Evaluation Of Bearing Capacity For Model Piles Driven In Sandy Soil

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Abstract

This study represents an effort to study the effect of driven pile type and relative density of the sand on the evaluation of bearing capacity of pile under two different types of loading, compression and tension (uplift) loads. Results of the observed failure load compared with common methods have been used to predict and calculate pile load capacity in case of compression and tension loads. Three types of piles were used in this study these were (precast concrete pile, closed-ended steel pile and open-ended steel pile). New values proposed to the bearing capacity factor (Nq) and the lateral earth pressure coefficient (K). These factors are functions of relative density of sand (Dr %), (L/D) ratio and pile types. Also new charts were proposed to determine the (End bearing pressure) and the (Uplift load pressure) depending on (L/D) ratio and relative density of sand, and the types of pile.
Keywords: Model piles, sandy soil, bearing capacity, driven piles.

تقييم قابلية تحمل نماذج من ركائز الدق في الترب الرملية

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الخلاصة :

إن الهدف الرئيسي من هذا البحث هو دراسة تأثير نوع الركيزة والكثافة النسبية للرمل على قابلية تحمل الركيزة في الترب الرملية تحت نوعين من الأحمال، الانضغاط و السحب (الرفع). تم الاعتماد في هذا البحث على حمل الفشل الملاحظ إثناء الفحص، نتائج حمل الفشل تم مقارنتها مع أربع طرق معتمدة تم استخدامها في تخمين وحساب قابلية تحمل الركيزة . ثلاثة أنواع من الركائز استخدمت في هذه الدراسة وهذه الركائز كانت (ركائز خرسانية مسبقة الصب، ركائز حديدية مسدودة النهايات وركائز حديدية مفتوحة النهايات) . المحددات التي اعتمدت في هذه الدراسة كانت ، نوع الركيزة ، عمق اختراق الركيزة و الكثافة النسبية للرمل . تم اقتراح قيم جديدة للمعاملات (N_q) و(K). وتبين أن هذه

المعاملات هي دالة لكل من نوع الركيزة، عمق الاختراق والكثافة النسبية للرمل . كذلك تم اقتراح مخططات لإيجاد كل من (End bearing pressure) و(Uplift load pressure) بالاعتماد على عمق الاختراق والكثافة النسبية للرمل للأنواع الثلاثة من الركائز.

List of Symbols:

Symbols	Definition
A_b	Area of pile base.
A_s	Perimeter area of pile shaft.
C	Cohesion of soil.
D	Width of pile foundation.
K	Coefficient of lateral earth pressure.
K proposed	Proposed Coefficient of lateral earth pressure K.
K_o	Coefficient of lateral earth pressure at rest.
K_a	Coefficient of active lateral earth pressure.
K_p	Coefficient of passive lateral earth pressure.
(K) proposed	Lateral earth pressure coefficient proposed.
L	Embedment length (depth) of pile.
Lc	Critical depth of pile.
L/d	The ratio of embedment length to diameter of pile.
Lc/d	The ratio of critical depth to diameter of pile.
Nc, Nq, Nγ	Bearing capacity factors of shallow foundation.
N_q	Bearing capacity factor of deep foundation (piles).
N_q proposed	Proposed Bearing capacity factor N_q
P_f	The failure load of pile.
$Q_{b.f}$	Failure end bearing capacity.
$Q_{u.f}$	Failure uplifts load capacity.
q'	Effective vertical stress at pile base.
q_b	The ultimate bearing capacity at pile base.
q_s	The ultimate skin friction of pile shaft.
Q_b	The end bearing resistance of the pile base.
Q_s	The total skin friction resistance of the pile shaft.
Q_{ult}	The ultimate load capacity of the pile.
W	Weight of pile.
γ	Unit weight of the soil.
Ø	Angle of internal friction of the soil.
Ø1	Angle of internal friction of soil prior the pile installation.
σ́av	Average vertical effective stress.
δ	Angle of soil – pile friction.

1. Introduction:

Pile are columnar element in foundation which have the function of transferring load from the superstructure through weak compressible strata or through water, onto stiffer or more compact and less compressible soil or onto rock. They may be required to carry uplift load when used to support tall structures subjected to overturning forces from winds or waves. Piles were used in marine structures are subjected to lateral loads from the impact of berthing ships and from waves. Combination of vertical and horizontal loads is carried where piles are used to support retaining walls, bridge piers and abutments, and machinery functions (Tomlinson 2008)[16]

2. Load-bearing capacity characteristics:

The bearing capacity of piles in sandy soil has been under investigation for many years. Many tests have been carried out with instrumental piles to measure the variation of axial pile load with depth. There are two classifications of piles, first End-bearing which is driven through weak soil rock, dense gravel or similar material and the piles load- bearing capacity is derived from the assistance of stratum at the toe of the pile. Second is skin friction, which is skin friction, develops between the surface area of the pile and the surrounding soil (similar to driving anile into timber). The frictional resistance developed must provide an adequate factor of safety for the pile load.

It is not uncommon for piles to rely on both types of load-bearing capacity. For example, if the stiff strata are compact gravel and good strata above is firm sand, then a pile driven into the gravel could rely both on end bearing from the gravel and skin friction from the sand. This type of pile is called end-bearing pile **(Figure (1-A)),** however if only the skin friction consider in design, then the pile would be called friction pile (**Figure (1-B)).**

For friction piles in cohessionless soils (sand and gravel) the applied load is transfer to the surrounding soil mainly through skin friction along the surface of the piles. A large part of the load is also carried by the pile toe. For friction piles in cohesive soil (clay) almost the whole load on the pile is transferred to the surrounding soil along the pile surface through skin friction and only a very small part through the pile toe (Broms,1966)[10].

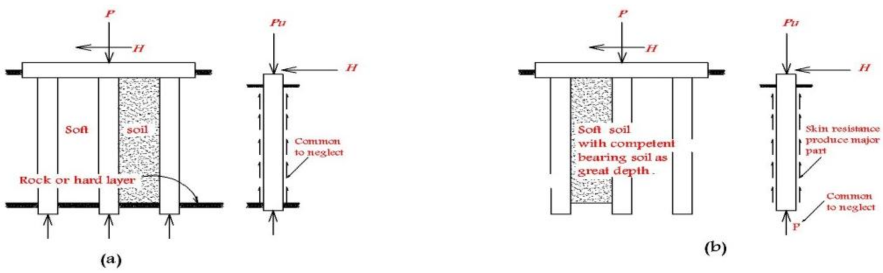


Fig .(1): (a) End-bearing pile. (b) Skin friction-pile

3. Experimental Program for evaluation the Pile Bearing Capacity:

Laboratory-scale investigations into piles behavior remain popular because of the high cost of field testing and the possibility of achieving specific soil characteristics in a laboratory environment. The monitored behavior of prototype structures has led to a better understanding of piles foundation and enables more reliable and economical design to be employed.

3.1. Sand container:

The model tank is a rectangular container, which is made of thick aluminum from three sides and the front size from thick glass with internal dimensions of (60cm×60cm) and (100cm) height (**Figure (2)**).

Fig .(2): Model of container

3.2. Model of Piles:

Three type of pile (open-ended steel box pile, closed-ended steel box pile and precast concrete pile) of cross- section (30×30) mm diameter are used as model piles in the experimental program in compression and tension tests. The lengths (embedment lengths) of the model piles that are taken in the experimental tests depend on the ratio of embedment length to pile diameter, (L/d) ratio. See **Figure (3a, 3b and 3c)**.

(a) Model of steel piles

(b) Model of steel pile

(c) Model of precast concrete pile

Fig .(3): model of piles

3.3. Sand properties:

The soil used for the model tests is clean, oven-dried, uniform quartz sand. The maximum and minimum dry unit weights of the sand were determined according to the ASTM (D4253-2000)[6]and ASTM (D4254-2000)[7] specifications, respectively, the specific gravity test is performed according to ASTM (D854-2005)[9], and the grain size distribution is analyzed according to ASTM (D422-2000)[8] specifications and direct shear test according to the ASTM (D 3689-1995)[5]. Figure (4) shows the grain size distribution of the sand. **Tables (1) and (2**) summarize the physical properties of the tested sand. The angle of internal friction is determined using the direct shear test which was carried out for the three types of sand.

