Effect of Using Equivalent Driving Energy on Small Model Driven Pile Capacity

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ABSTRACT

Physical modeling is performed in order to study particular cases of the behavior of prototype and to validate theoretical and/or empirical hypotheses.

However, most physical models will be constructed at much smaller scales than the prototype precisely because it is desired to obtain information about expected patterns of response more rapidly and with closer control over model details than would be possible with full-scale testing.

The main problem associated with physical model tests is the stress levels and soil particle size effects. These points should be considered which require deep and thorough research when studying the behavior of small scale model piles in sand. The tests indicate that the number of blows recorded when driving the model pile is affected by pile diameter more than with pile length. As well as, the heavier hammer shows precedence in bearing capacity than the light hammer because it leads to upgrade the soil properties during pile driving.

Keywords: Physical modeling, Driven pile, Stress level.

تأثير أستخدام طاقة الدق المكافئة على تحمل موديلات مصغرة من ركائز الدق

الخلاصة

النمذجة الفيزيائية تنجز لغرض دراسة الجوانب العملية لتصرف النموذج الأصلي ولتأييد الفرضيات النظرية او التجريبية. مع ذلك, أغلب النماذج الفيزيائية سوف تبنى بواسطة مقاييس أكثر صغراً من النموذج الأصلي وبشكل دقيق لأنه مطلوب الحصول على معلومات عن أنماط أستجابة متوقعة بسرعة وبتحكم خلال تفاصيل النموذج على أن يكون ممكناً مع فحص النموذج الكامل.

المشكلة الرئيسية المصاحبة لنتائج الموديلات الفيزيائية هي تأثير مستويات الأجهاد وحجم حبيبات التربة. هذه النقاط يجب ان تؤخذ بنظرالأعتبار والتي تتطلب بحث عميق وشامل عند دراسة نماذج الركائز المصغرة في الرمل. الفحوصات تشير إلى إنه عدد الضربات المسجلة عند دق نموذج الركيزة يتأثر بالقطر أكثر من طول الركيزة. أيضا, تظهر المطرقة الأثقل أفضلية عن المطرقة الأخف في قابلية التحمل لأنها تؤدي إلى تحسين خواص التربة أثناء دق الركيزة.

INTRDUCTION

In scaling effect topics, the stress level and soil particles size can be considered as the most important factors affecting the model behavior. Yet, there are no clear explanations of models behavior comparing with the prototype behavior; this is may be referred to the difficulties associated with the representation of the whole model conditions in laboratory.

Points to be Considered in Model Pile Test

The following points must be taken into consideration in model pile tested inside a container:

- ► Effect of sides of container walls may strongly reduce the vertical stress with depth, to avoid side friction of walls; the ratio of the container height to the diameter must be equal or less than one (Tarnet 1999, Garnier 2001).
- ► Effect of horizontal deflection of the container wall should be less than (H_c/2000) to keep K_o close to its assumed value for no lateral strain (Tarnet 1999), where H_c represents height of the container.
- ► To avoid effect of tip resistance on diameter/width of the container, the ratio of the diameter of container to diameter of the model pile should be larger than 30 in sand (Bolton et.al., 1999).
- ► In shallow foundations, sand thickness of 3B below the footing is adequate in eliminating any rigid bottom boundary effect (Cerato, 2005).
- ► To eliminate any rigid boundary resulting from pile driving in loose sand, the bulb of stress around pile is about (7D), this distance should be considered in design (Kishida, 1967).

Effect of Pile Dimensions on the Bearing Capacity

Meyerhof (1983) concluded that the ultimate end bearing for piles in sand tends to be less for larger diameter driven piles, this state may be attributed to the decrease in reduction factor of ultimate point resistance when the pile diameter increase. The reduction in end bearing capacity has been related to the decrease in the angle of internal friction with larger diameter.

So (1991) suggested that the dilation and hence the shaft resistance of a small-diameter (model) will be greater than of large-diameter pile.

