ULTIMATE BEARING CAPACITY OF RIBBED STRIP FOOTING UNDER VERTICAL AND INCLINED LOADS

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ABSTRACT

This paper investigates the ultimate bearing capacity of a strip footing stiffened with ribs connected to its lower surface. The effect of number and depth of ribs on the bearing capacity are investigated numerically using the finite element method.

Different footings resting on a clayey soil are analyzed under vertical and inclined loadings.

A new efficiency factors (ER) is proposed to be added to the general bearing capacity equation in order to take the effect of ribs into consideration.

The results indicate that, the ultimate bearing capacity of a strip footing is improved via the addition of ribs.

KEY WORDS

Bearing capacity, finite element, ribs, strip footing.

NOTATIONS

a	: ribbed depth (m)
B	: footing width (m)
c	: soil cohesion (kN/m^2)

ER	: new efficiency factor for ribbed footing
E	: modulus of elasticity (kN/m^2)
N_c, N_q, N_γ	: bearing capacity factors
q_u	: ultimate bearing capacity
t	: footing thickness
γ	: unit weight of soil (kN/m^3)
ø	: friction angle of soil (degree)
μ	: Poisson's ratio
α	: Load inclination angle (degree)

INTRODUCTION

When two or three ribs are added to the lower surface of the strip footing, they may lead to changes in the behavior of soil under the footing, especially in the value of ultimate bearing capacity. The main aim of this research is to investigate the change in the ultimate bearing capacity when one or more ribs in the lower surface of the strip footing are present. The footing is subjected to vertical and inclined loads with different inclination angles. The finite element method in conjunction with an elasto-plastic constitutive model are used to simulate the non –linear behavior of clayey soil under ribbed strip footings. For clayey soil, Von-Mises yield criterion is adopted Smith and Griffiths (1998)[1]. The problem is analyzed as a plane strain one and a two- dimensional eight –nodded isoparametric quadratiral

(1998)[1]. The problem is analyzed as a plane strain one and a two- dimensional eight –nodded isoparametric quadratiral element is selected. More details about the formulation of such stress analysis problem can be seen in Zienkiewiez (1971)[2].

SOIL BEARING CAPACITY

The ultimate soil bearing capacity under a strip footing is generally calculated using equation (1), in which the bearing resistance is approximated by superposition of three basic components, Bowles (1988)[3]

$$q_u = c.N_c + q\ .N_{q}. + 0.5\gamma B N_\gamma \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where

B = foundation width.

c = soil cohesion.

γ = soil unit weight.

N_c, N_q, N_γ = bearing capacity factors = f(ø)

q_u = ultimate bearing capacity of soil

q = effective over burden pressure at foundation level.

ø = soil angle of internal friction.

The Finite element method was utilized with plasticity theory, to predict the ultimate bearing capacity for a footing resting on (c-ø) soil in conjunction with Terzaghi's equation. In order to isolate the contribution of each component, Griffiths (1982)[4] adopted three cases to find the bearing capacity factors:

cohesionless soil under uniform surface surcharge; cohesionless soil with self-weight.

If the footing rests on the surface of the soil, equation (1) reduces to;

$$q_u = c.N_c + 0.5\gamma B N_\gamma \qquad (2)$$

If the soil under footing is a clayly soil under undrained conditions, equation (2) could be rewritten as:

$$q_u = c.N_c \qquad (3)$$

For ribbed strip footings, equation (3) takes the form

$$q_u = c.N_{c\,c}.E_R \qquad (4)$$

In which (ER) is a new efficiency factor proposed in this study to calculate the ultimate bearing capacity of ribbed strip footings under vertical and inclined loads. The efficiency factor (ER) is calculated by estimating the ultimate bearing capacity of the ribbed strip footing using the finite element method and comparing that value with the bearing capacity of an ordinary strip footing under the same conditions, so that:

$$ER = (q_u)_{ribbed} / (q_u)_{strip} \qquad (5)$$

PARAMETRIC STUDY

An extensive parametric study was conducted regarding number, depth, location of ribs and load inclination angle. The computer program used in the analysis process was drawn from Smith and Griffiths (1998) and modified by Al-Jubair(2004)[5]. It employs a visco-plastic strain algorithm to predict the nonlinear behavior of the problem and, the failure is assumed to be reached when the vector of the differences between displacements at two successive iterations does not satisfy certain convergence criterion.