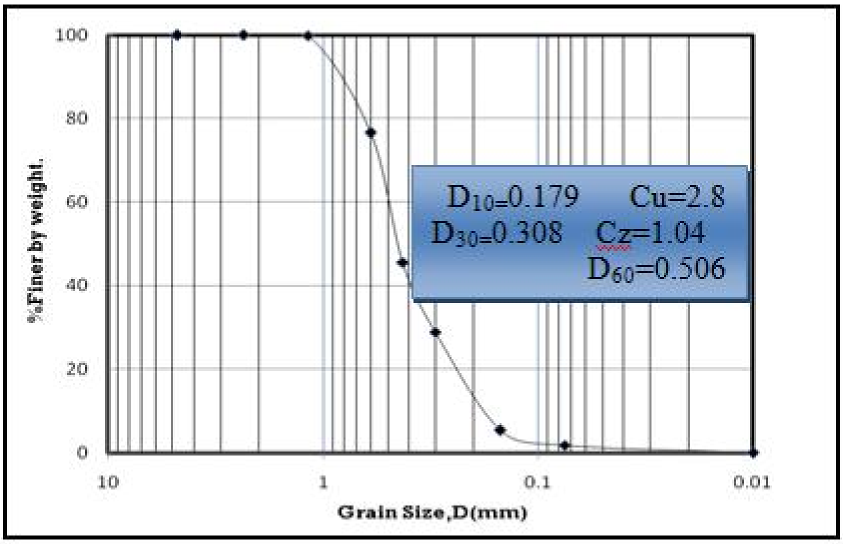


Fig .(4): Grain size distribution of the san

Table (1): Physical properties for the tested sand

Property	***Value***
Grain size analysis	
Coefficient of uniformity, C_u	2.8
Coefficient of curvature, C_c	1.04
Classification (USCS)*	SP
Specific gravity, G_s	2.65
Dry unit weights	
Maximum unit weight, $\gamma_{d\ (max)}$	18.1 kN/m^3
Minimum unit weight, $\gamma_{d\ (min)}$	14.2 kN/ m^3
Void ratio	
Maximum void ratio, e_{max}	0.874
Minimum void ratio, e_{min}	0.449

Table (2): Relative densities and the corresponding dry unit weights values for sand placement

Type of sand	***Relative density (Dr %)***	***Dry unit weight (γ dry) in (kN/m³)***
Dense	85	17.4
Medium	50	15.9
Loose	15	14.7

3.4. Direct shear test:

The angle of internal friction (Ø) for each type of sand are obtained from direct shear test by controlling the sample density of sand for each type tested in box of direct shear instrument, direct shear box test was performed again using steel plate (represents the pile surface material) to determine the soil-pile friction angle (δ) for each type of sand. The steel plate and concrete surface was placed in the upper half of the shear box and the sand was placed in the lower half with specified density, the values of (Ø) and (δ) for (dense, medium & loose) sands are listed in **Table (3)** below.

Table (3): values of angle of internal friction and soil-pile friction angle

Sand type	***Angle of internal friction (Ø)***	***Soil-pile friction angle(δ)***	
		Precast concrete piles	***Steel piles***
Dense	40	28	23
Medium	34	24	22
Loose	29	22	20

3.5. Sand Placement in the Model Tank:

The sand deposit was prepared using the sand raining technique. A special raining device was designed and constructed to obtain a uniform deposit with the desired density. The device consists of a steel frame, an upper funnel with the opening size of (10mm) connected to the hand lever by steel rope to allow funnel to move upward, the horizontal movement of the funnel was achieved by hand. The unit weight of the sand deposit in the raining method depends primarily on the drop height and the discharge rate of the sand (Vesic, 1967)[17]. The height of the free fall of the sand can be controlled by adjusting the elevation of the raining device with respect to the sand tank. To determine the density of the sand a number of trials have been carried out with varying heights of fall. It was understood that the density of sand increases when the height of fall increased. To verify this, a steel mold of size (11.6cm) diameter and (10.18cm) height was used to pour the sand by the funnel. The mold was filled with sand for different heights of fall i.e. 5cm, 10cm, 15cm, 20cm, 25cm, 30cm, 35cm, 40cm, 50cm, 60cm.For every height of fall, the corresponding unit weight and relative densities were calculated. **Figure (5)** and **Figure (6)** show the details of pouring of sand in the container.

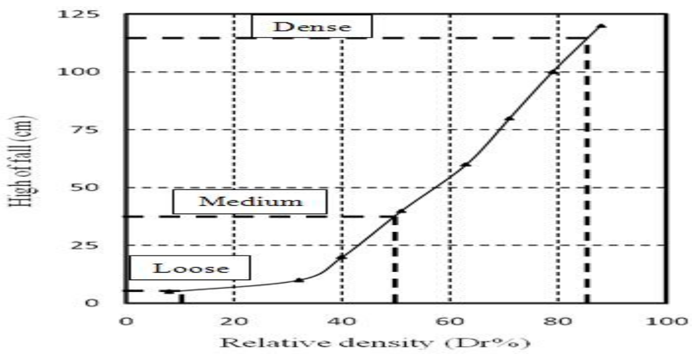


Fig. (5): Relationship between height of fall and relative density of sand

Fig .(6): pouring process of sand

3.6. Driven pile technique:

Drop hammer was used for driving the model piles which consist of, a cylindrical steel weight (1.5kg) lined by cylindrical steel case fixed in steel frame which fixed to the ground as shown in **Figure (7a),** a steel rod was used to pull the hammer with particular distance, a fall height between (80-200) mm was used to fall the hammer on the pile head. **Table (4)** contains the specific height of fall of hammer and the number of blows for all type of pile in three different relative densities of sand. Height of hammer falls specified by fixing steel ruler on the main frame **(Figure (7d)).** To prevent the damagein the head of concrete pile,a pile cap on the head of pile wasprovided (**Figure (7e)).**

(b) Hammer weight.

(c) Hammer weight details.

(d) Steel rule.

(a) Hammering process

(e) Pile cap.

Fig .(7): Details of Driving pile by drop hammer

Table (4): Number of blows for all type of piles

Group one *Model piles in loose sand*				*Group two* *Model piles in medium sand*				*Group three* *Model piles in dense sand*			
Pile Type	Embedded length (mm)	No. of blows	H of hammer Mm	Pile Type	Embedded length (mm)	No. of blows	H of hammer mm	Pile Type	Embedded length (mm)	No. of blows	H of hammer mm
Precast	300	66	130	Precast	300	99	160	Precast	300	120	200
	450	99	130		450	140	160		450	167	200
	600	130	130		600	166	160		600	207	200
	750	180	130		750	215	160		750	312	200
Closed-ended	300	65	100	Closed-ended	300	74	140	Closed -ended	300	115	175
	450	101	100		450	119	140		450	160	175
	600	128	100		600	163	140		600	215	175
	750	178	100		750	195	140		750	256	175
Open-ended	300	65	80	Open-ended	300	85	120	Open-ended	300	95	150
	450	102	80		450	110	120		450	143	150
	600	133	80		600	151	120		600	191	150
	750	180	80		750	194	120		750	248	150

3.7. Loading Frame for the Compression and Tension Test:

The loading system for compression and tension test consists of a mechanical jack, as shown in **Figure (8a),** which is connected from the top with steel support in main frame and connected from the bottom with load cell by two twisting shafts. This jack has the ability to move upward and downward to apply compression and tension load on the load cell which connected to a digital load indicator. The load indicator displays the load values on a screen in a positive value in compression state and negative value in tension state (**Figure (8c &D)).** The lower shaft is connected to the pipe and this pipe connected to the head of pile on the pile cap (**Figure (8e &F)).** The lower shaft and the pipe pass through a suitable steel pipe shaft fixed with a steel angle. The purpose of the suitable steel pipe shaft is to prevent the lateral which movement and any eccentric load during the test. The loads are applied to the piles according to the maintained load (ML) test procedure by adding dead weights by mechanical jack. **Figure (8g)** shows the details of loading frame.

(a) Mechanical jack

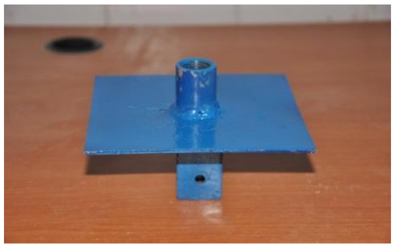
(b)Load cell

(c) Load indicator in compression state.

(g) Loading mechanism.

(d) Load indicator in tension state

(e) Pile cap for compression test



(f) Pile cap for tension test

Fig . (8): Details of loading frame

3.8. Testing Program of Compression & Tension Tests:

Thirty-six compression and thirty-six tension tests are carried out on model piles (precast concrete, open-ended steel and closed ended steel) driven into three states of sandy soil, which are (loose, medium and dense). Each test program is divided into three groups andeach group includes twelve tests performed on the twelve model piles driven into specified states of sandy soil with different lengths. **Figure (9)** shows the details of the testing program for the model piles.

Each pile within these groups is loaded, concerning compression tests program, the pile is loaded until failure, and each increment is sustained by the pile with the corresponding final settlement is recorded. The load settlement curve is considered to assess the pile capacity corresponding to observed pile failure. Concerning tension tests program, the pile is loaded where the axial failure that is considered to occur when the pile moves out of the sand.