Effect of Soil Particles Size

Scale effects may be observed in a small-scale footing test and it is related to the assumed shear zone formation in the active region directly beneath the footing.

Scarpelli and Wood, (1982); Muir Wood, (2004) noticed the phenomenon of shear zone in direct shear box. Shear zone is a group of shear bands formed in the shear surface. ***Shear bands*** are defined as narrow regions of intensely sheared material. The bigger the box, the larger the horizontal shear ruptures, the more room the soil particles have to rearrange and more room for shear zone to fully develop to a critical state.

Essentially, the shear zone has room to fully propagate in a larger shear box and is therefore a more realistic representation of the strength found in field conditions (shear bands developed have an inverse proportion with the angle of internal friction).

Behavior of Driven Piles in Sandy Soils

When a pile is driven into sand and other cohesionless soils, the soil is usually compacted by displacement and vibration, resulting in rearrangement and some crushing of the particles. The driving of pile is associated with moving large amounts of sand in vertical and radial direction. The vibrations resulted from driving a pile in sand have two effects densifying the sand (increase angle of internal friction) and increasing the value of lateral earth pressure around the pile.

In loose sand, the pile capacity is increased as a result of the increasing the relative density caused by driving. The compaction of sand extends to the surrounding soils and the increase in relative density around the pile has been presented by Robinsky and Morrison (1964).

Kishida (1967) proposed a simple method of estimating the effects of driving in loose sand in vicinity of the tip; it was assumed that the diameter of the compacted zone around a pile is 7 times the diameter and angle of internal friction changes linearly with distance from the original value of ϕ_1 at a radius (r = 3.5D) to a maximum value of ϕ_2 at the pile tip. The relationship between ϕ_2 and ϕ_1 is taken to be as:-

$$\phi_2 = (\phi_1 + 40)/2 \quad \dots (1)$$

Where:

(ϕ_1 and ϕ_2) = angle of internal friction before and after driving process.

The driving process imposes three types of motion on the soil around a pile firstly, relatively large magnitude vertical shearing along the pile shaft, secondly vibration of the soil due to the hammer blow, and radial compression of the soil around the pile.

When piles are driven into relatively dense sand, whose possess tendency to dilate, the dilation generates large normal stress against the pile shaft, after installation shearing develops between the pile shaft and the soil. Dilative sand will generate additional normal compressive stresses against pile shaft. As a result, k can be significantly greater than k_o for very dense sand (Salgado, 2006).

EXPERIMENTAL WORK

Material used and soil characterization

Karbala sand was used in present study. Standard tests were performed to determine the physical properties of the sand. The details of these properties are listed in Table (1).

Model piles details

Steel solid piles covered with cement mortar with specific weight of (7.75gm/cm^3) and modulus of elasticity of (1.85×10^8 kPa) (Murphy, 1950) are used. All details are shown in Figure (1).

Model setup formulation

To simulate the pile load test in the field, a new apparatus was manufactured and described as the following:

Description of setup

Steel container is used to host the bed of soil. It was made from five separated parts. The internal dimensions of the container are (75×75×75) cm. Each part from the container is made of (6 mm) thick steel plate. A steel base was made to support the container and the loading frame weight. The axial load is applied through a hydraulic jack system.

The maximum load that can be applied is about (10 ton) according to hydraulic jack catalogue. The bed of soil is prepared with a dry unit weight of 16.5 kN/m^3 at a height of drop equal to 20 cm using the raining technique.

The driving system consists of a base plate with (86cm × 20cm) and 20mm in thickness. This plate involves three holes manufactured to be considered as focus place to penetrate the piles in the box. The steel helmet was manufactured with different grooves that are suitable for all model piles sizes that are used in the tests.

These grooves are designed to make sure the fixity of piles and as possible to reserve the vertical direction for pile penetration without tilting during the driving process. Details of setup and pile driving hammer device are shown in Figures (2 and 3).