The basic geometric configurations of the problem are shown in Fig.1, whereas the finite element mesh is shown in Fig.2. The properties of soil and footing material (concrete) are listed in Table (1).

The results of analyses are presented in Table (2), which indicate considerable increase in bearing capacity due to the presence of ribs.

The load- settlement curves for footings with two and three ribs are compared to that of strip footings for a certain ribs depth (a/B =0.25) and different load inclination angles in Figs. (3 to 8). It is clear that the ribbed footing can withstand higher load with more settlement (in general) at failure. The increase in number of ribs has a little effect on the results.

In order to isolate, the effect of embedment depth from that of ribs, a burried strip footing, with embedment depth and thickness equal to ribs' depth, was analyzed. The results are compared in Fig.9. It can be realized that the increase in bearing capacity is attributed to the existence of ribs.

The effect of the location of one rib beneath the footing is also investigated. Fig.10 indicates that the rib location has no effect on the results for the axially loaded footings, whereas Fig.11 suggests the location of the rib to be beyond the point of application of the inclined load. Fig.12 shows the effect of ribs depth on the results. It is apparent that more improvement in bearing capacity can be gained by increasing the depth.

The variations of efficiency factors with load inclinations are shown in Figs.(13 to 15) for different values of ribs depth. It can be realized that the effects of ribs are more pronounced for inclined loading. Number of ribs or ribs' depth does not affect the general trends of curves.

CONCLUSIONS

The main points that can be drawn from this study are summarized as follows:

1. The ultimate bearing capacity of a ribbed strip footing on a clayey soil is grater than that of an ordinary strip footing with similar properties.

2. The recorded settlement at failure is more than that for flat strip footings.

3. The increase in bearing capacity may be attributed to the effects on the failure mechanism and slip surfaces.

4. Increasing the number and depth of ribs, increase the improvement in soil bearing capacity. The number of ribs has less effect on the results.

5. The improvement is more pronounced in footings subjected to inclined loadings and it is proportional with the angle of loading inclination.

6. If one rib is used, in a way similar to the key that resist sliding, its preferable location is beyond the point of application of the inclined loading.

REFERENCES

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[2]-Zienkiewicz,O.C.(1971),"The Finite Element Method" , McGraw- Hill, U.K.,

[3]- Bowles, J.E.(1988),"Foundation Analysis and Design", McGraw-Hill Book Co.-Singapore.

[4]- Griffiths, D. V.(1982),"Computation of Bearing Capacity Factors using Finite Elements", Geotechnique, Vol.32,

No.3, pp.195-202 Engineering Mechanics Division, Vol. 104. No.EM5,1978, pp.1043-1057.

[5]- Al- Jubair, H.S. (2004),"The Effect of Rigidity of Eccentrically Loaded Footings on the Load Carrying Capacity", Engineering & Technology, Vol.23, No.12, pp.790-798.

Table (1) Material properties

Material / Properties	Clay	Concrete
cu (kN/ m^2)	50	1650×10^2
ø (degree)	0.0	50
E (kN/ m^2)	0.5×10^5	250×10^5
μ	0.5	0.15

Table (2) Efficiency factors(ER) for ribbed footings

Efficiency factors for (a/B) =0.075						
α(deg.) / No.	0.0	10	15	20	25	30
2-ribs	1.082	1.125	1.184	1.23	1.274	1.34
3-ribs	1.12	1.166	1.236	1.262	1.333	1.44
Efficiency factors for (a/B) = 0.15						
2-ribs	1.168	1.195	1.22	1.313	1.362	1.42
3-ribs	1.208	1.242	1.278	1.371	1.433	1.55
Efficiency factors for (a/B) = 0.25						
2-ribs	1.216	1.285	1.305	1.411	1.506	1.59
3-ribs	1.232	1.322	1.355	1.48	1.567	1.71

