد تطبيق التحميل الزلزالي وقوة السحب على الركيزة أقل من التباين بعد تطبيق التحميل الزلزالي في التربة الرملية المتخلخلة في وسط وأسفل .

الكلمات الرئيسية: الزلازل, ضغط ماء المسام, فحص السحب.

1. INTRODUCTION

Structures foundation like retaining walls, transmission towers, tall chimneys, off shore structures are subjected to tension loads **(Shelke and Patra, 2009), (Deshmukh, et al., 2010)** & **(Vanitha, et al., 2007).** Like these structures, the overturning moments are move out to the piles of the structure and piles becomes under two types of loads compression in some piles and tension on others. Earthquakes are wide-banded ground seismic movement, resulting from many types of causes such landslides, volcanism, tectonic motions, man-made explosions, and rock bursts. Of these, the tectonic-related earthquakes are the largest and most important **(Chen and Lui, 2006).** A major 7.3 magnitude earthquake hit the Iran- Iraq border during November 2017, injuring thousands and 530 people was killed in Iran alone. 550 were injured and nine people were killed in Iraq, all in the Kurdistan region (north of Iraq), according to the United Nations **(Al-Taie and Albusoda, 2019).** Many numerical, experimental and theoretical researches were done on determining the capacity of piles subjected to tension loads. few study like **(O'Neill,, et al., 1990)** have been performed under the influence of seismic. This experimental research devoted to determining the variation of pore water pressure during pile pullout tests before and after apply seismic loading.

2. EXPERIMENTAL WORK

The sand used in the tests was air-dried, crumbled and sieved on sieve #10 (2 mm), then filled in the LSB. LSB was filled with sand by raining technique with tamping in layers. The layers above the filter divided into six layers and the thickness of each sand layer was 10 cm for loose and dense sand. The experimental tests were conducted on pile model with length 450 mm and diameter 18mm (L/D= 25) installed in saturated sand soil. Pore water pressure transducers (PWPT) were placed into two positioned as shown in **Fig. (1).** First PWPT at position near the middle of pile (MOP) at a depth 0.225 m and the second PWPT at position near the bottom of pile (BOP) at a level of 0.45 m below the surface and at 2cm beside the pile model.

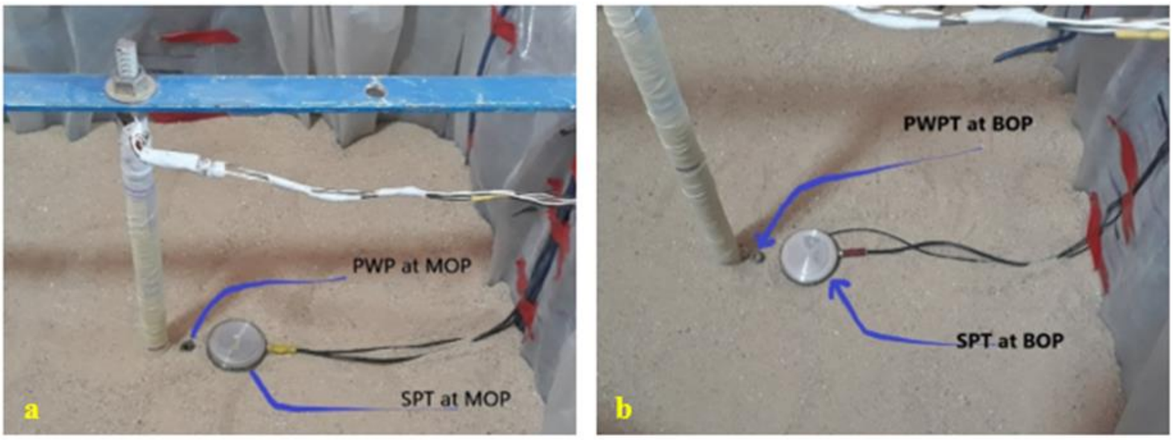

Figure 1. (a)The PWPT at the MOP, (b)The PWPT at the BOP.

3. SHAKING TABLE –PULLOUT DEVICES SYSTEM

In the present study, a shaking table – pullout devices system as shown in **Fig.(2)** was manufactured to represent the pile –soil model under many cases included effect of tension and seismic loads on piles in dense and loose sandy soil. The system consists of following devices :

1. DIGITAL DATA ACQUISITION.
2. UPLIFT DEVICE.
3. LAMINAR SHEAR BOX (LSB).
4. SOIL SATURATION SYSTEM.
5. SHAKING TABLE DEVICE:

Figure 2. Shaking Table –Pullout Devices System.

