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EFFECT OF RIGIDITY OF ECCENTRICAL LOADED FOR RECTANGULAR FOOTINGS WITH WIDTH DIRECTION ON THE CARRYING CAPACITY

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ABSTRACT

The finite element method is utilized to study the behavior of eccentrically loaded rectangular footings (with width direction only) on clayey and sandy soils. Also the effects of variation in footing dimensions and soil properties are investigated. It is proved that Meyerhof's principle of effective width gives, in general, conservative values of the load carrying capacity for footings resting on clay, whereas it overestimates those for footings erected on sand. For the studied practical ranges, the variations in footing dimensions ratio (thickness of footing/ width of footing) and the ratio of (E_f/E_s) where (E_f the elastic modulus for footing and E_s the elastic modulus for soil), have negligible effects on the values of carrying capacity reduction factor (R_f

KEY WORDS: Bearing Capacity, Eccentric Loading, Finite Element, Rectangular Footings, Soil.

تأثير الجساءة لأسس مستطيلة محملة لامركزيا" باتجاه العرض على سعة التحمل

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كلية الهندسة/جامعة تكريت

الخلاصة

استخدمت طريقة العناصر المحددة لدراسة تصرف أسس مستطيلة محملة لامركزيا " (باتجاه العرض فقط) مقامة على ترب طينية ورملية . كذلك تم استكشاف تأثيرات تراوح أبعاد الأساس وخصائص التربة . لقد برهن أن مبدأ العرض الفعال لمايرهوف يعطي (بصورة عامة) قيم محافظة لسعة التحمل با لنسبة للأسس المستقرة على الطين ، بينما يبالغ في تقدير قيمها للأسس المقامة على الرمل . للمجالات ذات الطابع التطبيقي قيد الدرس، فأن التراوح في نسبة أبعاد الأساس (سمك الأساس/ عرض الأساس) ونسبة (E_f/E_s) حيث إن (E_f معامل المرونة للأساس و E_s معامل المرونة للتربة)، كان له تأثيرات مهملة على قيم معامل تقليص سعة التحميل(R_f) .

INTRODUCTION

Eccentric loading may result from a load applied off the center of the footing or from a concentric load plus a bending moment. For the purpose of determining the pressure under the footing, the moment may be removed by shifting the vertical load to a fictitious location with an eccentricity (e = moment/vertical load) [Teng (1962)]. For determination of bearing capacity of an eccentrically loaded footing, the concept of effective width has been introduced by Meyerhof (1953).

Research and observations [Meyerhof (1953) and Hansen (1970)] indicate that the effective footing dimensions so obtained (**Fig.1**) are:

$L' = L - 2\,e_l \qquad B' = B - 2\,e_b \qquad (1)$

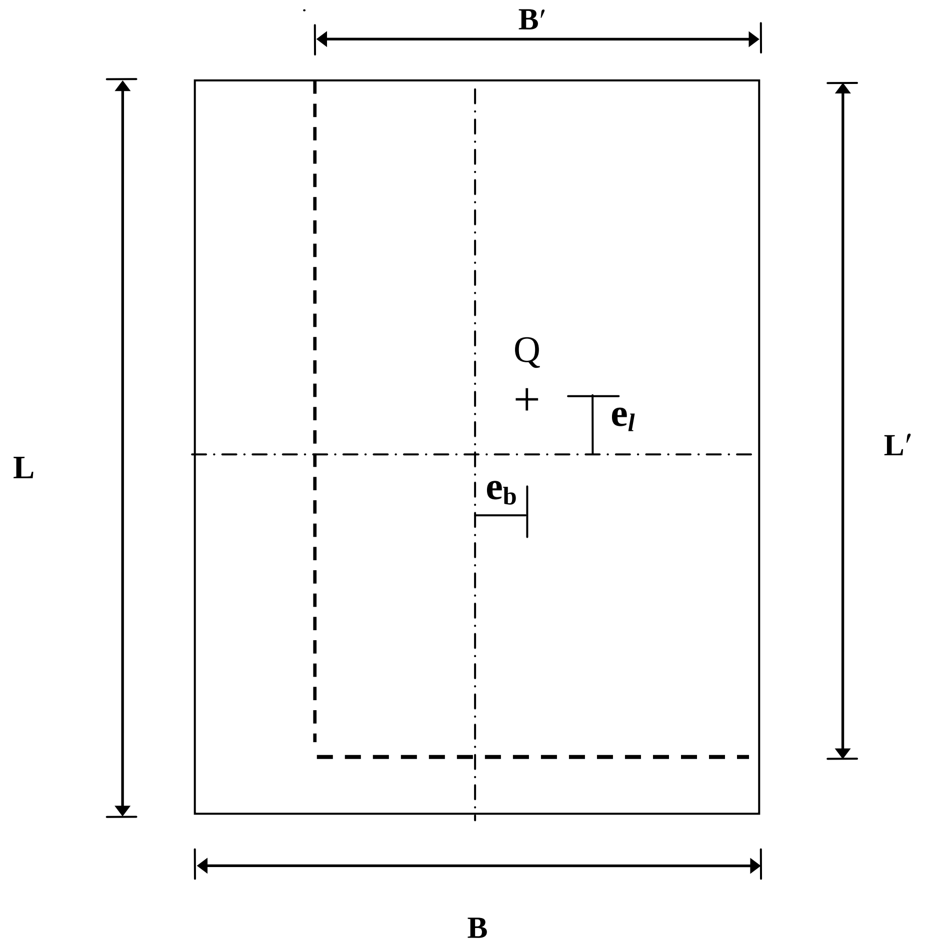

Fig (1): Footing subjected to eccentric loading**.**

These are used in subsequent computations to obtain the effective footing area as:

$A_f = B' L' \qquad (2)$

The ultimate bearing capacity, using Meyerhof or Hansen equations, is obtained by using the effective width in the third term and the effective dimensions in computing the shape factors [Bowles (1988)]. The ultimate footing load would be computed as:

$P_u = q_u\, A_f \qquad (3)$

An alternative method for obtaining the reduced bearing capacity for eccentrically loaded footings was proposed by Meyerhof (1953). In this procedure the bearing capacity of the footing is determined on the basis that the load is applied at the center of the footing. Then this value is corrected by multiplying with a reduction factor (R_f), obtained from (**Fig.2**).

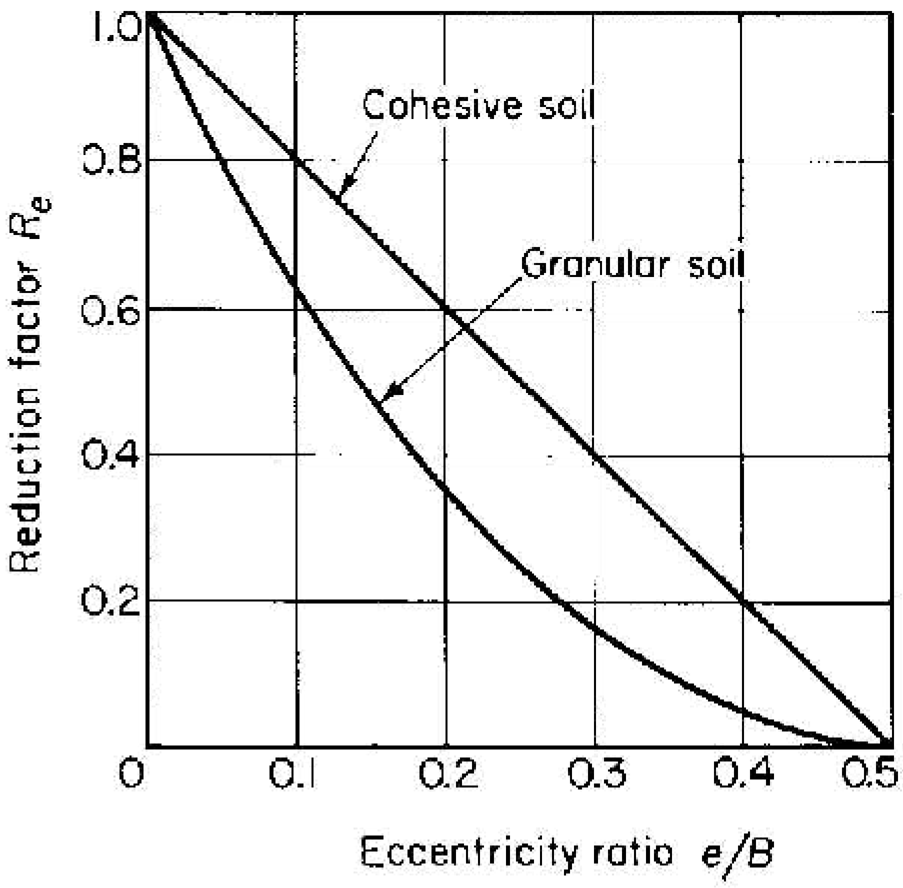

Fig (2): Bearing capacity of eccentrically loaded footing.
[After AREA as reported by Teng (1962)]