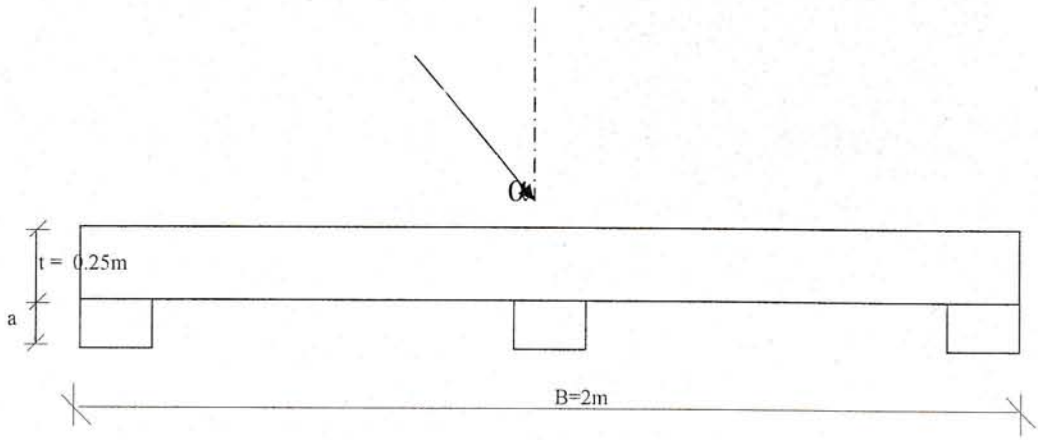

Fig.(1) The geometric configurations of the footing used in the

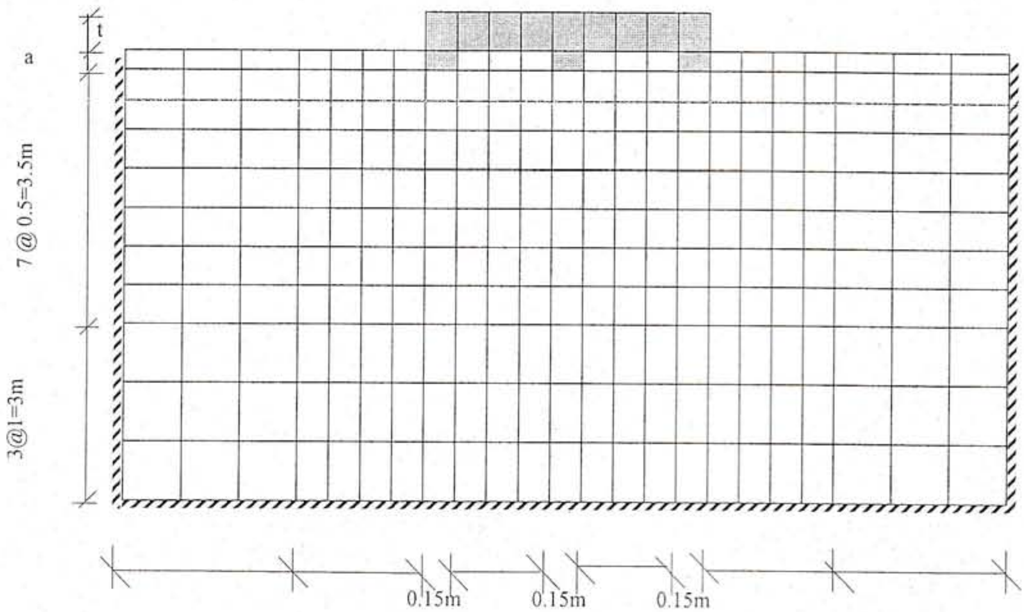

Fig.(2) Typical finite element mesh used in this study

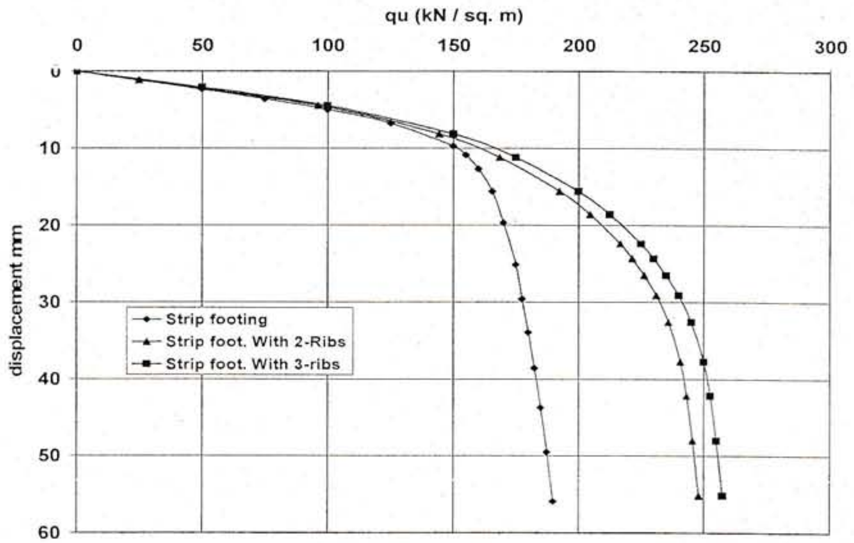

Fig.(5) Bearing stress – displacement curve for footing ,and (a/B)=0.25̊under inclined load with (α) =15