4. HALABJAH EARTHQUAKE

The earthquake of Halabjah was chosen for the research which was the highest earthquakes occurred through the last years in IRAN-IRAN border. Real earthquake acceleration histories data of Halabjah earthquake was implemented to study the effects of acceleration characteristics on the required different parameters, real acceleration histories for Halabjah was utilized as shown in **Fig. 3**. **Table (1)** presents the data of the Halabjah earthquake.

Table 1. Data of Halabjah earthquake **(Al-Ghanim, 2019).**

Earthquake	Halabjah
Date (UTC)	12/11/2017
Position	Iran-Iraq border
Depth of epicenter, (Km)	19
Magnitude, (M)	7.3 M_W
Acceleration direction	E-W
Station code	BHD
Station distance to epicenter, (Km)	218.8
Duration, (sec)	300
Maximum acceleration, (g)	0.16

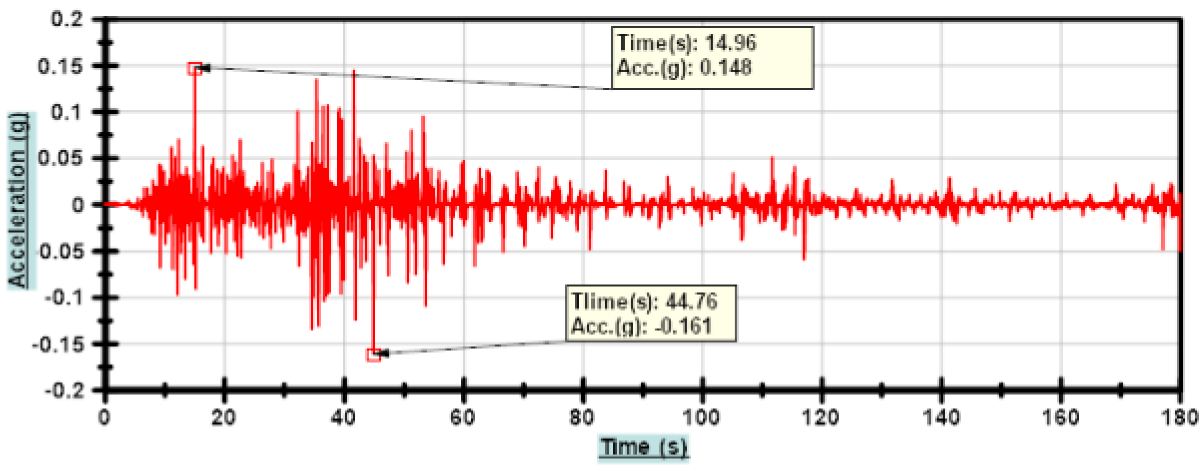

Figure 3. Time versus acceleration for earthquake of Halabjah according to **(Al-Ghanim, 2019).**

5. PROPERTIES OF SOIL USED

Several tests on the soil used were conducted to get it its properties. The soil used in this study were bring out from Karbala governorate. The sieve analysis curve for backfill soil as shown in **Fig.4**. According to the Unified Soil Classification System, the soil is classified as poorly graded sand (SP). **Table 2** show the chemical and physical properties of the sandy soil**.**

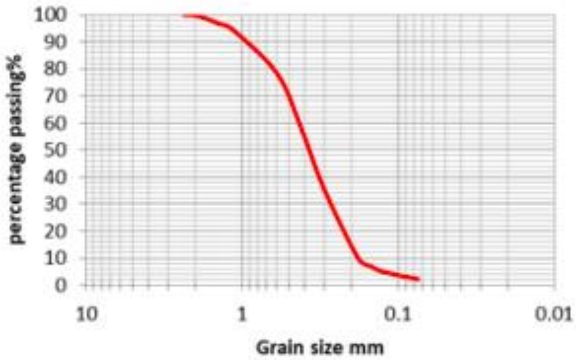

Figure 4. Sieve analysis of the sandy soil.

Table 2. Chemical and Physical Properties of the sandy soil.