The concept of the effective width means that the bearing capacity of a rectangular footing resting on the surface of clay or sand deposit decreases linearly with the eccentricity of load. In cohesive soils, this linear relationship prevails, but in granular soils, however, the reduction is parabolic rather than linear referred to (**Fig.2**). In addition to that contradiction, no attention has been paid to the footing rigidity.

PROBLEM DEFINITION

Concrete rectangular footings resting on the surface of clayey and sandy soils are analyzed. It is well known that the rigidity is controlled through the variation of footing dimensions ratio and the ratio of elastic properties of footing material and the supporting soil. Footing thickness (t) was (0.3m and 0.5m) with constant width (B = 2m) and length (L = 4m) are considered. Each footing was subjected to varying eccentricity (e) ranging (0.0, 0.5 and 1.0m). The elastic modulus of concrete was taken as (E_f = 25000 MPa) [Winter and Nilson (1979)]. The geometric configurations of the problem are shown in (**Fig.3**) and (**Fig.4**) shows the mesh of finite element used in analysis. The properties of the soil and the footing are presented in **Table (1)**.

The finite element method is utilized to predict the ultimate load for each case. The general matrix equations for a deformable solid under external loading can be found in many texts [e.g. Bathe (1996)]. A computer program using 20-node brick elements (3dim.) was drawn from Smith and Griffiths (1998) and modified by the author herein. It employs the visco-plastic method to compute the response to loading of elastic-perfectly plastic materials. The following modifications are added to the program:

1. The capability of handling different element properties was introduced.
2. The possibility of manipulating frictional soils in addition to the cohesive soils.
3. It was modified to adopt Von-Mises and Mohr-Coulomb yield criteria simultaneously to account for the two types of soil.

Table (1): Properties of the soil and footing.

Parameter	Value for the soil	Value for the footing
Modulus of Elasticity (MPa)	50 to 100	25000
Unit weight (kN/m^3)	18	0.0
Angle of internal friction (degree)	sand 30 clay 0	50
Cohesion(kPa)	sand 0 clay 100	$165x10^3$
Poisson's ratio	0.3	0.15

