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The performance Evaluation of Skirted Foundation: A Review Study

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Abstract— Civil engineers are constantly developing innovative methods to improve the bearing capacity and reduce settlement of footing rest on the soil. The skirted foundation is one of the ways that civil engineers have devised to reduce settlement and increase the bearing capacity of footing rest on the soil. A skirted foundation can be more robust than traditional foundation types; its cost effect made it an alternative to a deep foundation in case of the low bearing capacity of the soil. Skirted foundations are usually used with offshore structures. The skirt prevents soil erosion since it prevents water from reaching the underlying soil. It works to confine soil between the skirt wall and make a resistance ageist sliding by skirt side.

Keywords— Skirted Foundation, Cost effect, settlement, deep foundation

1. Introduction

Gypseous soils are located in many regions in the world including Iraq, which covers more than (31%) of the surface area of the country [5]. It is considered a collapsible soil that represents challenges to geotechnical and structural engineering in the world [6].
The skirted foundation is one of the latest techniques for improving the foundation bearing capacity and has studied isolated foundations. This type of foundation is either made of concrete, or steel [1], which has a raft top footing connected with a skirt. The term "Skirt " is defined as one or more walls surrounding the foundation connected to the lower part of the foundation [2]. The skirt may be vertical or inclined wall works as a single unit with the foundation, which penetrates soil works to confine the soil between the walls and transfer load from the structure to soil. Skirts side/s reduces sliding failure. Skirts were used with a shallow foundation of rectangular, square, and circular foundation shape [1] [3]. It considered an alternative to using a deep foundation, and it is cost-effect compared with other improvement techniques [4][8][9][18]. Because it uses fewer materials for installation mechanisms and saves time [8], skirted foundations gradually replace the costly foundation. The behavior and performance of skirted foundations study through numerical and analytical studies. Laboratory test makes to determine the effect of increasing skirt length and how the skirt inclination angle effect improves the performance of the skirted foundation [1] [2].

2. Applications Of Skirted Foundation

Skirted foundations consider an alternative in using the surface, pier, and piles in oil and gas facilities and offshore structures (Prof. S. W. Thakare 1, 2016) (Adarsh Thakur, 2020) (Arekal Vijay1, 2016) (HUGO E. ACOSTA-MARTINEZi), 2008), jacket structures, and wind turbines (Byrne et al., 2012) (HUGO E. ACOSTA-MARTINEZi), 2008). The main applications of offshore foundations are listed below:

1- Jack-Up Unit Structure.

2- jacket unit structure.

3- Subsea system.

4- Wind turbine.

5- Petrol gas and oil plan.

6- Skirted foundation with bridge sub-structure (Byrne et al.2012) (Barari, et al., 2017).

A selection of applications of skirted foundations is shown in figures (1), (2), (3).

Figure 1: jack-up unit structure (Hambly, 1985) [10] [11].

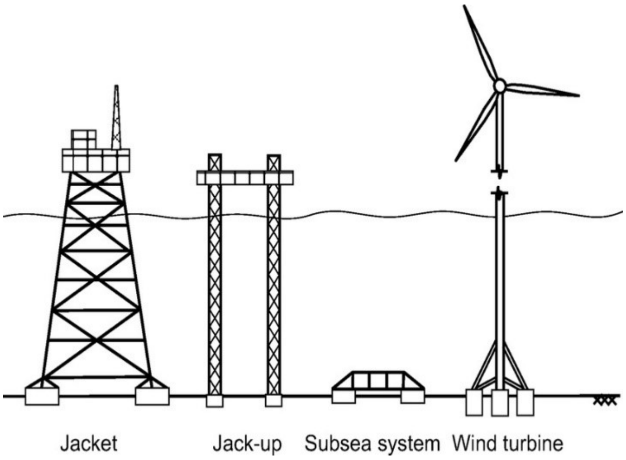

Figure 2: skirted foundation with Jacket, Jacket-Up, Subsea System, and Wind Turbine (Byrne et al., 2013) [11] [12].

[Center span: 500~600m] [center span: 2,000~2,500]

Figure 3: Skirted foundation with bridge sub-structure (Byrne et al.2012Tripathy,2013) [11][13].