Property of Soil	Loose Sandy	Dense Sandy	Test Standard
γ_d (kN/m^3) (Dry Unit Weight)	15.92	16.83	-
γ_{max} (kN/m^3) (Max. Unit Weight)	17.7		ASTM D 4253 (2000)
γ_{min} (kN/m^3) (Min. Unit Weight)	15.1		ASTM D 4254 (2000)
W_c (%) (Water Content)	22	18	ASTM D2216 (2010)
γ_t (kN/m^3) (Total Unit Weight)	19.43	19.94	-
D_r (%) (Relative Density)	35	70	-
e_{max} (Maximum Void Ratio)	0.69		-
e_{min} (Minimum Void Ratio)	0.44		-
e (Void Ratio)	0.6	0.52	
G_s (Specific Gravity)	2.60		ASTM D854 (2014)
Sand %	98		ASTM D422 (2007)
Coarse sand%	0.2		
Medium sand%	40.9		
Fine sand%	56.9		
D_{60}	0.425 mm		
D_{50}	0.390 mm		
D_{30}	0.285 mm		
Effective Size, D_{10}	0.185 mm		
Coefficient of Curvature, Cc	1.033		
Coefficient of Uniformity, C_u	2.297		
Classification of Soil	Poorly-graded sand ,(SP)		ASTM D2487 (2010)
Coefficient of Permeability, $k_{(cm/sec)}$	2.54×10^{-3}	1.38×10^{-3}	ASTM D2434 (2006)
Angle of Friction, Ø	32°	38°	ASTM D4767 (2011)
SO_3, %	1.6		BS-1377 (1967)
Gypsum %	1.59		

6. RESULTS AND DISCUSSIONS

Results of variations of PWPS values during pull-out tests in dense and loose soils for pile with L/D=25 divided into three parts, variation of PWP values before shaking test, variation of PWP values after applying seismic loading (ASL) and variation of PWP values after subjected combined loading (ACL) as follow below:

6.1 VARIATION OF PWP DURING PULL-OUT TEST IN SATURATION LOOSE SAND SOIL BEFORE AND AFTER SHAKING TABLE TESTS

Figs. (5 and 6) shows the PWP variation during pullout test in loose sand soil near (MOP) and (BOP) before apply seismic loading as relationship between PWP in kPa and time of pullout test in second. **Fig. (5)** shows that PWP at start of test in loose sand is equal to 2.27 kPa at position near the (MOP), and at the position near the (BOP) is equal to 4.55 kPa as shown in **Fig. (6)**. These values changed during pullout test, at (MOP) it increased to 2.44 kPa then dropped to 1.71 kPa and after the test finished it reached to near value at start of the test, while in (BOP) the PWP decreased from 4.55 kPa to 2.57 kPa and then reached to start value. Changing of PWP at maximum pull out load for (BOP) was -1.98 kPa and for the (MOP) was -0.56 kPa.

The results indicate that during pull out test of pile in loose sand the PWP decreased at MOP and BOP and the changing at the BOP was more than at MOP and at BOP occurred first.

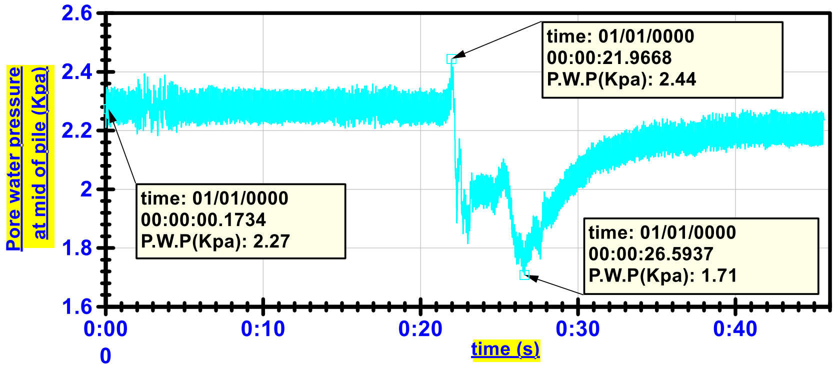

Figure 5. values of PWP at **(**MOP) during pullout tests for Pile of L/D=25 in loose sand saturation.