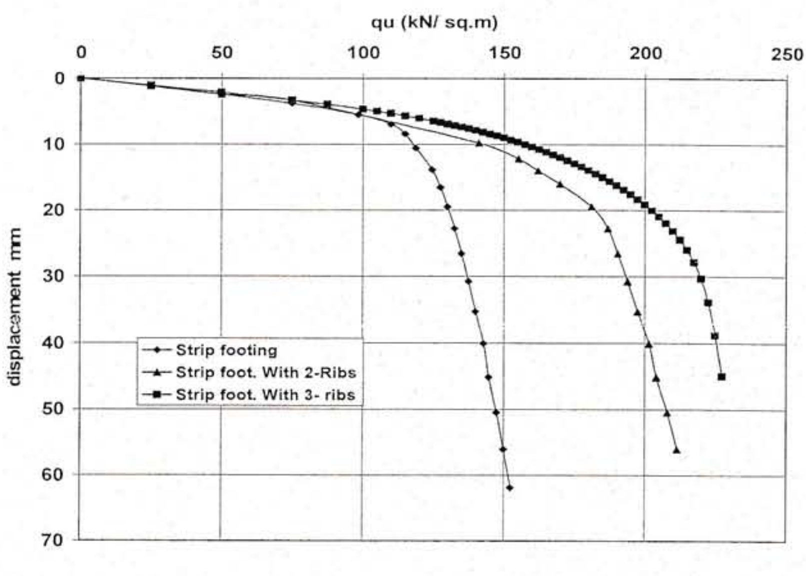

Fig.(6) Bearing stress – displacement curve for footing under inclined load with (α) =20 ,and (a/B)=0.25°

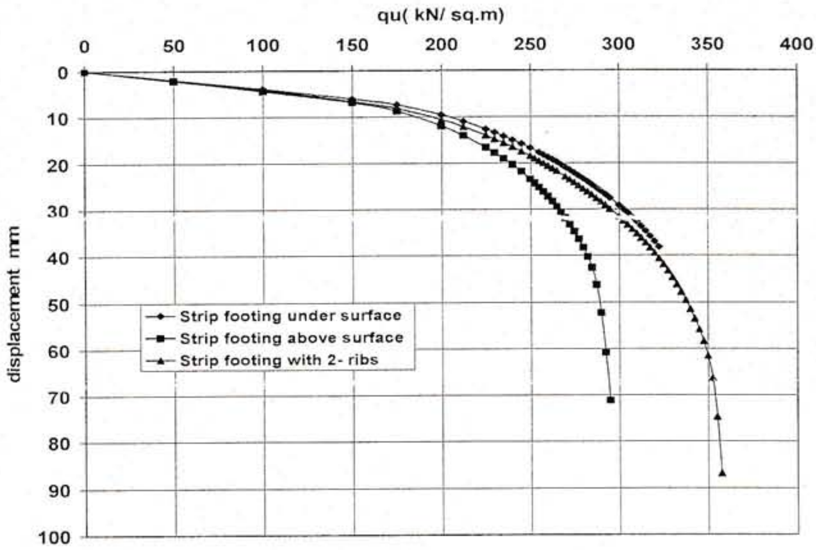

Fig.(9) Bearing stress – displacement curves, for footings under axial load and (a/B)=0.25, to show effect of depth