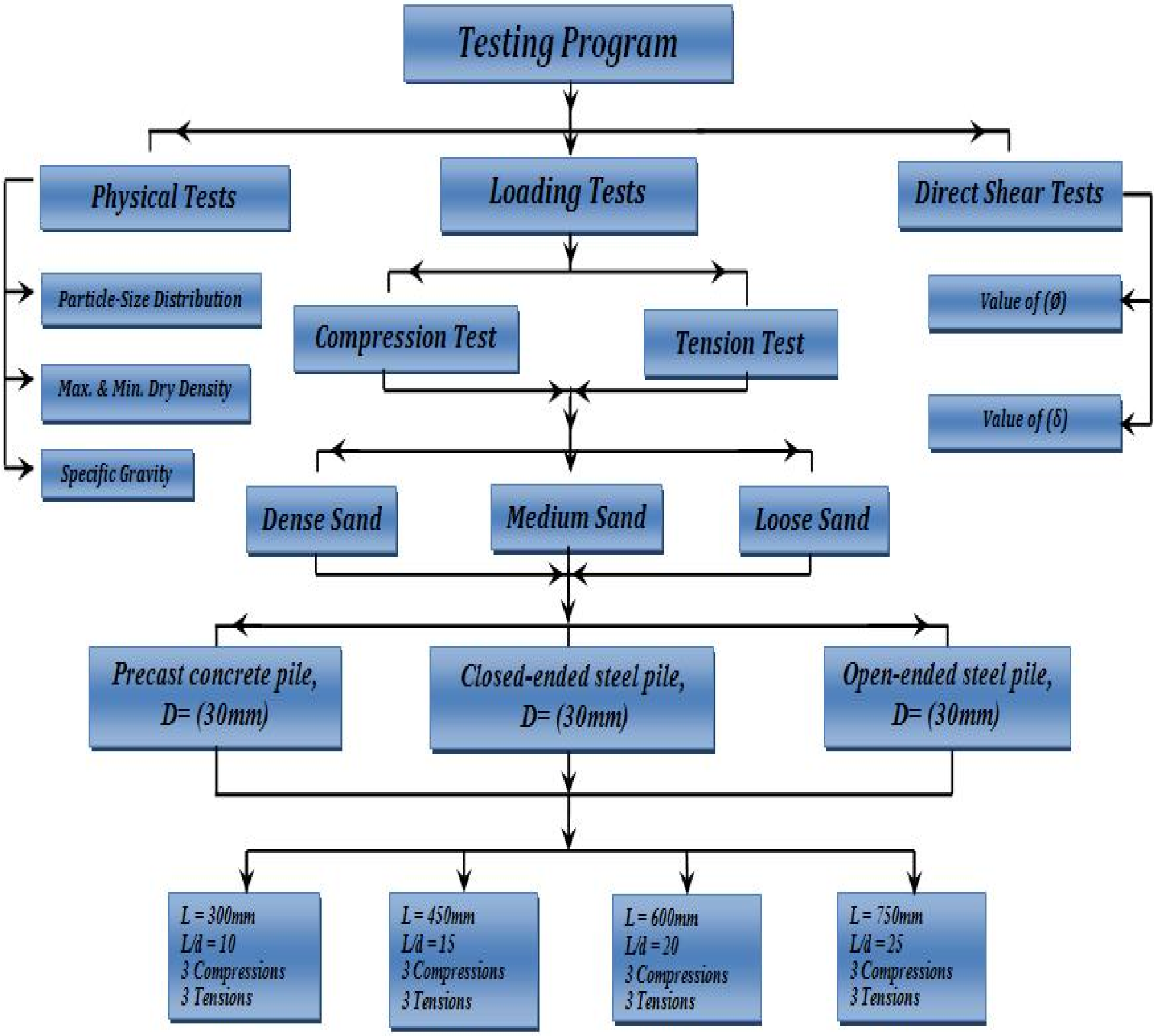


Fig .(9): Flow-chart of testing program

4. Experimental results and discussion:

The aim of this study is to explain the effect of pile type and its material with soil properties on the pile load- bearing capacity in compression and tension condition. First, it is essential to know some important criteria's to distinguish between the following pile load capacities:

- **Predicted Pile load capacity**: is achieved by common pile capacity equations, Meyerhof (1976)[13],Tomlinson (1977)[15], Poulos & Davise (1980)[14].Coyle & Castello (1981)[11] and Broms (1966)[10] to obtain pile load capacity predicted (P_{pre}) for compressive load and Broms and American petroleum institute (API)[3] for uplift load.
- **Observed Pile load capacity**: is achieved by carrying out tests on model piles according to slow maintained load test procedure by using pile load capacities predicted in stage one above to assess load-settlement curves for compression load test and load- axial displacement curves for uplift load test.

In this study, the prediction of the failure load is very important for analysis the results obtained from the tests. The failure load occurs when observation a large displacement or settlement occurs due to small increment of applied load, thus this load called (P_f). This criterion was used by(Al-Azzawi 2006[2] and Al-Adly 2008[1]).

4.1. Pile subjected to compression load:

Thirty-six pile tests under compression were performed to reach the ultimate pile load capacity in three states of sand (loose, medium and dense) and three different types of model piles:-

A. Precast concrete model pile.
B. Closed-ended steel model pile.
C. Open-ended steel model pile.

Twelve tests were performed for each group. These tests were divided into three categories depend on the state of sand (Loose, Medium and Dense) and into four categories depend on (L/D) ratios (10, 15, 20 and 25). The model piles had a fixed cross-section (30×30mm).

4.1.1. Pile Load Capacity Prediction:

Numerous methods are used to calculate the pile load capacity in compression Load. In this study, Meyerhof (1976)[13], Tomlinson (1977)[15], Poulos & Davise (1980)[14] and Coyle & Castello (1981) [11]methods were used to evaluate end bearing capacity. Broms (1966)[10] and (API, 1993)[4] were used to evaluate the skin friction resistance. In all methods, the bearing capacity factor (N_q) and the lateral earth pressure coefficient (K) are very important in pile load capacity calculations.

4.1.2. Results of compression pile load capacity:

Results of the observed compression load capacities for three types of piles are presented in **Figure (10).**

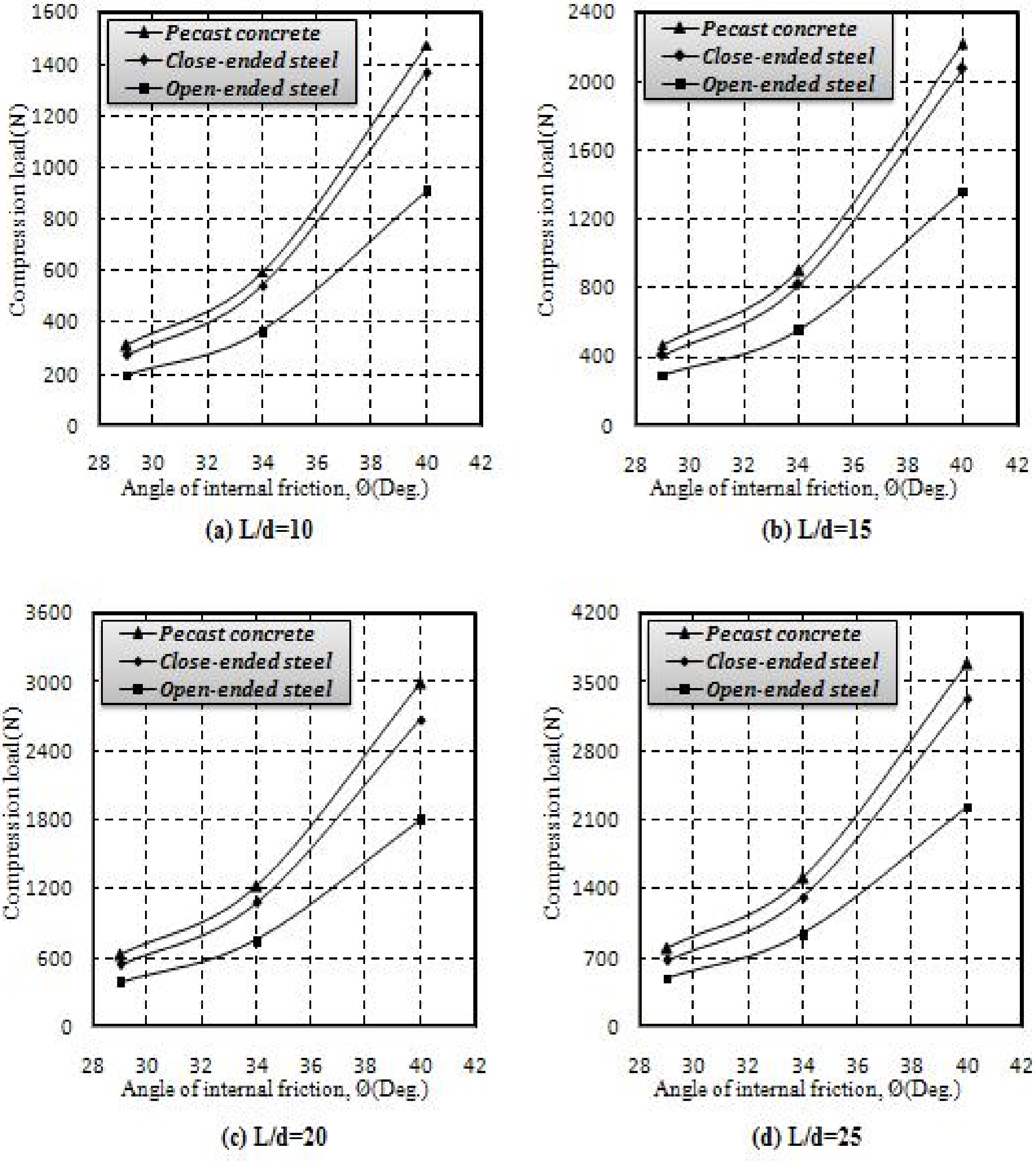


Fig .(10): Relationship between compression load and angle of internal friction (Ø) for three types of model piles and different (L/D) ratio