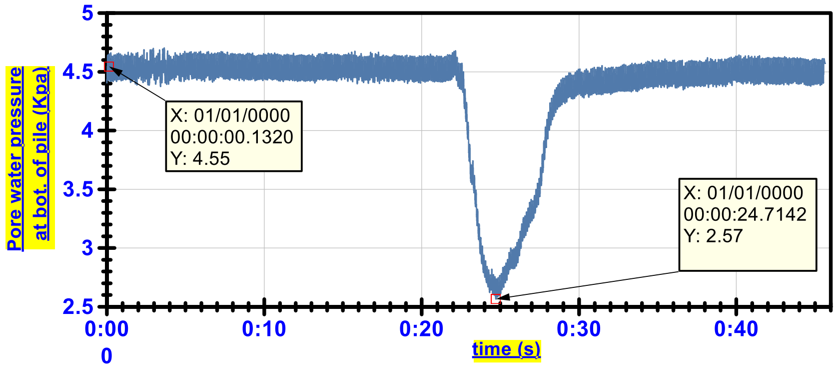

Figure 6. values of PWP at (BOP) during pullout tests for Pile of L/D=25 in loose sand saturation .

Figs. (7 and 8) shows the variation of PWP with time at **(MOP)** and **(BOP)** in loose sand after **ASL**. PWP at MOP was varition from 2.05 kPa at start of test to 1.34 kPa at time 63.794 sec. and decreased from 4.18 kPa to 2.12 kPa at BOP at 61.9303 sec. The varition at MOP was -0.71 kPa while at BOP was -2.06 kPa.Results indicate that variation of PWP at BOP was more pronounced than MOP and the variation occurred first. Also PWP is decreased during pullout test and the decreasing at BOP is more than at MOB. decreasing after ASL is more than before ASL at MOPand BOP.

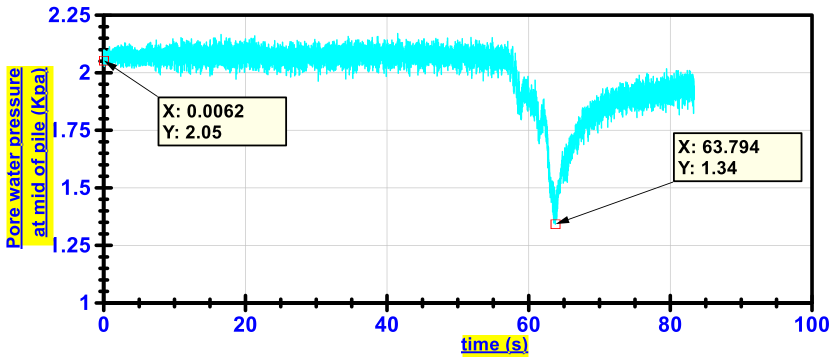

Figure 7. Values of PWP at MOP during pullout test after ASL for pile of L/D=25 in loose sand saturation.

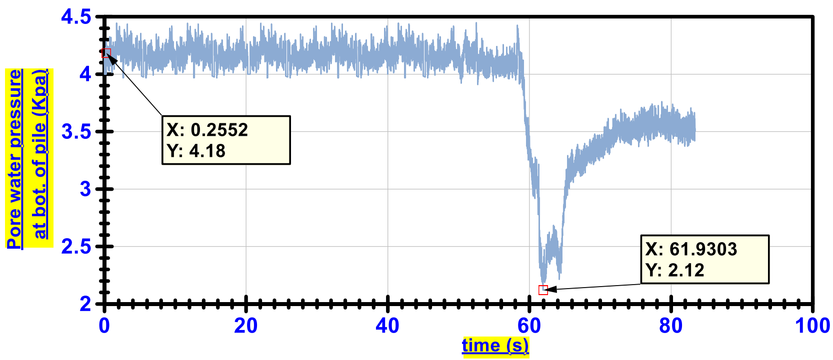

Figure 8. Values of PWP at BOP during pullout test after ASL for pile of L/D=25 in loose sand saturation.

Figs. (9 and 10) show the results of variation of PWP at MOP and BOP during pullout test after ACL in loose sand. PWP at MOP was 2.2 kPa at start of test, increased to 2.24, drop to 1.84 kPa at failure due to pullout the pile then increased to 2.11 kPa. While the PWP at BOP was 4.42 kPa at start of test, increased to 4.45 kPa, drop to 3.71 kPa at failuer then return to same value at start of test. The variation at MOP was -0.36 kPa and at BOP was -0.71 kPa which means that variation at BOP was greater than MOP and it occur first. In this case the varition is less than the case after ASL.