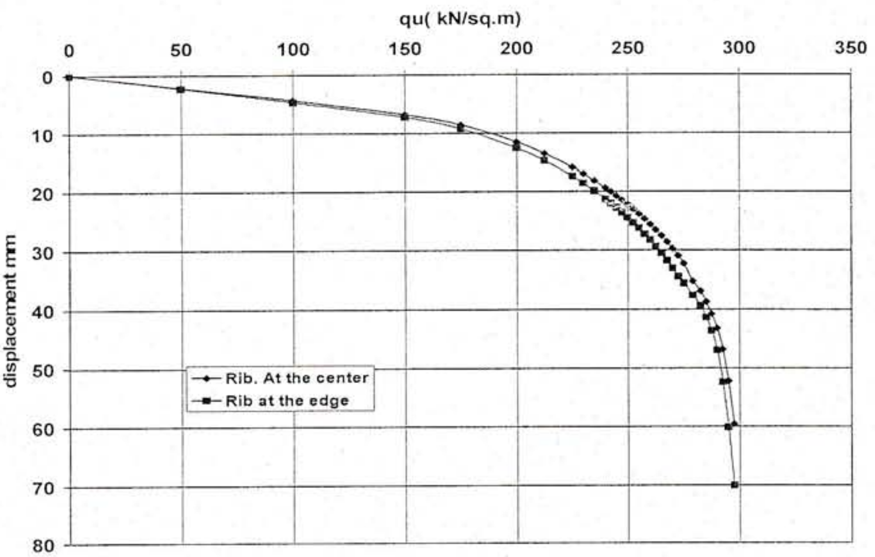

Fig.(10) Bearing stress – displacement curves, for footings having one rib under axial load and (a/B)=0.25,

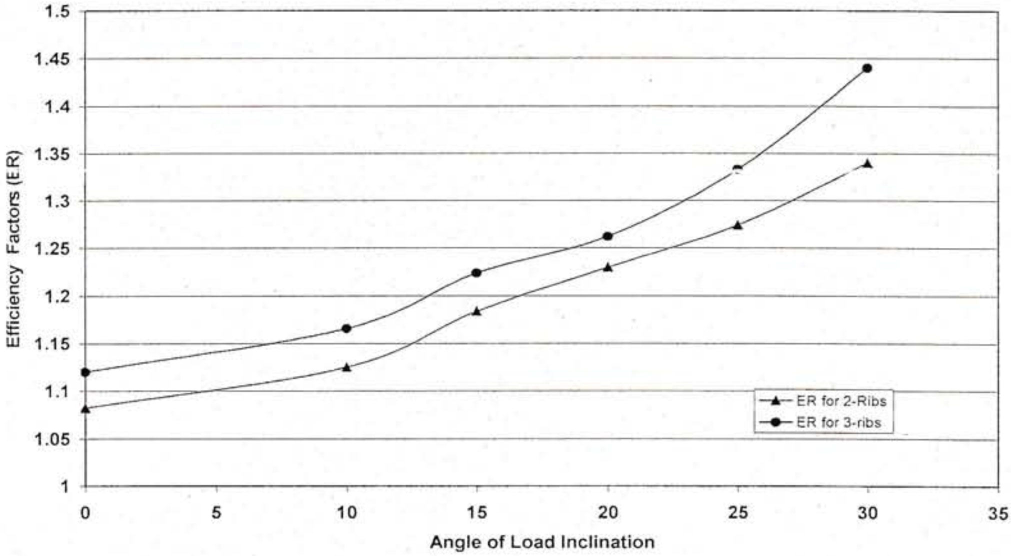

Fig.(11) Bearing stress – displacement curves, for footings .having one rib under inclined load with (α) =15

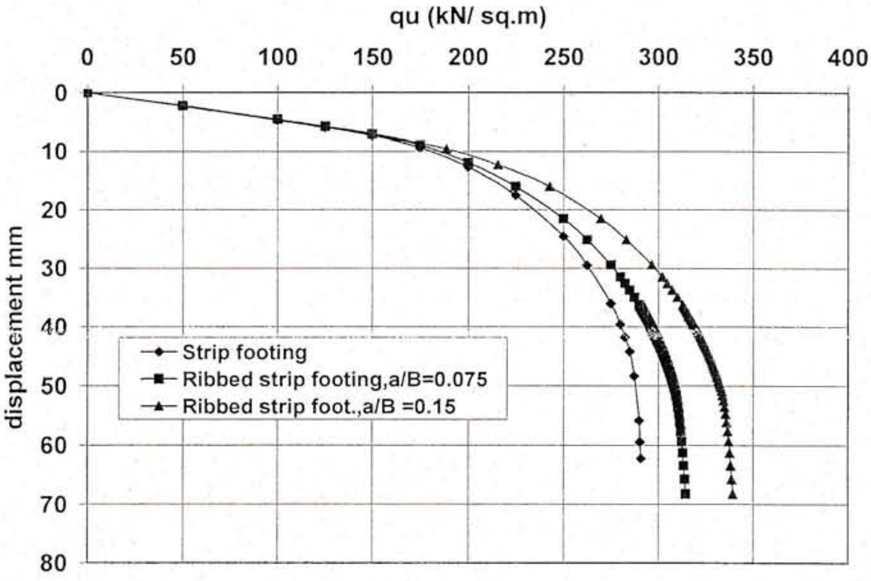

Fig.(12) Bearing stress – displacement curve for strip footing with two ribs under axial load for different value of (a/B)