4.2. Piles subjected to uplift load:

Thirty-six pile tests under uplift were performed to reach the ultimate pile load capacity in three states of sand (loose, medium and dense) and three different types of model piles:-

A. Precast concrete pile.
B. Closed-ended steel pile.
C. Open-ended steel pile.

Twelve tests were performed for each group. These tests were divided into three categories depend on the state of sand (loose, medium and dense) and into four categories depend on (L/D) ratio (10, 15, 20 and 25). The model piles had a cross-section (30×30) mm.

4.2.1. Tension (Uplift) Load Capacity Prediction:

Broms (1966)[10] and American Petroleum Institute (API, 1993)[4] methods are considered to calculate the uplift load capacity of piles and to verify their validity in predicting the ultimate uplift pile-load capacity. The lateral earth pressure coefficient (K) is found according to API (1993)[4] and Broms (1966)[10] methods.

4.2.2. Results of uplift pile load capacity:

Results of the observed uplift load capacities for three types of piles are presented in **Figure (11).**

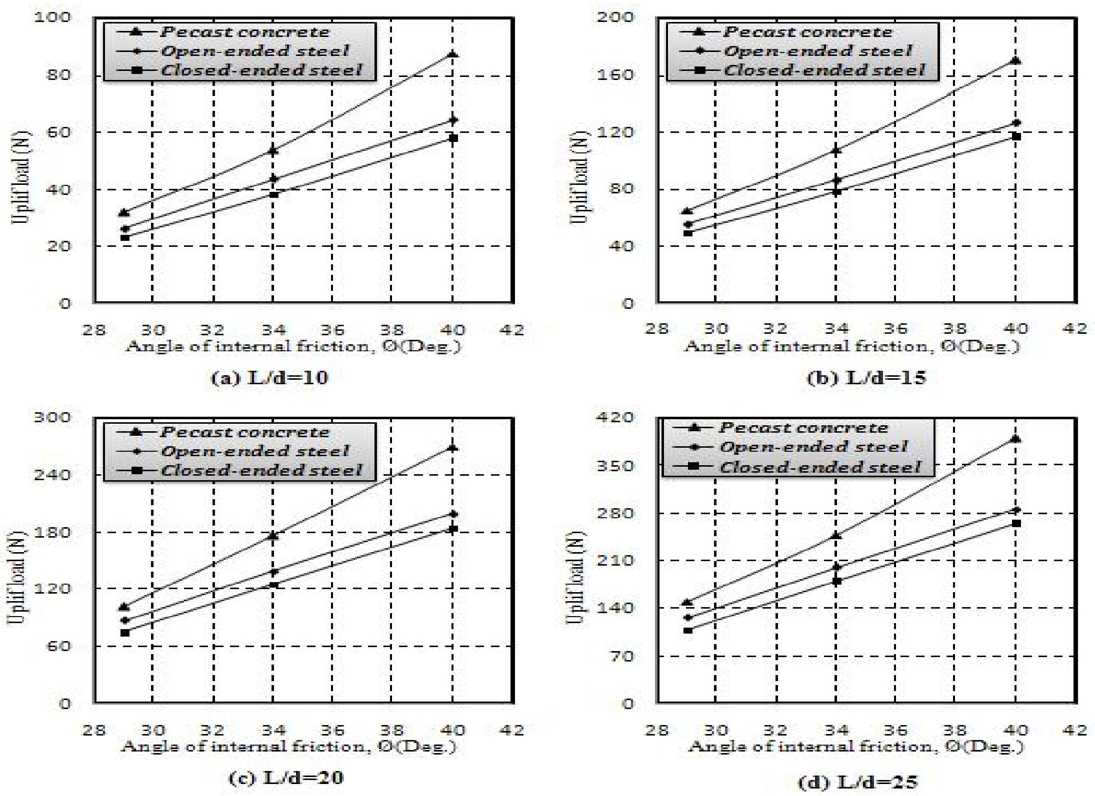


Fig .(11): Relationship between uplift load and angle of internal friction (Ø) for three types of piles and different (L/D)

4.3. Comparison between experimental and theoretical results:

The experimental results were verified to prove its validity leading to accurate behavior to get clear picture of soil and pile approach, the following comparisons and evaluations had been done:

4.3.1. Bearing capacity factor (Nq):

The results of the bearing capacity factor (Nq) are used to check the validity by comparing them with those values of (Nq) proposed by Meyerhof (1976) [13], Tomlinson (1977)[15], Poulos & Davise (1980)[14] and Coyle and Castello (1981)[11] respectively. These comparisons are presented in **Figures (12) To (14).**

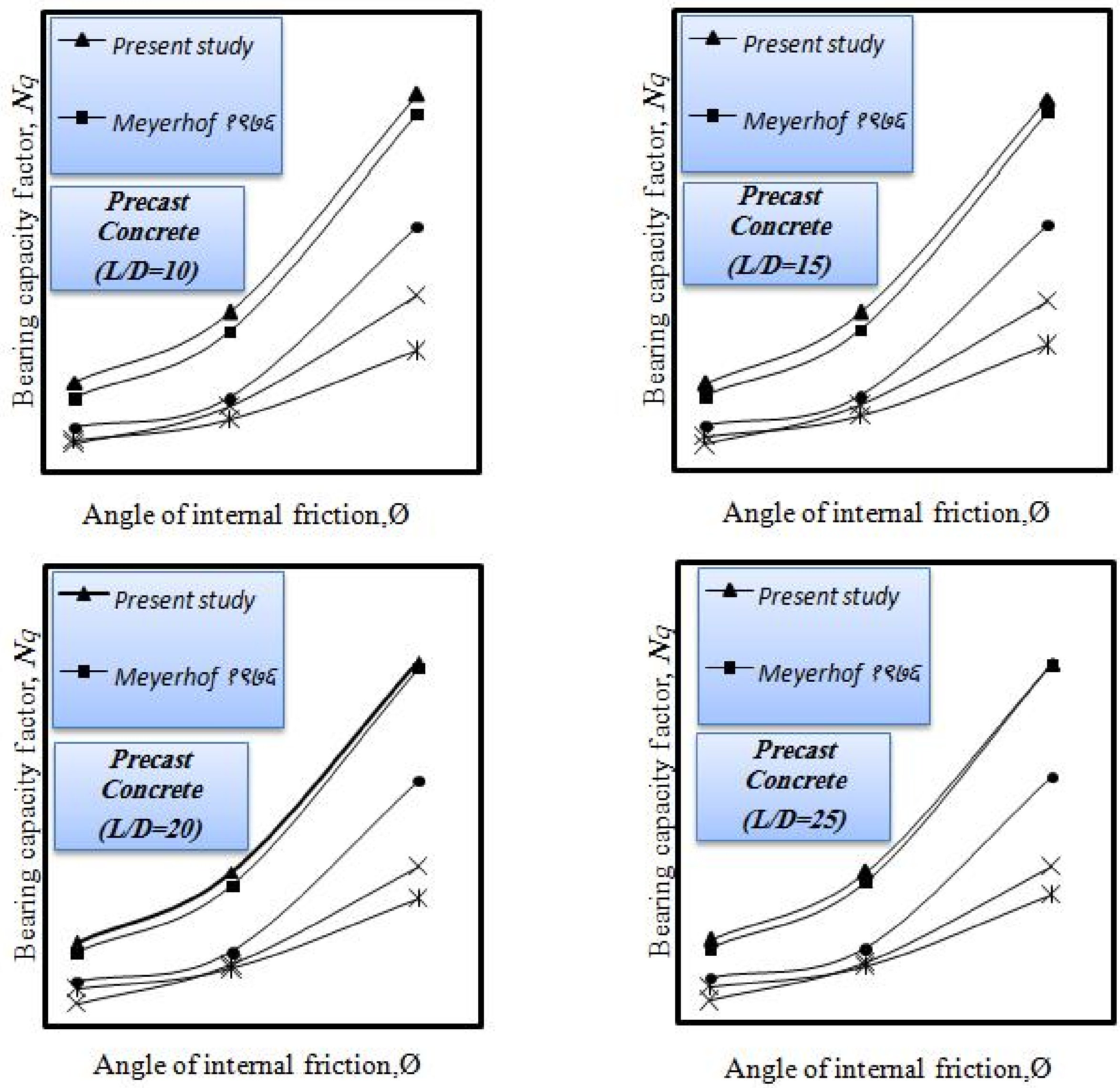


Fig. (12): Comparison between predicted and calculated value of bearing capacity factor (Nq) for precast concrete pile