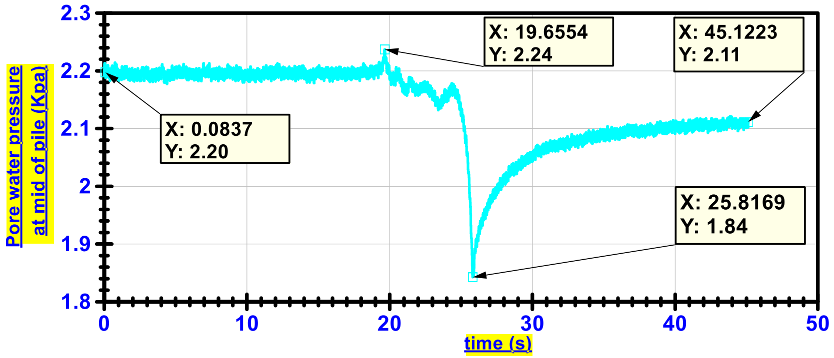

Figure 9. Values of PWP at MOP during pullout test after ACL for pile of L/D=25 in loose sand saturation.

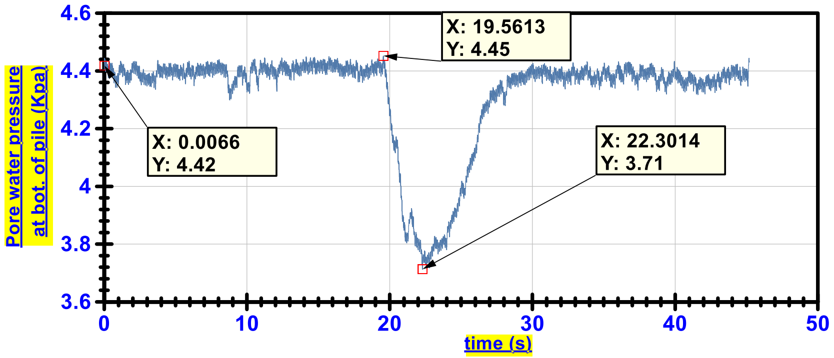

Figure 10. Values of PWP at BOP during pullout test after ACL for pile of L/D=25 in loose sand saturation.

6.2 VARIATION OF PWP DURING PULL-OUT TEST IN SATURATION DENSE SAND SOIL BEFORE AND AFTER SHAKING TABLE TESTS

Figure (11 and 12) shows the PWP variation during pullout test in dense sand soil near (MOP) and (BOP) before apply seismic loading as relationship between PWP in kPa and time of pullout test in second. **Figure (11)** shows that PWP at start of test in dense sand is equal to 2.21 kPa at position near the (MOP), and at the position near the (BOP) is equal to 4.41 kPa as shown in **Figure (12)**. These values changed during pullout test, at (MOP) it was dropped from 2.21 to 1.57 kPa then reached to near value at the start of test, while in (BOP) the PWP decreased from 4.41 kPa to 3.68 kPa and then reached to near the start value. Changing of PWP at failure at (BOP) was -0.73 kPa and at the (MOP) was -0.64 kPa. The results indicate that during pull out test of pile in dense sand, the PWP decreased in MOP and BOP and the changing at the BOP was more than at MOP and in BOP the variation occurred first. PWP is decreased during pullout test before shaking tests in loose and dense sand soil and at MOP and BOP. PWP change occurred first at BOP and PWP at BOP was greater than PWP at MOP.

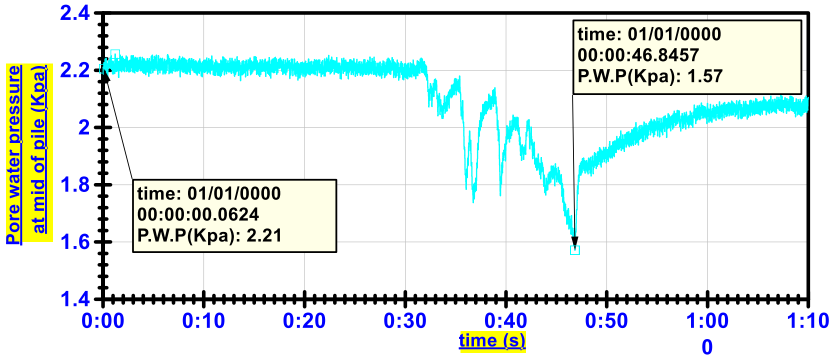

Figure 11. variation of PWP at (MOP) for Pile of L/D=25
in saturation dense sand during pullout test.