3. Previous studies on skirted foundations

The previous studies present the contributions made by researchers about the skirted foundations. It aims to know the behavior and performance of skirted foundations through numerical and analytical studies. A structural skirt was used for a long time in offshore structures and other positions where pure water can be a problem (Bransby and Randolph 1998; Watson and Randolph 1998; Hu, Randolph,1999) [14] [15]. The finite element method (F.E.M.) was used by (Bransby and Randolph, 1999) to study the effect of vertical skirts with strip and circular foundation; the results indicated that using a skirt with a circular foundation is more efficient than the use of skirt with strip foundation [2][16]. The ANSYS software package was used to study the effect of using a skirt to prevent tilt due to eccentric loading; it was indicated that using a vertical skirt with footing will reduce tilt to almost zero when an eccentric load is applied on footing (Ahiyar and Patel, 2000) [2]. (Ortiz, 2001) investigated the inserting of a vertical skirt around the foundation, and the results showed an increase in the bearing capacity by 20% and a decrease in the settlement [2][17]. The behavior of one (or more) sides skirted foundation and the skirt inclined or vertical wall subjected to an inclined, and the eccentric load was studied by Saleh et al. (2008) The results showed the skirted foundation with inclined or vertical wall leads to confining the underlying soil and make a resistance against sliding by skirt side [2]figure (4). Table (1-1) Show some of the previous studies.

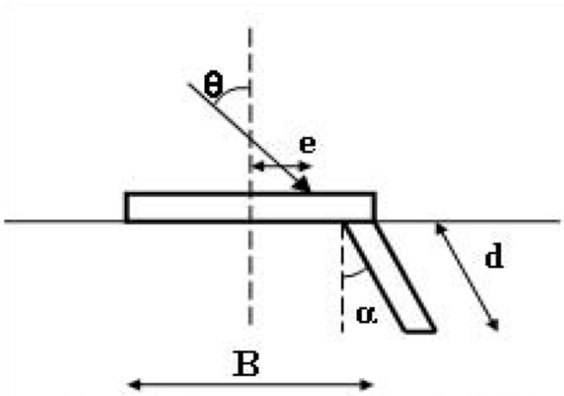

Figure 4: parameters used in the analysis (after Saleh et al., 2008) [2].

Table 1: Some previous studies

on skirted foundations.

Author	Description of work
Binquet and Lee, 1975	A theoretical solution has been proposed to design a reinforced shallow foundation[19].
Rao and Narhari,1979	Developing a skirted plug foundation indicated that the use of a skirt was generally helpful and applicable when settlement is restricted to a specific load [2].

Ranjan and Rao, 1985	Granular pile surrounded with skirts was used to improve the soil; it was found that the use of granular skirted pile has a lot of Potential for structures subjected to heavy load and sensitivity to settlement [2].
Mahmoud and Abd-Rabbo,1989	The effect of vertical reinforcement of soil on bearing capacity was studied; the study suggested that the bearing capacity will increase by 1.5 to 2 times compared with un-reinforced soil[17][19].
Bransby and Randolph, 1999	Use the finite element method (F.E.M.) to study the effect of vertical skirts with strip and circular foundation; the result indicated that the improvement with the use of a skirt with a circular foundation is more efficient than the use of a skirt with strip foundation [2][15][16][20].
Runrattanasin et al. (2003)	Study the performance of square skirted foundations resting on the sand using geotechnical tests and compare the results with surface foundation tests; the result shows that the length increases of skirts lead to an increase in bearing capacity.
Azzam and Nazir (2010)	Study the bearing capacity of footing resting on clay; the footing was with and without skirts. The study shows that the bearing capacity failure mechanisms of footing rest on clayey soil can improve by using sand piles with and without skirts [1] [16].
Saleh et al.(2010)	Studied the performance of skirted strip footing using" PLAXIS" version 7.1, the footing subjected to Eccentric Inclined Load they study various inclination