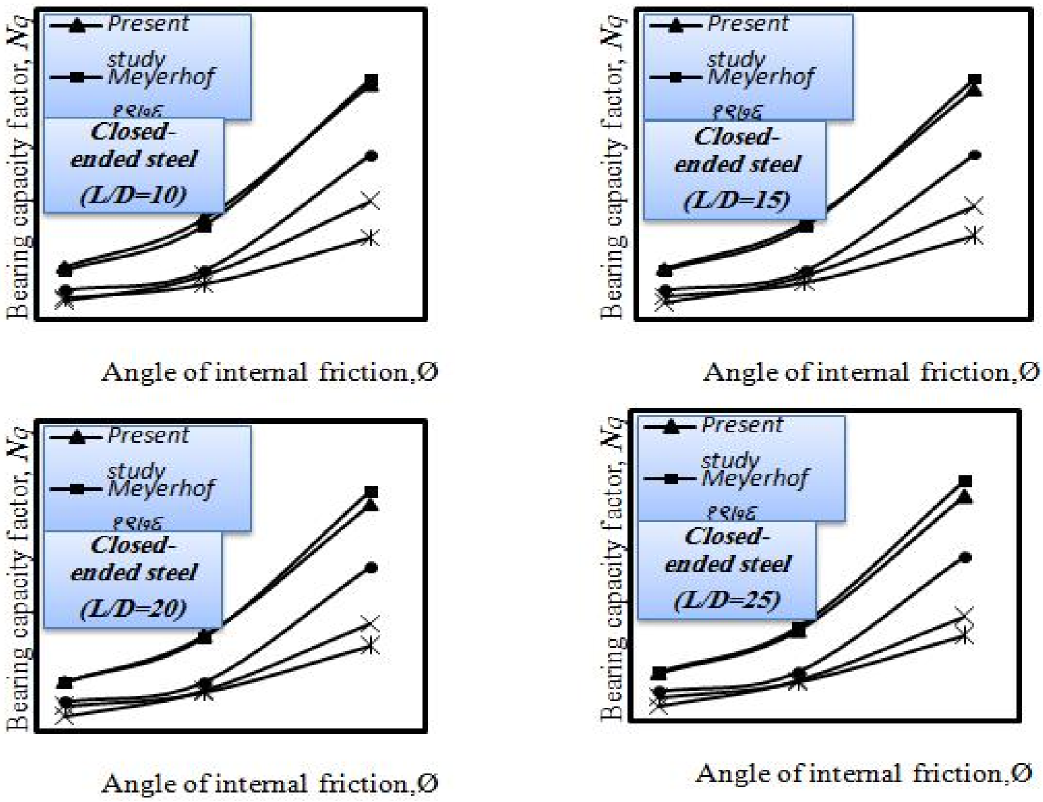


Fig .(13): Comparison between predicted and calculated value of bearing capacity factor (Nq) for Closed-ended steel pile

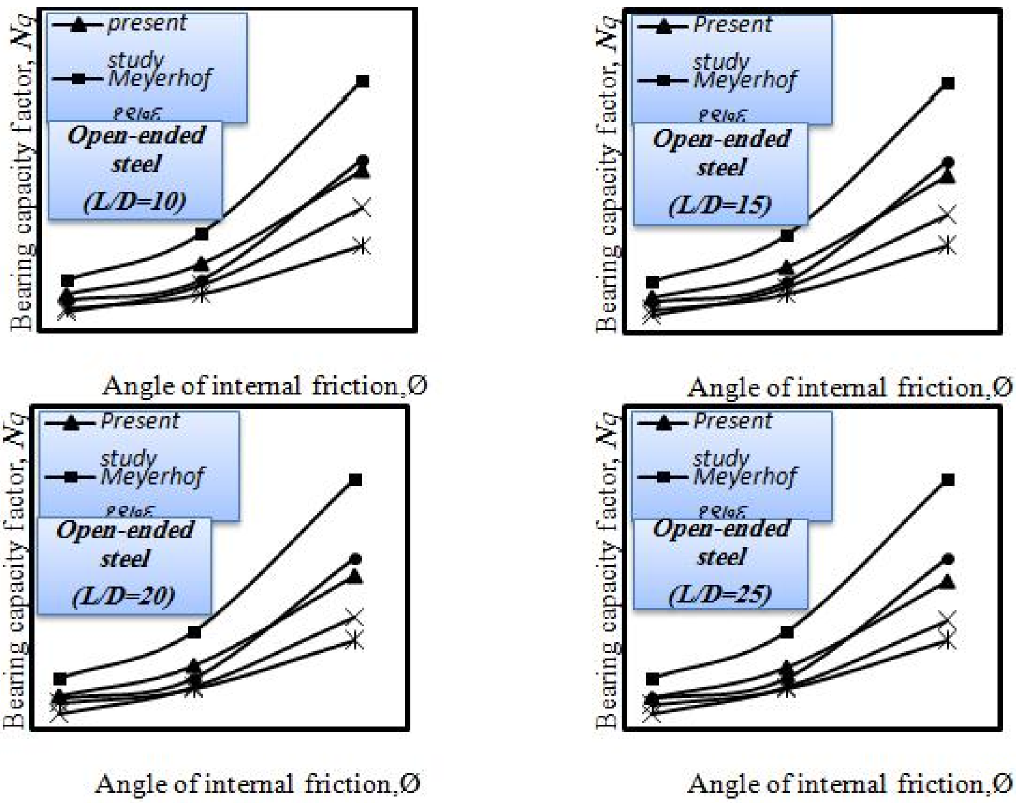


Fig .(14): Comparison between predicted and calculated value of bearing capacity factor (Nq) for open-ended steel pile

4.3.2. Lateral earth pressure coefficient (K):

The results of the lateral earth pressure coefficient (K) used to check the validity by comparing them with those values calculated from theories proposed by Borms (1966)[10], Fory et al. 1998[12]and API (1993)[4](**Figures (15) To (17)).**