ANALYSIS AND DISCUSSION OF TEST RESULTS

This study involves four models of driven piles tested to assess the effect of equivalent energy equal to (W=2.175kg × H=5.3cm) instead of (W=1.4kg × H=8cm). For this group the model piles used in the test are (D=2.1cm, L=40cm, circular), (B=1.6cm, L=50cm, square), and (B/D=2.1cm, L=50cm) of square and circular shapes.

The piles are embedded in sandy layer with different lengths and diameters/widths. Piles with square and circular cross-sections under the effect of vertical static compression loads are tested.For all model tests, the failure criterion adopted is that proposed by Terzaghi (1943) by which the failure load is defined as the load required to cause a settlement corresponding to 10% of the footing or pile width. Summary of test results is shown in Table (2).

The test results show noticeable convergence in penetration values for piles driven using equivalent energies.

Figures (4) to (7) show the behavior of model piles driven by heavy and light hammers (keeping energy constant), from which it can be noted that using heavy hammer improves soil compaction and leads to improve model pile capacity to a certain extent compared with model piles driven with light hammer.

Since, the impact velocity is independent of the mass of hammer and function of gravity and height of fall, $v=\sqrt{2gh}$ where (v) is impact velocity of hammer and (h) is falling height; thus, if the piles are driven by light hammer the force generated in the pile overcoming the soil resistance will be larger but the light hammer generated shorter stress wave which may decay faster than the heavier hammer; therefore, the light hammer is probably unable to drive the long piles as the heavy hammer can.

CONCLUSIONS

Based on analysis of the 8 model piles tests performed as driven piles, the following conclusions can be drawn:

1. When two piles are driven with same equivalent energy, the heavier hammer shows precedence in bearing capacity because the energy generated by the light hammer may decay faster during the driving process as well as effect of P/W ratio.
2. If two piles of the same total areas (bearing and surface area) are driven by constant driving energy, the pile with larger diameter gives higher bearing capacity.
3. The number of blows has pronounced effect on pile diameter as compared to pile length, in case two piles have same total areas are driven by the same constant driving energy.

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Table (1) Physical properties of the sand used in present tests.

No.	Index property	value
1	Specific gravity (G_s)	2.66
2	D_{10} (mm)	0.148
3	D_{30} (mm)	0.35
4	D_{60} (mm)	0.58
5	Coefficient of uniformity (C_u)	3.92
6	Coefficient of curvature (C_c)	1.43
7	Maximum dry unit weight (kN/m^3)	19
8	Minimum dry unit weight (kN/m^3)	15.6
9	Dry unit weight (kN/m^3) at R.D = 31%	16.5
10	Relative density (R.D %)	31
11	Angle of internal friction (ϕ) at R.D =31%	35°
12	Soil classification (USCS)	SP

Table (2) The results of model pile capacities using equivalent energy.

B/D (cm)	L (cm)	Q_{ult} (N)	Q_{ult} (N)	Set mm/blow	Set mm/blow	Pile shape
		W=1.45kg H=8cm	W=2.17kg H=5.33cm	W=1.45kg H=8cm	W=2.17kg H=5.33cm	
2.1	40	179	173	2.85	3.33	Circular
2.1	50	205	250	2.2	2.2	Circular
1.6	50	152	160	4	3.3	Square
2.1	50	304	320	1.33	1.6	Square