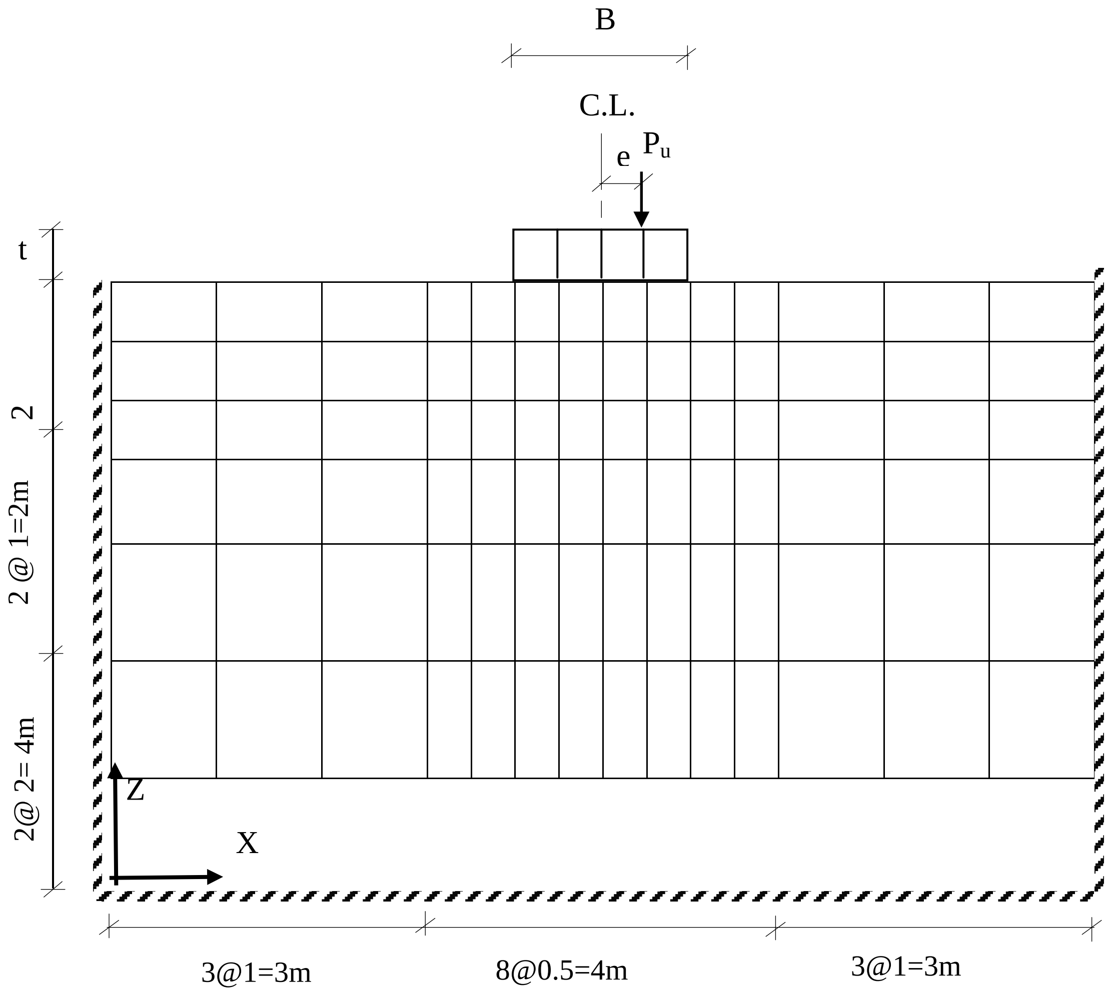

Fig (3): The geometric configurations of the problem (section in XZ plane)