	angles of applied load, skirt length, and eccentricities load. The result shows that using a skirt with footing reduces the lateral movement of soil [1].
Pusadkar and Bhatkar (2013)	Using PLAXIS 2D" an investigation makes to study "Behavior of raft foundation with an inclined skirt." They conclude that using two-sided skirted raft footing leads to increase bearing capacity and reduced settlement [1] .
Al-Aghbari and Mohamedzein and El-Wakil, 2013	Study the states that adding the skirt to the shallow foundation can be an alternative technique to reduce settlement and increase bearing capacity. The authors also added that the state of the foundation interfaces influences the pressure-settlement behavior of the skirted foundation resting on the sand [17].
Abd Ali, L.H (2018)	Study the performance of skirted foundations supporting sand soil and subjected to vertical load. The results showed that using a skirt improves the load-carrying capacity of the foundation.
Jasim. A.K (2019)	Study the performance of the skirted foundation resting on gypseous soil. The result of the study shows that using of skirt lead to an increase in bearing capacity and reduced settlement
B.Naiket.al (2020)	The settlement of skirt isolated square footing was studied, and the study results show that the effectiveness of skirted foundation is height when the skirt contact with all sides of footing [17].

Thorough knowledge of previous studies, several parameters can be compared, which work to increase the bearing capacity and reduce settlement such as the depth of skirt, the number of skirts and its location, Shape of foundation, the relative density of soil, the surface of the skirt if is rough or not. The skirt location and the number of skirts affect the ability of the footing in improving bearing capacity and reducing settlement figure (5) shows the variation of skirt location.

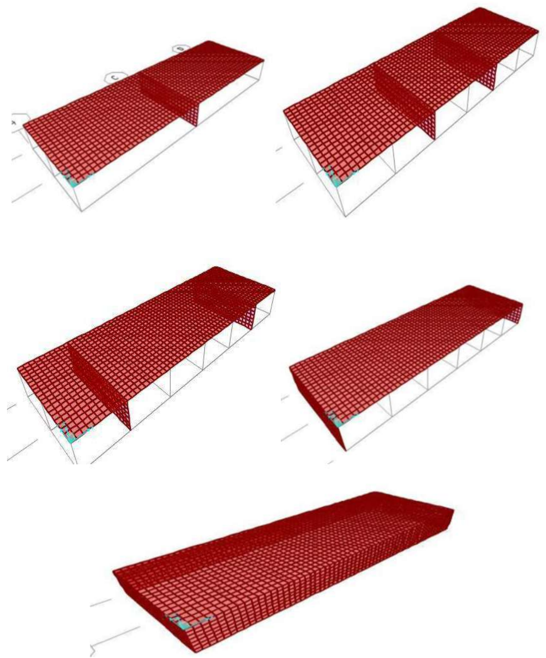

Figure 5: The variation of skirt location [21].

The relationship between number of skirts attached with footing and the failure loading is shown in figure (6).

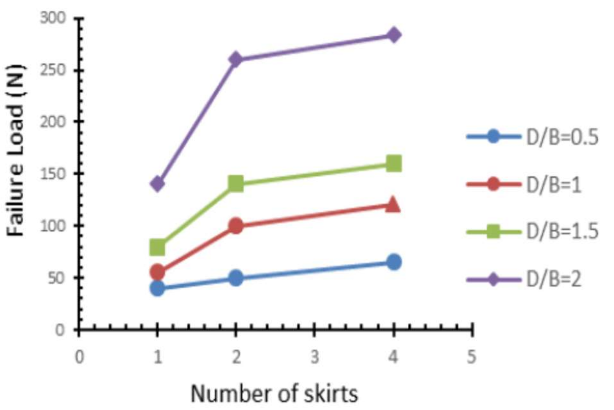

Figure 6: The effect of the skirt number with various D/B ratios Vs. Failure load. [1].

The increase in foundation width with and without a skirt also increases the bearing capacity figure (7).

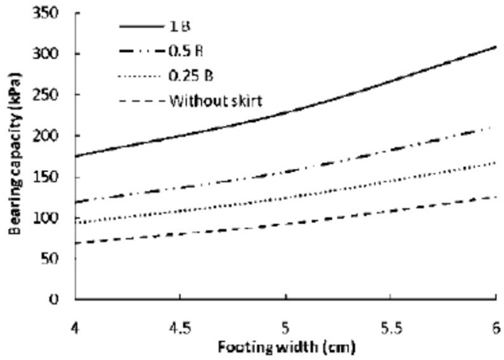

Figure 7: The variation of bearing capacity with increasing footing width with and without a skirt [19].