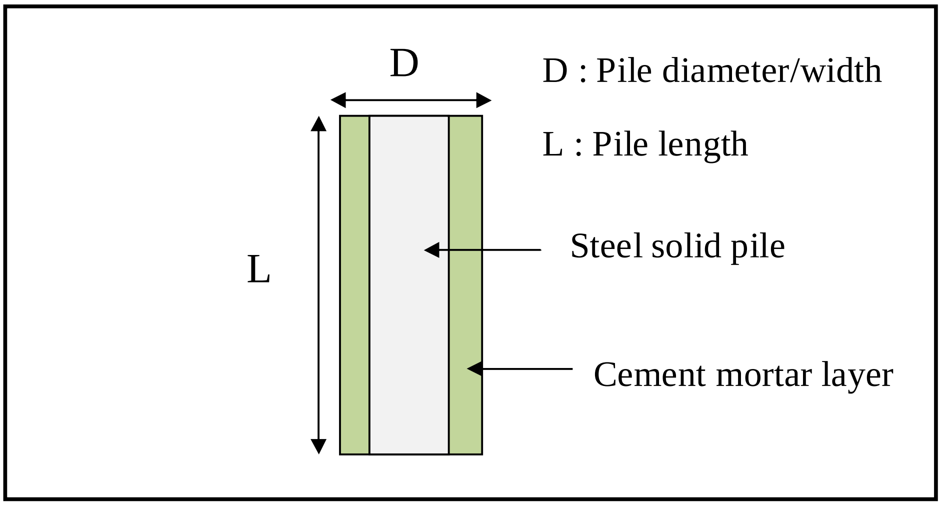

Figure (1) Details of model pile used in the present study.

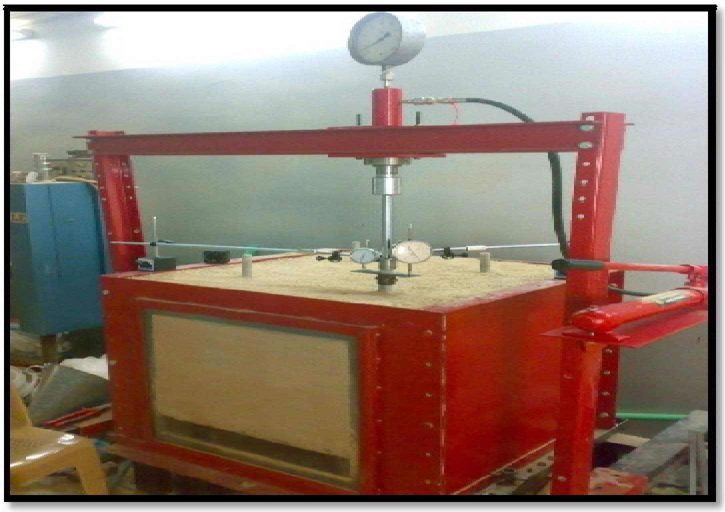

Figure (2) Setup formulation simulated to pile load test.

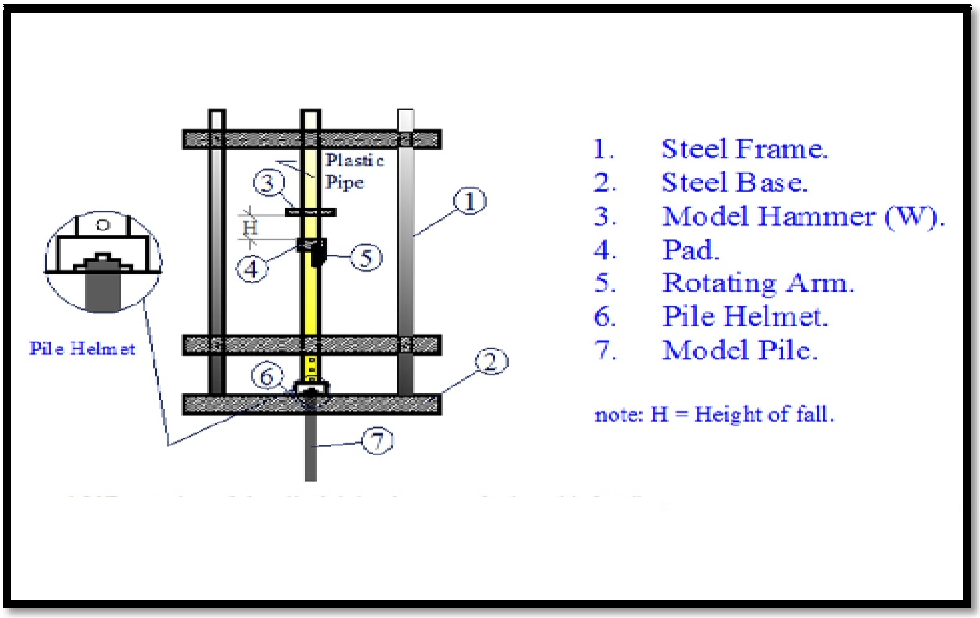

Figure (3) Front view of the pile driving hammer device with details.