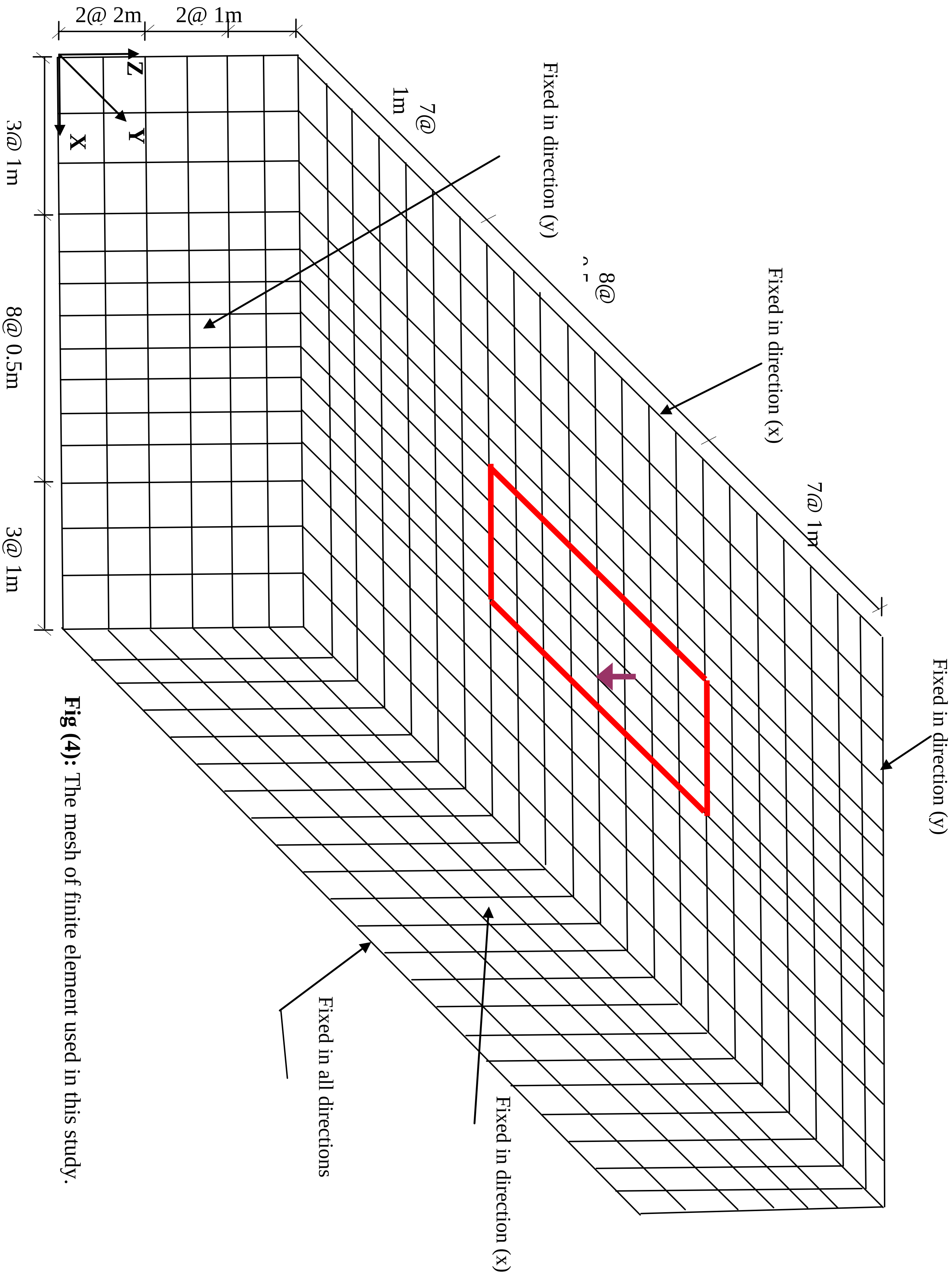

Fig (4): The mesh of finite element used in this study.

FOOTING REST ON CLAYEY SOIL

Saturated clayey soils under undrained conditions were adopted as supporting media. The elastic modulus for soil were varied (from 50 to 100 MPa) [Jamiolkowski *et al.* (1979) as reported by Barnes (2000)] to cover the practical range. The material is assumed to obey Von- Mises yield criterion. The results of analysis are shown in **Tables (2 and 3)**.

Table (2): Values of the reduction factor (R_f) for rectangular footings on clayey soils (t/B=0.25)

e/B — E_f/E_s	0	0.250	0.500
250	1	0.5733	0.3320
300	1	0.5735	0.3344
350	1	0.5730	0.3337
400	1	0.5690	0.3341
450	1	0.5740	0.3298
500	1	0.5738	0.3335

Table (3): Values of the reduction factor (R_f) for rectangular footings on clayey soils (t/B=0.15)

e/B — E_f/E_s	0	0.250	0.500
250	1	0.5820	0.3335
300	1	0.5825	0.3340
350	1	0.5818	0.3332
400	1	0.5820	0.3336
450	1	0.5833	0.3301
500	1	0.5835	0.3344

FOOTING REST ON SANDY SOIL

Different sandy deposits obeying Mohr-Coulomb yield function were selected to support the footings. The values of elastic modulus for soil were varied (from 50 to 100 MPa), [Bowles (1988)]. The results of the analyses are illustrated in **Tables (4 and 5)**. It can be noted that the magnitude of reduction factor decreases with an increase in the value of ratio e/B for both soils.

The lowest values of the reduction factor obtained from different combinations of footing dimensions and soil properties for each type are presented in the form of a design chart in **(Fig. 5)**. The line representing the values associated with Meyerhof's principle of effective width is also shown.

Table (4): Values of the reduction factor (R_f) for rectangular footings on sandy soils (t/B=0.25)

E_f/E_s \ e/B	0	0.250	0.500
250	1	0.1853	0.0355
300	1	0.1851	0.0327
350	1	0.1852	0.0337
400	1	0.1853	0.0344
450	1	0.1858	0.0350
500	1	0.1853	0.0343

Table (5): Values of the reduction factor (R_f) for rectangular footings on sandy soils (t/B=0.15)

E_f/E_s \ e/B	0	0.250	0.500
250	1	0.1817	0.0390
300	1	0.1825	0.0365
350	1	0.1819	0.0353
400	1	0.1818	0.0354
450	1	0.1833	0.0386
500	1	0.1837	0.0321