The inclination angle of the skirt increase the bearing capacity ratio and reducing settlement. Bearing capacity ratio (BCR) defined as the ratio of the ultimate bearing load in soil with using skirt to the ultimate bearing capacity in soil without using skirt (BCR=$\frac{q_u(with\ skirt)}{q_u(without\ skirt)}$). Figure (8) shows the effect of the inclination angle of the skirt on improving bearing capacity.

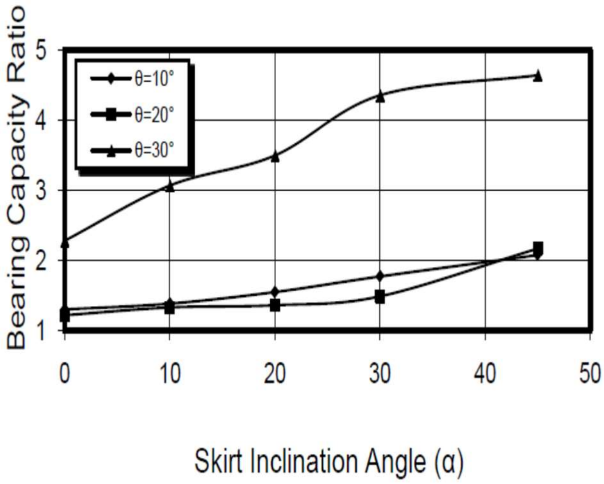

Figure 8: The effect of the inclination angle of the skirt on improving bearing capacity [2].

The inclination angle of applied load also affects bearing capacity, as shown in figure (9).

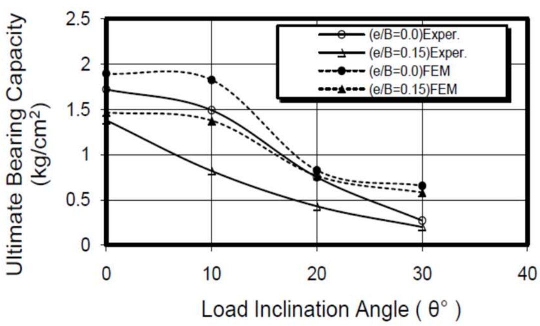

Figure 9: The effect of Load inclination angle on bearing capacity [2].

The soil density affects the behavior of skirted foundations and the degree of improving bearing capacity Where (L/D) is width or diameter to the skirt depth figure (10).

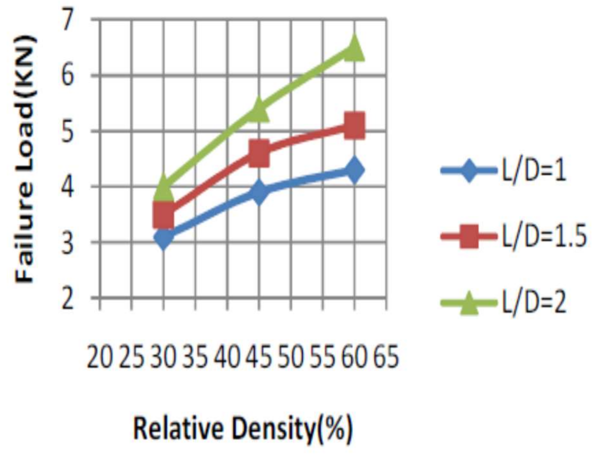

Figure 10: Show the relationship between relative density and failure load with various L/D ratios [4].

The state of the footing surface, if it is rough or smooth, will affect the bearing capacity factor (Nq, Nγ). For circular and strip footing with rough and smooth surface many tests were applied to give indication on the effect of footing surface (rough or smooth) on bearing capacity factor (N_γ). Figure (11) shows the relationship between surface condition (smooth or rough) of circular and strip footing and the bearing capacity factor (Nq, Nγ).