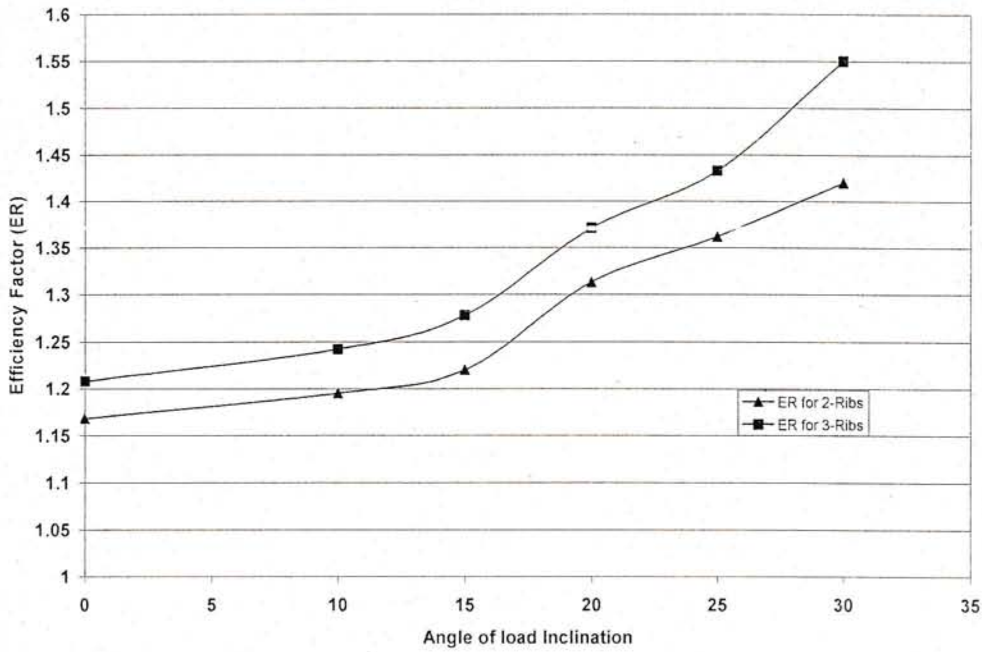

Fig.(13) Effect of load inclination angle (α) on the Efficiency factor (E_R) for footing having (a/B) =0.075

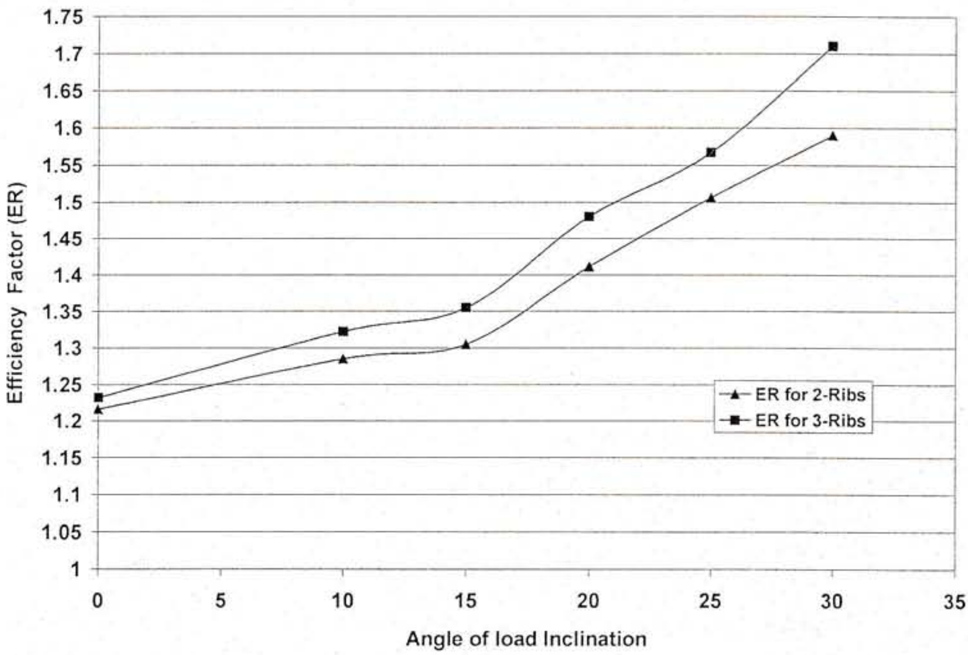

Fig.(14)Effect of load inclination angle(α)on the Efficiency factor(E_R)for footing having(a/B) =0.15