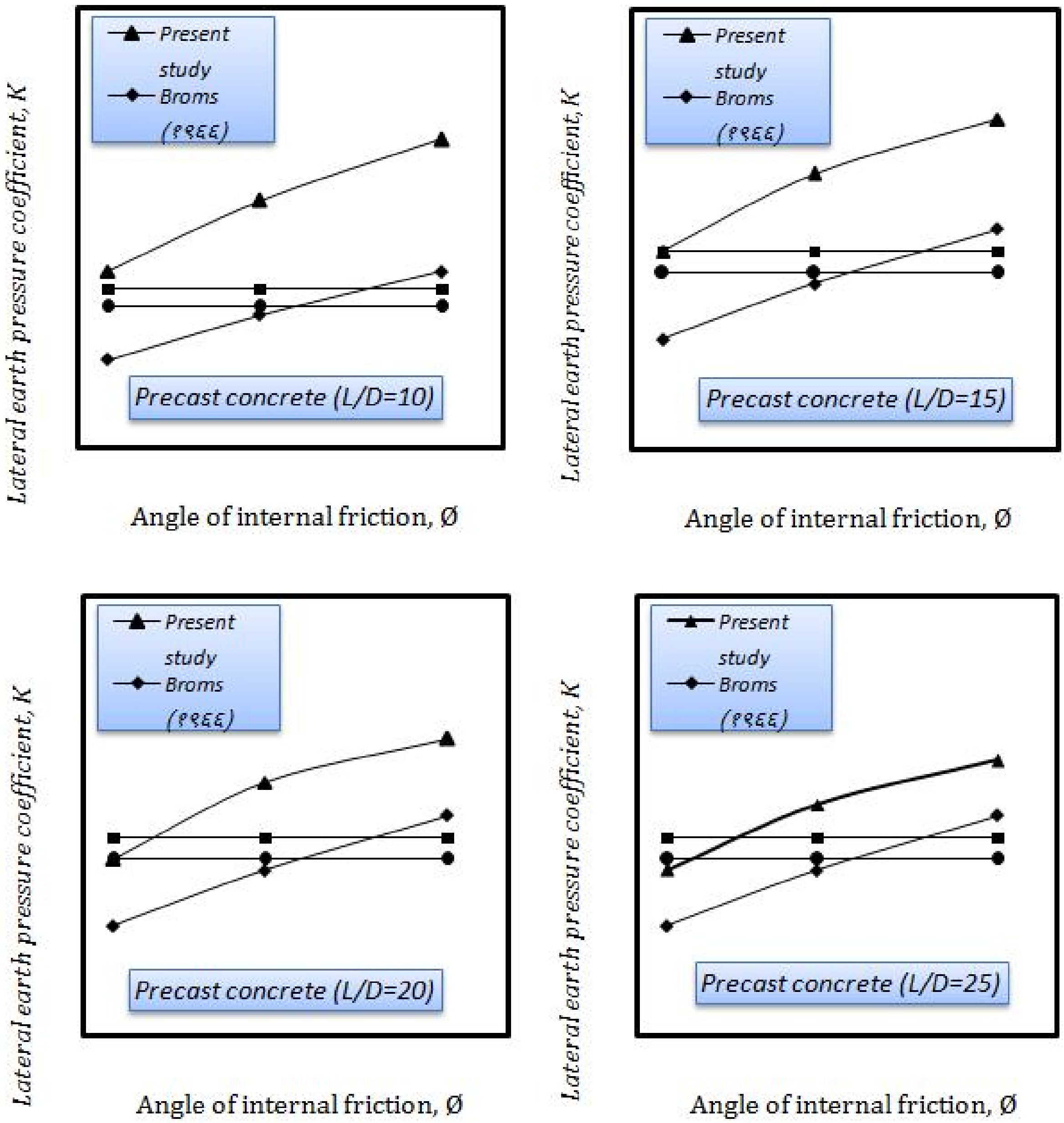


Fig .(15): Comparison between predicted and calculated values of lateral earth pressure coefficient (K) for precast concrete pile

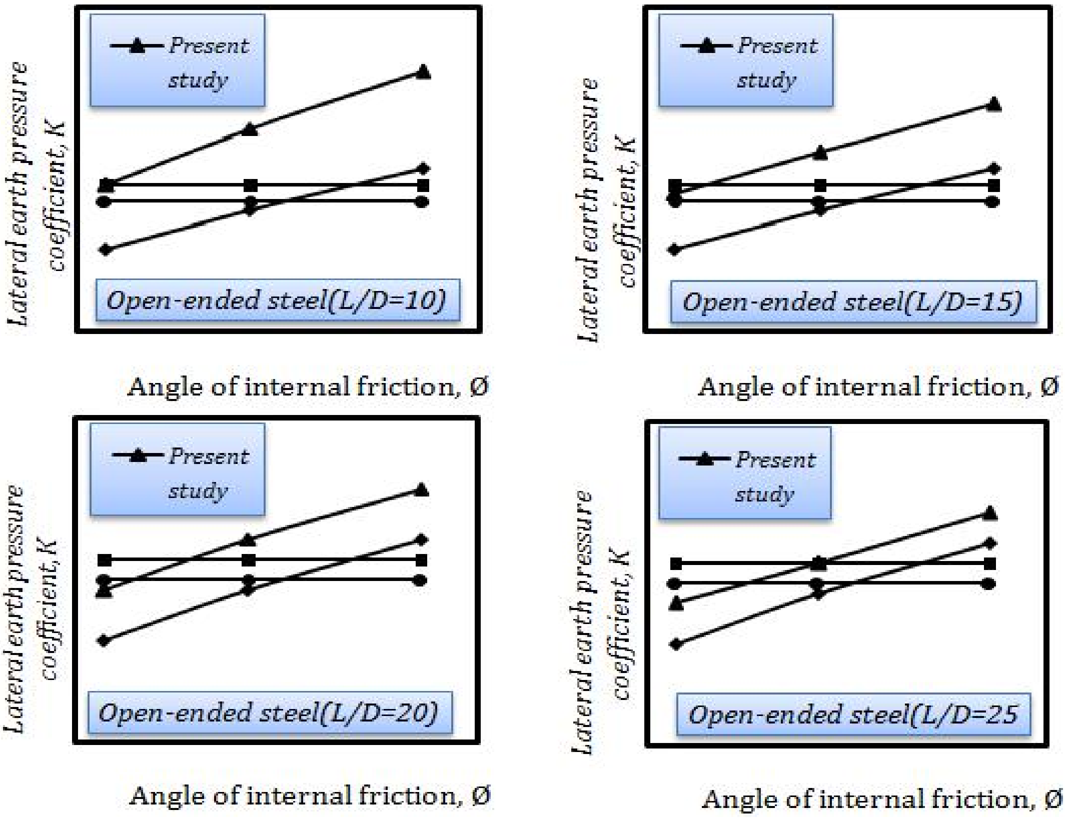


Fig . (16): Comparison between predicted and calculated values of lateral earth pressure coefficient (K) for open-ended steel pile

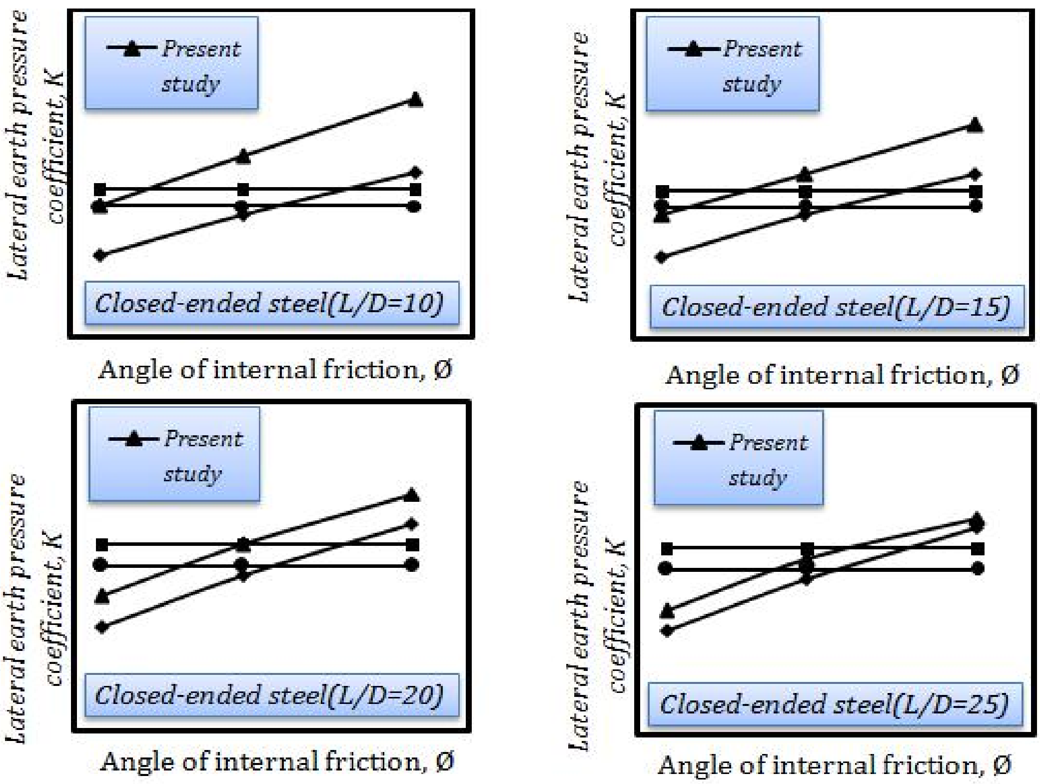


Fig. (17): Comparison between predicted and calculated values of lateral earth pressure coefficient (K) for closed-ended steel pile

4.4. Analysis and verification of the experimental results:

Four major objects have been suggested in this study as below:-

1- Ultimate pile-end bearing pressure.
2- Ultimate pile-uplift pressure.
3- New value for bearing capacity factor (Nq).
4- New value for lateral earth pressure coefficient (K).

4.4.1. Ultimate pile end bearing pressure:

The new values of end bearing pressure is obtained from the divided of end bearing load capacity (Q_{bf}) on the cross section area of pile. The end bearing load capacity of pile is the net load that is carried out by the soil beneath the pile (i.e. the net load = total load – friction resistance capacity), **Figures (18) To (20)** show the proposed end bearing pressure for different types of pile with different (L/D) ratio and different relative density of soil.