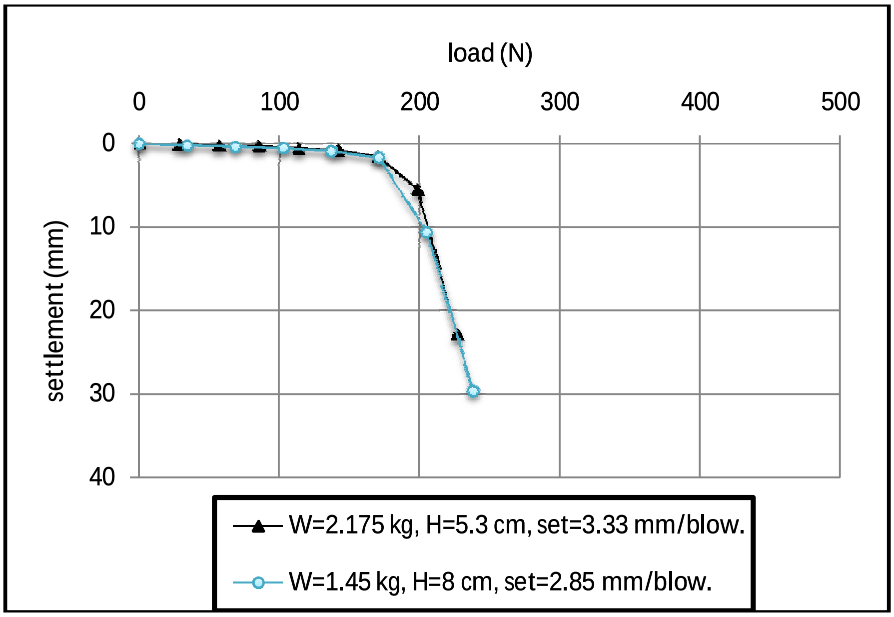

Figure (4) Effect of using equivalent energy on model pile behavior for circular pile with D=2.1cm, and L=40cm.

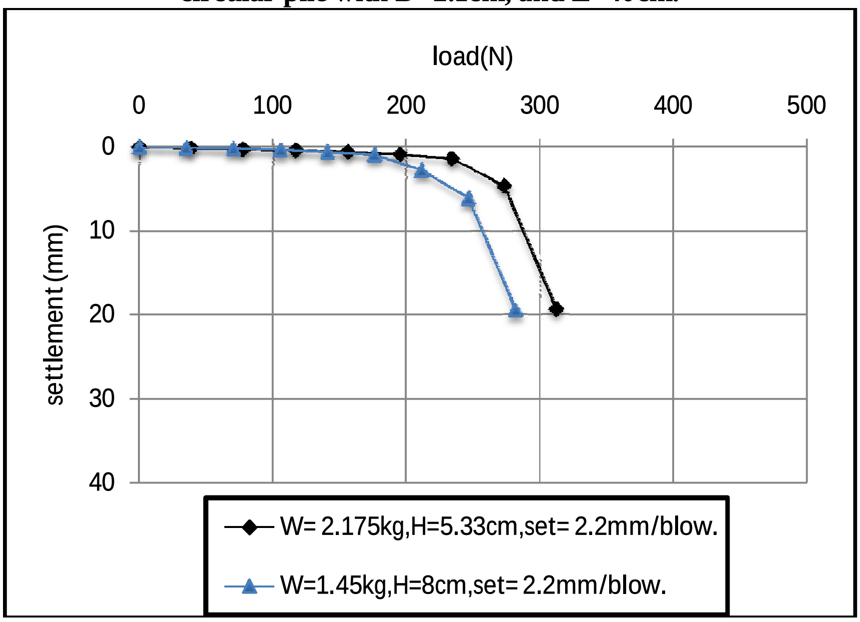

Figure (5) Effect of using equivalent energy on model pile behavior for circular pile with D=2.1cm, and L=50cm.