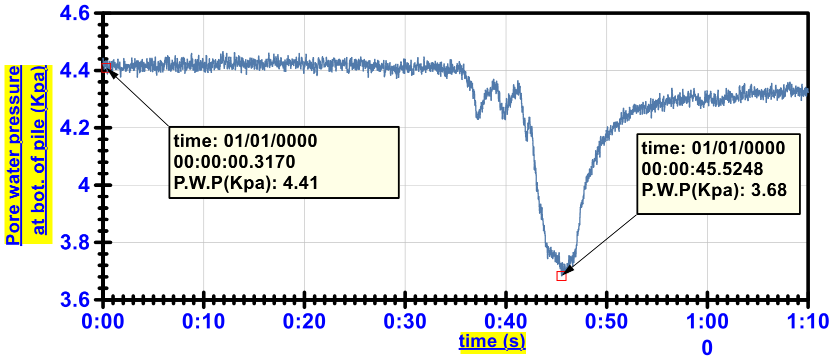

Figure 12. Variation of PWP at (BOP) for Pile of L/D=25
in saturation dense sand during pullout test.

Figs. (13 and 14) shows the variation of PWP with time at **(MOP)** and **(BOP)** in dense sand after ASL. PWP at MOP was varition from 2.16 kPa at start of test to 1.16 kPa at time 59.7746 sec. and decreased from 4.41 kPa to 2.41 kPa at BOP at 56.7683 sec. The varition at MOP was –1.00 kPa while at BOP was -2.00 kPa.

Results indicate that PWP is decrease during pullout test at MOP and BOP and the variation of PWP at BOP was greater than MOP and it occuerred first. Also, decreasing after ASL is more than before ASL in MOP and BOP.

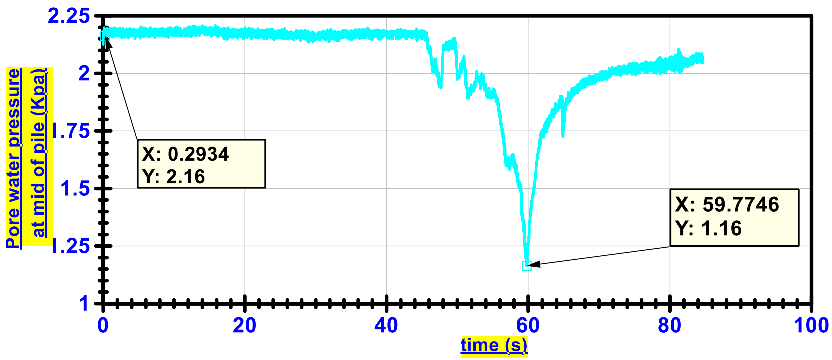

Figure 13. Variation of PWP at MOP during pullout test after ASL
for pile (L/D=25) in saturation dense sand.

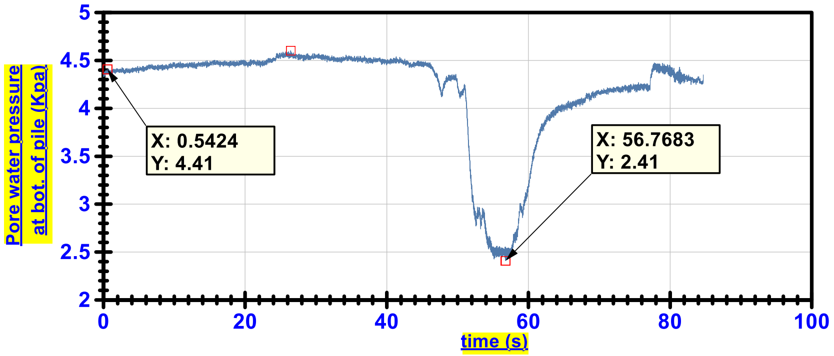

Figure 14. Variation of PWP at BOP during pullout test after ASL for pile (L/D=25) in saturation dense sand .