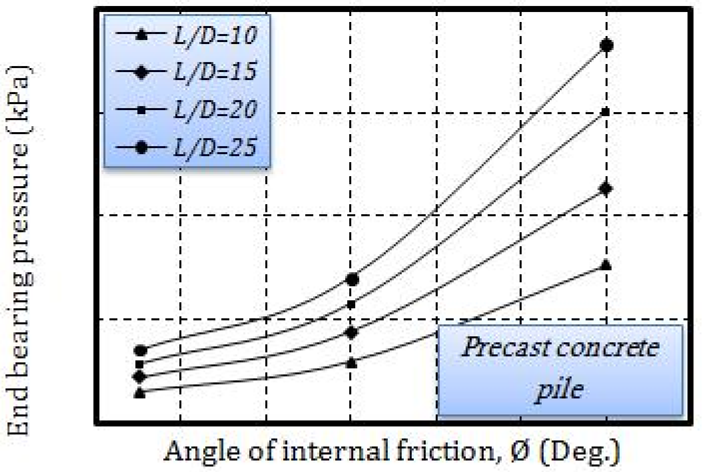


Fig .(18): proposed value of end bearing pressure for precast concrete pile for different lengths.

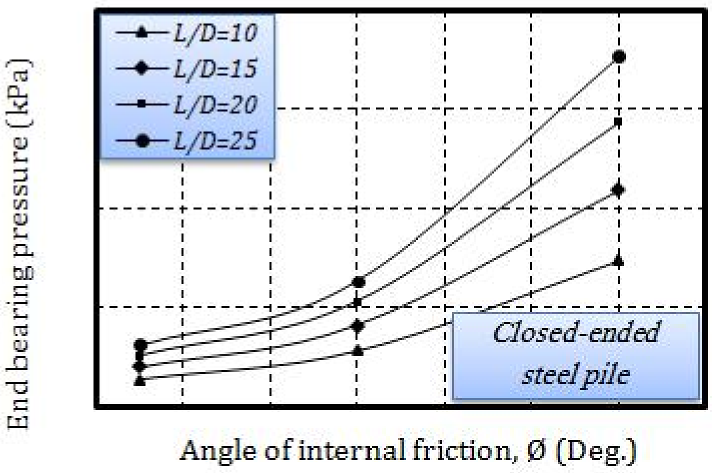


Fig .(19): Proposed value of end bearing pressure for closed-ended steel pile for different lengths.

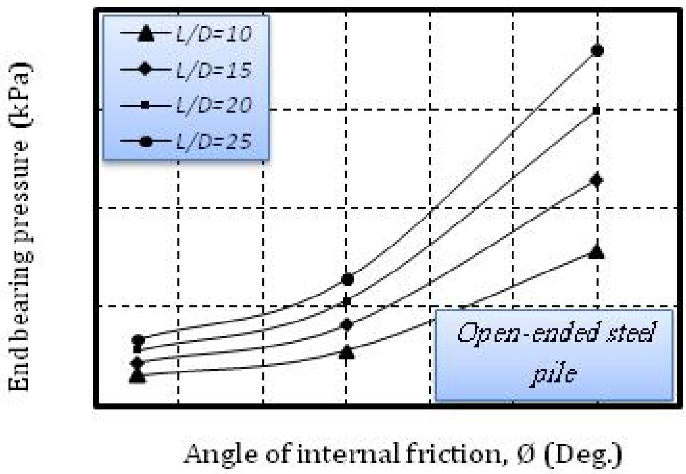


Figure (20): Proposed value of end bearing pressure for open-ended steel pile for different lengths.

4.4.2. Ultimate Uplift pressure:

The new values of uplift pressure obtained by divided the uplift loaf capacity (Pf) on the surface area of pile. **Figures (21) to (23**) show the proposed uplift pressure for different types of pile with different (L/D) ratio and different state of soil.

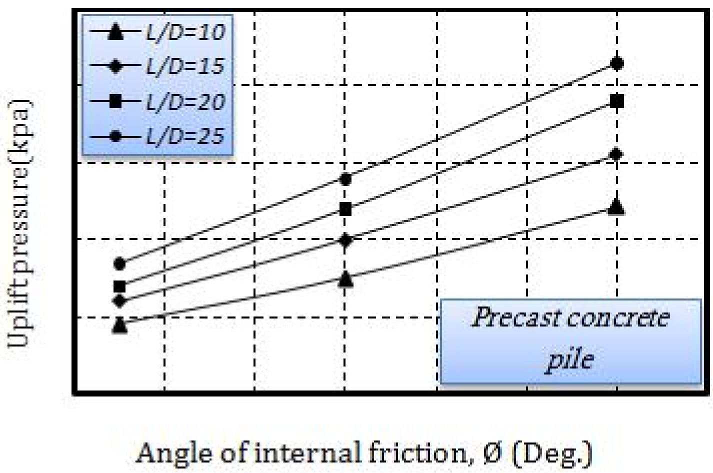


Fig . (21): Proposed value of uplift pressure for precast concrete pile for different lengths.

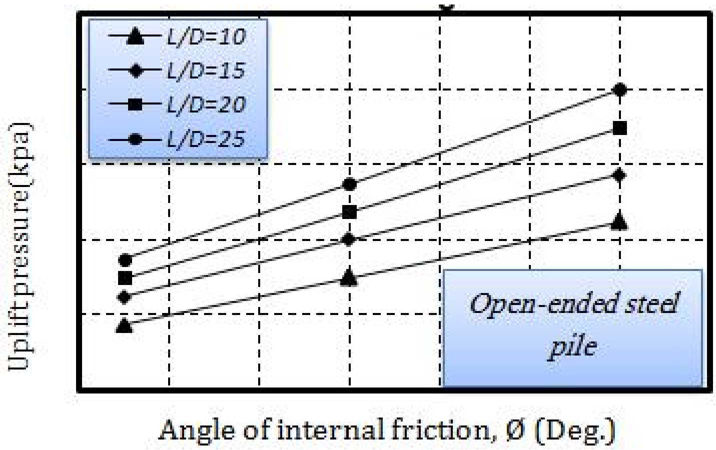


Fig .(22): Proposed value of uplift pressure for open-ended steel pile for different lengths.

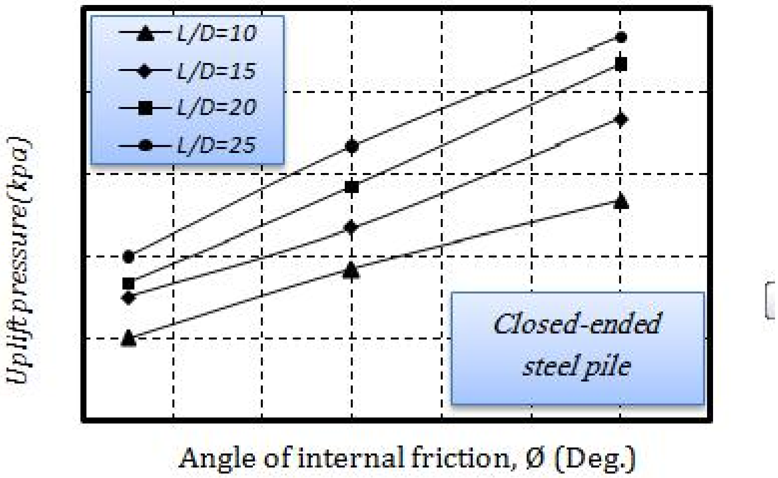


Fig .(23): Proposed value of uplift pressure for closed-ended steel pile for different lengths.

4.4.3. Proposed Bearing capacity factor (Nq):

The bearing capacity factor (Nq) is very important for evaluating end-bearing load capacity for pile (Q_b). In this study, new chartswere suggested to evaluate bearing capacity factor (N_q) for three type of piles (precast concrete, open-ended steel and closed-ended steel).

The value of bearing capacity factor (N_q) calculated is depending on the observed end bearing capacity (Q_{bf}). The value of (Q_{bf}) was calculated by dedicate the value of (P_f) in compression test from the value of (P_f) in uplift test. The value of N_q will be as below:

$$Nq = \frac{P_f\,(Compression\ test) - P_f\,(Uplift\ test)}{A_b \times P_o} \quad \ldots (1)$$

Figures (24 to 26) show the relationship between proposed bearing capacity factor (N_q) and (L/D) ratio for different types of piles in sandy soil.

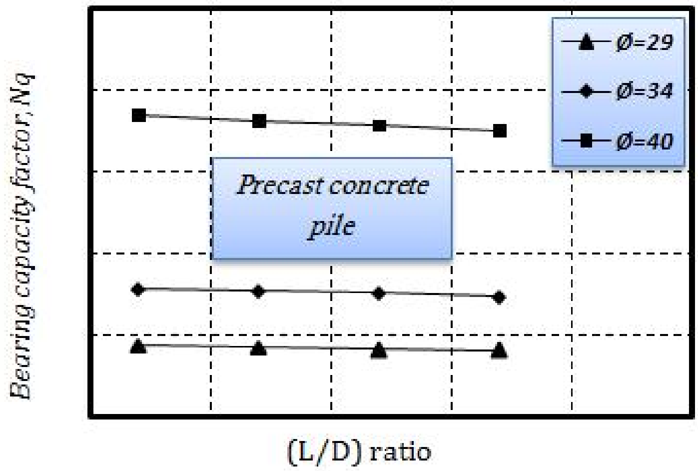


Fig .(24): Proposed value of bearing capacity factor (Nq) for precast concrete pile in different relative density of sandy soil.