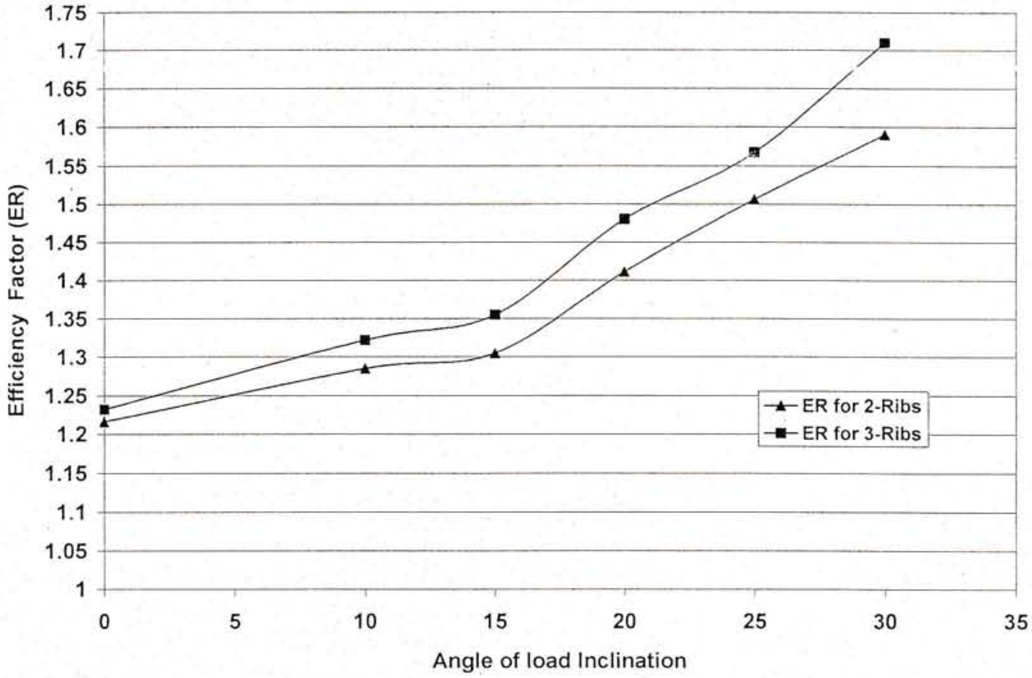

Fig.(15) Effect of load inclination angle (α) on the Efficiency factor (E_R) for footing having (a/B) =0.25

قابلية التحمل القصوى للاسس الشريطية المزودة بأضلاع تحتانية والمعرضة لاحمال متمركزة عمودية ومائلة

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الخلاصة

في هذا البحث تم حساب قابلية التحمل القصوى للاساس الشريطي المقوى باضافة اضلاع للسطح السفلي من الاساس باستخدام نمـوذج رياضـي وطريقـة العناصر المحددة. حيث تم استقصاء تاثير عدد الاضلاع المـضافة وعمـق هـذه الاضلاع على قابلية التحمل القصوى للاساس الشريطي المضلع.

كما تم تعريض الاساس الى حمل مركزي عمودي وحمل مائـل بزوايـا ميلان مختلفة وتم التعامل مع التربة الساندة على انها تربة طينية في ظروف عـدم البزل.

تم اقتراح معامل كفاءة جديد(ER) لكي يضاف الى المعادلة العامة لحساب قابلية التحمل القصوى للاساس الشريطي المضلع.

النتائج تشير الى ان قابلية التحمل للاساس الشريطي المضلع غالبا" ما تكون اعلى من مثيلاتها للاساس الشريطي الاعتيادي.

الكلمات الدالة

قابلية تحمل التربة، العناصر المحددة،اضلاع،اساس شريطي