Figs. (15 and 16) shows the results of varition of PWP at MOP and BOP during pullout test after ACL in dense sand. PWP at MOP was 2.21 kPa at start of test, increased to 2.27, drop to 0.77 kPa at failure due to pullout the pile then increased to 1.97 kPa. While the PWP at BOP was 4.35 at start of test, drop to 2.42 kPa at failuer then increased to 4.06 kPa as shows n in **Fig.(15)**.
The variation at MOP was –1.44 kPa (decrease PWP) and at BOP was -1.93 kPa which means that variation at BOP was greater than MOP and it occuer first.The variation at MOP after ACL is more than after ASL while the variation at BOP is approximate equal for ASL and ACL**.**

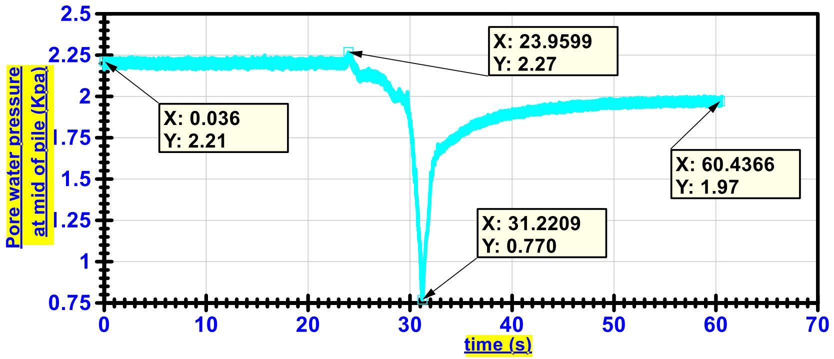

Figure 15. Variation of PWP at MOP during pullout test after ACL for pile L/D=25 in saturation dense sand .

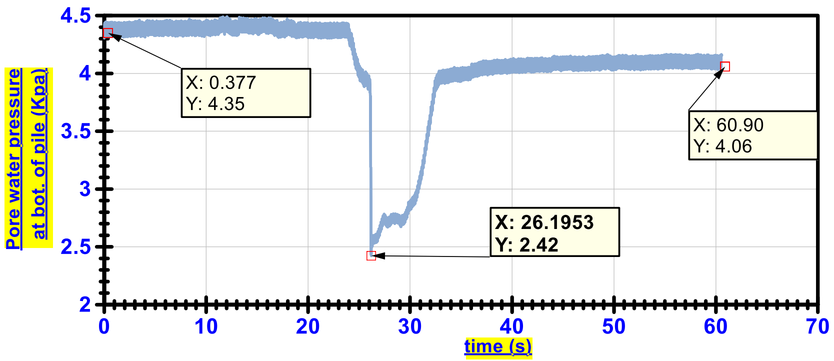

Figure 16. Variation of PWP at BOP during pullout test after ACL for pile L/D=25 in saturation dense sand.

7. CONCLUSIONS

Results of changing PWP during pullout tests for pile of L/d=25 installed in saturation loose and dense sand before and after shaking table tests are collected in **Table (3)**, the results shows the following indications:

1. The variation of PWP near the BOP is more than variation at MOP in all tests.
2. Variation PWP after ASL is more than variation before ASL in MOP and BOP and in loose and dense sand.
3. Variation after ACL is more than the variation before ACL in dense sand, while the variation in loose sand is less after ACL in MOP and BOP.
4. Variation of PWP after ACL is less than the variation after ASL in loose sand at MOP and BOP
5. Variation of PWP in dense sand after ACL is more in MOP and less in BOP.

Table 3. PWP value in kPa during pullout tests at MOP and BOP for loose and dense sand soils

		MOP			BOP		
		start	Maximum PWP at failure	difference	start	Maximum PWP at failure	difference
Loose sand	Before	2.27	1.71	-0.56	4.55	2.57	-1.98
	ASL	2.05	1.34	-0.71	4.18	2.12	-2.06
	ACL	2.20	1.84	-0.36	4.42	3.71	-0.71
Dense sand	Before	2.21	1.57	-0.64	4.41	3.68	-0.73
	ASL	2.16	1.16	-1.00	4.41	2.41	-2.00
	ACL	2.21	0.77	-1.44	4.35	2.42	-1.93

8. ACKNOWLEDGEMENTS

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