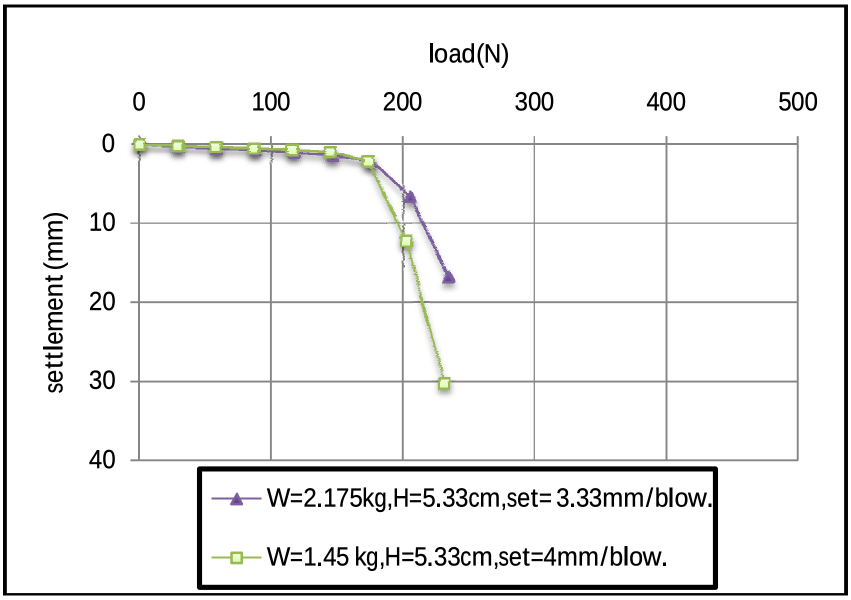

Figure (6) Effect of using equivalent energy on model pile behavior for square pile with B=1.6cm, and L=50cm.

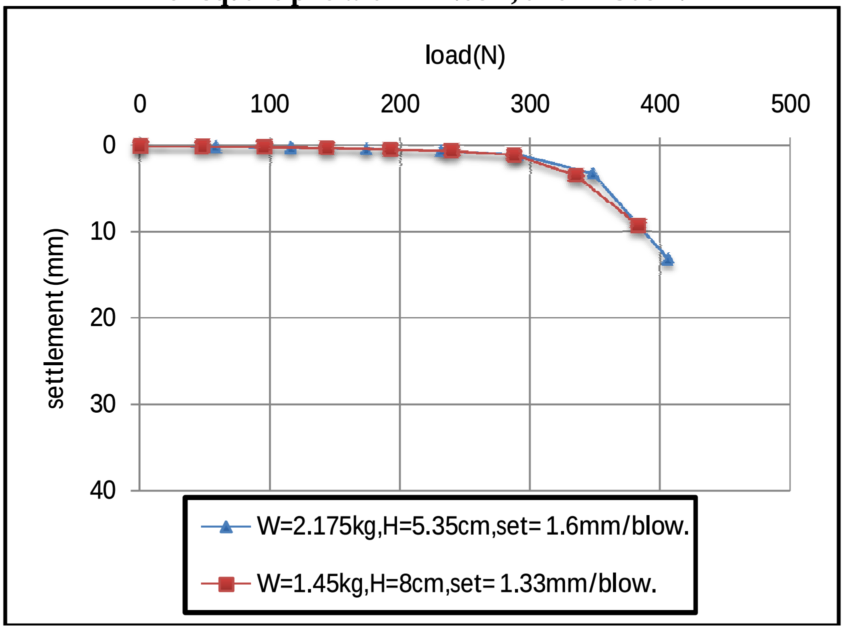

Figure (7) Effect of using equivalent energy on model pile behavior for square pile with B=2.1cm, and L=50cm.