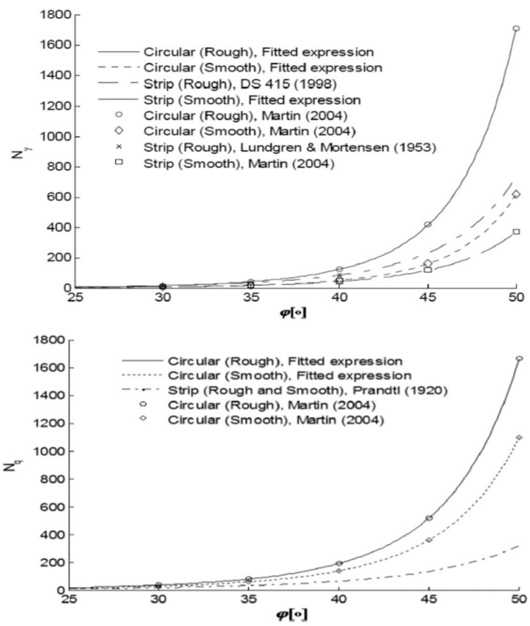

Figure 11: The relationship between footing surface (rough& smooth) of circular /strip footing and bearing capacity factor (Nq, Nγ) [11].

4. Bearing capacity of shallow foundation

Two independent conditions are required to make the foundation performance successful with the soil. The first condition is that the pressure on the foundation should not exceed the bearing capacity of the soil, and the second condition is that the settlement should not exceed the acceptable limits. For more than eighty years, experimental and theoretical research was conducted to accurately determine the shallow foundation's bearing capacity. A previous study showed that the bearing capacity of square footing was greater than those of the circular and rectangular footings [7]. Also, Previous research found solutions for flat circular, flat strip circular, and conical footing, but there are no solutions for skirted foundations. The flat foundation is a special case of a skirted foundation but without a skirt. The study of flat foundations can be considered a starting point for studying the skirted foundation. A general bearing capacity formula was estimated by **(Terzaghi 1943)** on a footing of length L and width B as shown in figure (12) subjected to vertical loading the footing is resting on soil with cohesion C, surcharge γ, and internal fraction angle φ. The bearing capacity equation can be written as follows:

$$Qult = C\,Nc + q\,Nq + 0.5B\,\gamma\,N\,\gamma$$

Where

Qult= ultimate bearing capacity.

q = $Df * \gamma$

Df = Foundation depth.

γ = Unit weight of soil.

B= footing width, and

Nc, Nq, and N γ = Bearing capacity factors. Additional correction factors for depth, Shape, load inclination, ground, and base factors are proposed by **(Hansen 1970 and Vesic, 1973).**

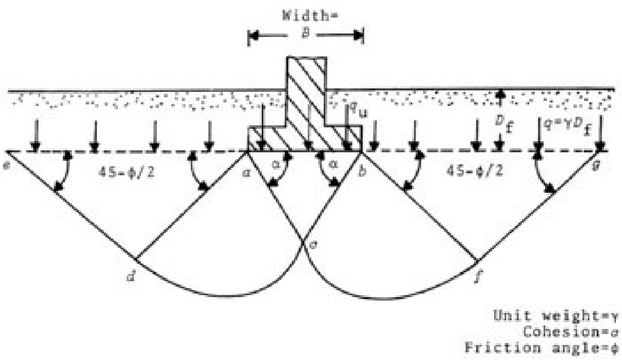

Figure 12: Bearing capacity failure mechanism in soil under a rough rigid continuous foundation subjected to vertical central load (Terzaghi, 1943).

5. Bearing capacity of skirted foundation

Adjustments were made to the general equation of the ultimate bearing capacity to much the shallow strip foundation with structural skirts that rested on dense sand and subjected to a central vertical load on footing have length L and width B Figure (13). The applied modification to the general ultimate bearing capacity equation can be summarized as follows:

(I) The soil above the lower edges of the skirts shall, in all cases, be treated as a surcharge, similar to the method proposed by **(Terzaghi 1943)** for shallow strip foundations.

(II) A skirt factor **(Fγ)** should be introduced into the second part of the general equation to determine the ultimate bearing capacity of a skirted shallow strip foundation, to calculate all the characteristics of the soil, foundation, skirts, and the loading, which effect on the ultimate bearing capacity of the foundation. The depth of the skirt can account for the effect of a skirt, so no factor is included in the first part of the bearing capacity general equation. The equation of the modified ultimate bearing capacity can be written as follow:

$$qult = \gamma(Dfs + Ds)Nq + \frac{1}{2} * B'\gamma N\gamma F\gamma$$

Where:

Dfs = depth to foundation base below ground level,

Ds = depth to the lower edge of the skirt below the foundation base,

B′= total foundation width with skirts (B+2Bs),

Bs = skirt thickness, and

Fγ= skirt factor.