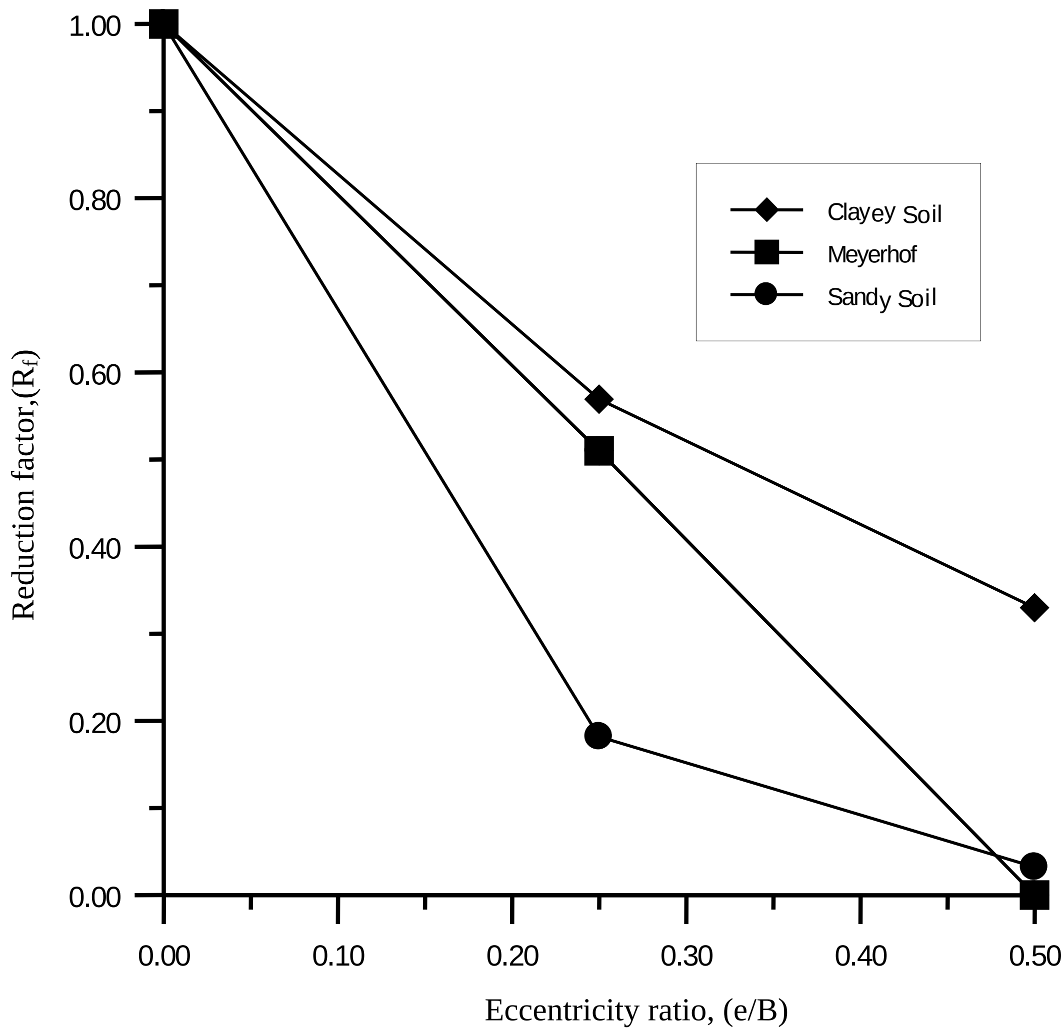

Fig (5): Reduction factors for eccentrically loaded footings**.**

CONCLUSIONS

The following conclusions are drawn from the present analysis:

1. Effects of the values of dimensions ratio (t/B) and elastic properties (E_f/E_s) was negligible on the values of reduction factor (R_f) due to eccentricity.
2. For both soils, the magnitude of reduction factor decreases with an increase in the value of ratio e/B.
3. Meyerhof's theory will not be applicable at the surface both for center and eccentric loads on sand soil.
4. The values of reduction factor obtained using the finite element method for footings on saturated clay or sand and those predicted according to the principle of effective width are almost the same and have linear trends.

5. Application of the principle of effective width gives conservative values for the load carrying capacity of footings on saturated clay.

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NOTATIONS

A_f : Footing effective area,(m^2).
B : Footing actual width, (m).
B' : Footing effective width, (m).
E_f : Elastic modulus of the footing material, (MPa).
E_s : Elastic modulus of the supporting soil, (MPa).
e : Loading eccentricity, (m).
e_b : Loading eccentricity parallel to the footing width, (m).
e_l : Loading eccentricity parallel to the footing length,(m).
L : Footing actual length, (m).
L' : Footing effective length, (m).
P_u : Ultimate load carrying capacity, (kN).
q_u : Ultimate bearing pressure, (kN/m^2).
R_f : Reduction factor due to eccentric loading.
t : Footing thickness, (m).