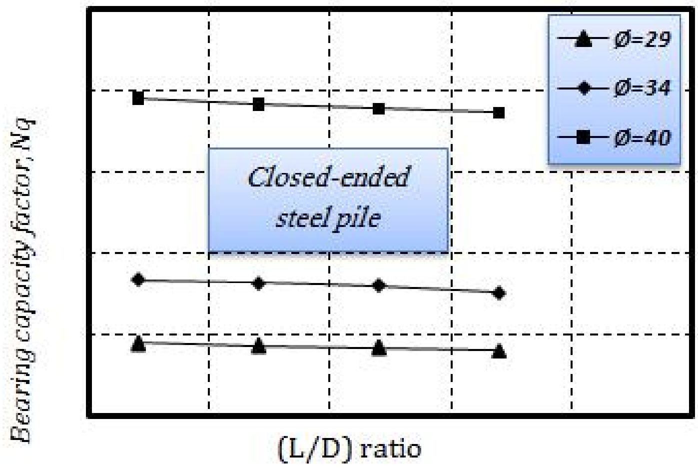


Fig .(25): Proposed value of bearing capacity factor (Nq) for closed-ended steel pile in different relative density of sandy soil.

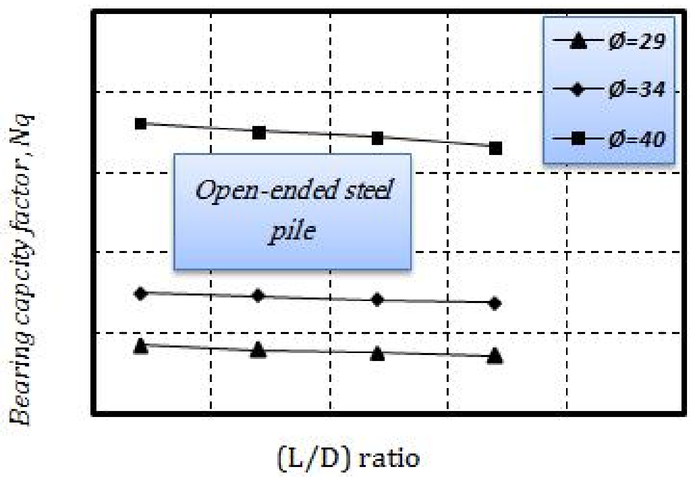


Fig .(26): Proposed value of bearing capacity factor (Nq) for open -ended steel pile in different relative density of sandy soil.

4.4.4. Proposed Lateral earth pressure coefficient (K):

The lateral earth pressure coefficient (K) is very important for evaluating uplift load capacity and shaft friction resistance for pile. New chartswere suggested to evaluate lateral earth pressure coefficient (K) for three types of piles (precast concrete, open-ended steel and closed-ended steel).The value of (K) is calculated depending on the observed uplift load capacity (Q_{uf}).The value of (K) will be calculated as below:

$$K = \frac{P_f\,(Uplift\ test)}{\acute{\sigma}av\ \tan(\delta)\ A_S} \qquad \ldots (2)$$

Figures (27) to (29) show the relationship between proposed lateral earth pressure coefficient (K) and (L/D) ratio for different types of piles in sandy soil.

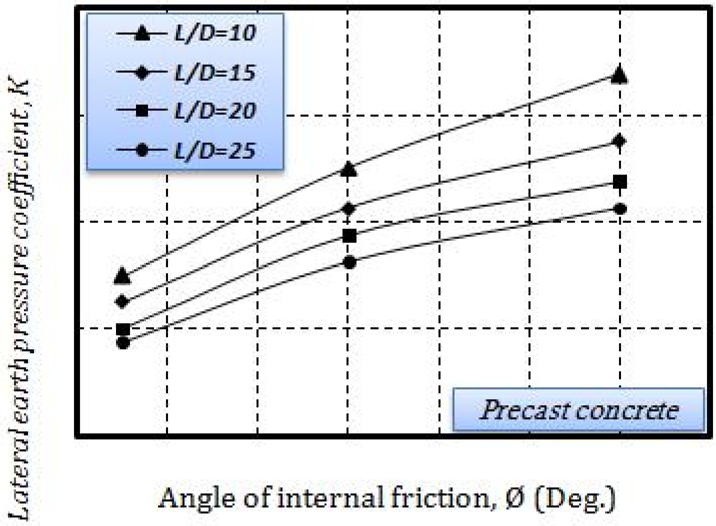


Figure (27): Proposed values of lateral earth pressure coefficient (K) for precast concrete piles in different relative density of sandy soil.

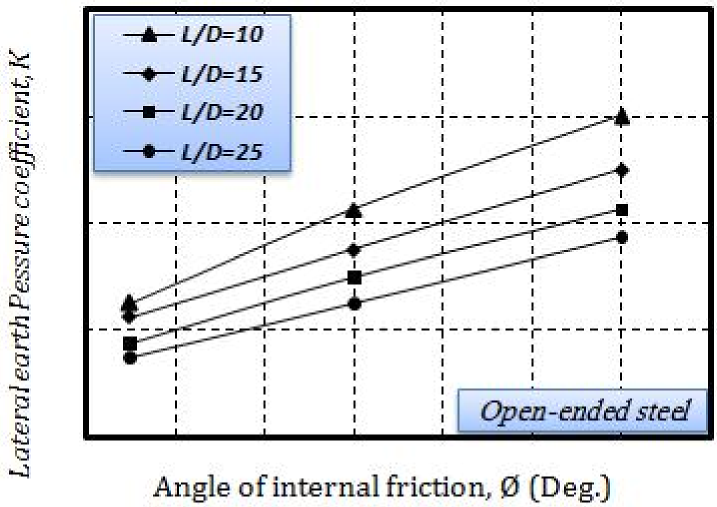


Fig .(28): Proposed values of lateral earth pressure coefficient (K) factor for open-ended steel piles in different relative density of sandy soil.

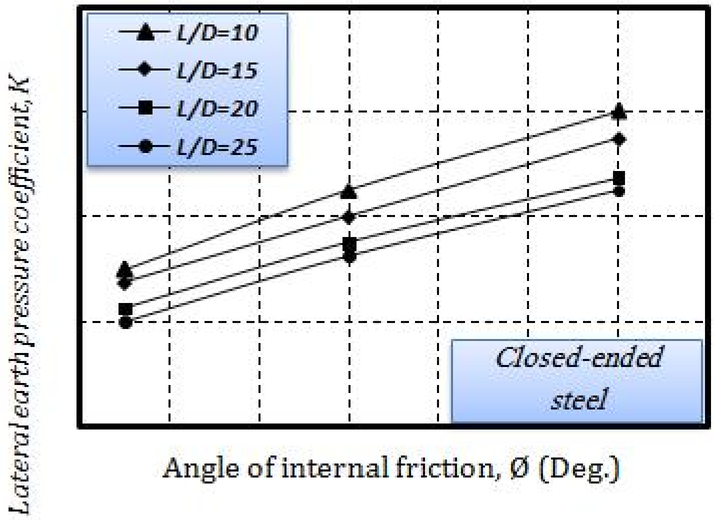


Fig .(29): Proposed values of lateral earth pressure coefficient (K) factor for closed-ended steel piles in different relative density of sandy soil.

5. Conclusions:

1. The observed pile capacity:

The value of observed pile load capacity increases as (L/D) ratio increases for all types of piles .Thus, the critical depth has no significant on pile load capacity for the pile ofL/D ratio (10-25).

- ***Pile Under Compression Load :***
  - Ø The observed pile load capacities for the precast concrete are(9%-12%) times that of the closed-ended steel pile.
  - Ø The observed pile load capacities for the precast concrete are (60%-63%) times that of the open-ended steel pile.
  - Ø The observed pile load capacities for the closed-ended steel pile are (39%-49%) times that of the open-ended steel pile.
- ***Pile Under Uplift load :***
  - Ø The observed uplift load capacities of the precast concrete are(36%-48%) times that of the closed-ended steel pile.
  - Ø The observed uplift load capacities of the precast concrete are(19%-36%) times that of the open-ended steel pile.
  - Ø The observed uplift load capacities of the open-ended steel pile are (10%-15%) times that of the closed-ended steel pile.

2. **Present values for bearing capacity factor (Nq) and the lateral earth pressure coefficient (K).**

- (Nq) factor and (K) coefficient are not constant values. They are a function of the pile type, sand relative density (loose, medium or dense) and the (L/d) ratio.
- For sand of a given relative density, (Nq) factor and (K) coefficient decreases as (L/d) ratio is increased.

  The values of (Nq) factor and (K) coefficient increases when relative density increases.

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