Skirt factor (Fγ) is written as follow:

$$F\gamma = F\gamma f.F\gamma d.F\gamma r.F\gamma s.F\gamma c$$

Where:

Fγf =Foundation base friction,

Fγd =Skirt depth factor,

Fγr =Skirt side roughness factor,

Fγs =Skirt stiffness factor, and

Fγc =Soil compressibility factor.

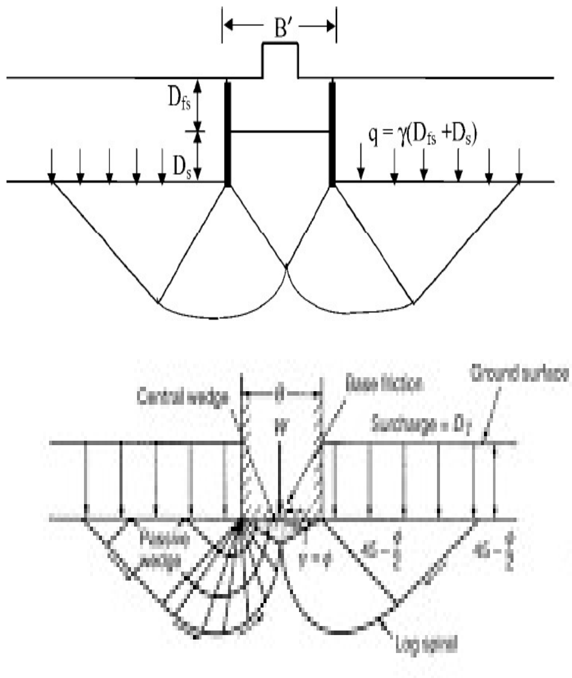

Figure 13: Failure mechanism in soil under continuous foundation with a structural skirt.

6. CONCLUSIONS

1- Skirted foundation cost effect made it an alternative to deep foundation in problematic soils such as soft or weak soils.

2- Using a skirted foundation improves bearing capacity and reduces settlement. Improving bearing capacity depends on footing width to skirt depth ratio (B/D).

3- Shape of the skirted foundation, relative density of soil, and the internal friction angle(particle-particle) and friction angle between soil and skirt material affect the degree of improvement.

4-Skirted foundations are usually used with offshore structures. The skirt prevents soil erosion since it prevents water from reaching the underlying soil.

5- The skirted foundation with inclined or vertical wall leads to confining the underlying soil and make a resistance against sliding by skirt side.

6-the bearing capacity of square skirted footing may be close to pier foundation bearing capacity when they have the same width.

7-The circular skirted footing bearing capacity is higher than the bearing capacity of the strip skirted foundation with the same skirt length.

8- Increasing friction angle of soil and the adequate size lead to an increase of the bearing capacity of the footing (Un-skirted, single and double skirt).

9-Using a skirted foundation on loose sand is more effective than using medium to dense sand.

10-Scarce studies are available in the literature on the use of skirted foundation on collapsible soil up to the date of preparing this paper.

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تقييم اداء اساس الحواف : دراسه استعراضيه

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الخلاصة – يعمل المهندسون المدنيون باستمرار على تطوير طرق مبتكرة لتحسين قدرة التحمل وتقليل هبوط الاساس الذي يستند على التربه.الاساس ذو الحواف هو إحدى الطرق التي ابتكرها المهندسون المدنيون لتقليل الهبوط وزيادة قدرة تحمل الاساس الموضوع على التربة. يمكن أن يكون الأساس ذي الحواف أكثر قوة من أنواع الأساس التقليدية ؛ هذا النوع من الاساس قليل الكلفه مقارنه بالاسس العميقه مما جعلها بديلاً لاستخدام الاساس العميق في حالة انخفاض قدرة تحمل التربة. عادة ما تستخدم الأسس ذات الحواف مع الهياكل البحرية. تمنع الحواف تآكل التربة لأنه يمنع الماء من الوصول إلى التربة الأساسية. يعمل على حصر التربة بين جدار الحواف وتعمل على مقاومة الانزلاق بواسطه الحواف.

الكلمات الرئيسية – "اسس الحواف" ، "تاثير التكلفه" ، "الهبوط" ،"الاسس العميقه".