BEARING CAPACITY OF ECCENTRICALLY LOADED STRIP FOOTING NEAR THE EDGE OF COHESIVE SLOPE

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ABSTRACT

The finite element method is used to investigate the behavior of a strip footing constructed near the edge of a sloping cohesive ground. The effects of variation in footing closeness, loading eccentricity and slope angle are studied also. It is proved that Bowles method overestimates the load carrying capacity of the concentrically loaded strip footings on cohesive soils. Decreasing the distance between the footing and the slope edge, increasing the eccentricity and slope angle reduce the ultimate bearing capacity. Slope effect diminishes as the footing distance from the edge approaches (1.5) times its width.

KEY WORDS

Bearing capacity, finite element, slope, strip footing.

NOTATIONS

b : distance between footing edge and slope.(m)

B : footing width (m)

c : soil cohesion (kN/ m^2)

D : depth of surcharge

e : eccentricity of load (m)

E : modulus of elasticity (kN/m^2)

N_c, N_q, N_γ : bearing capacity factors

q_u : ultimate bearing capacity

γ : unit weight of soil (kN/m^3)

ø : friction angle of soil (degree)

μ : Poisson’s ratio

β : slope angle (degree)

INTRODUCTION

The bearing capacity of an eccentrically loaded footing maybe determined using the concept of useful (or effective) width proposed by Meyerhof (1953)[1]. It means that the bearing capacity of a strip footing resting on the surface of soil decreases linearly with the eccentricity of load.

For determination of bearing capacity of footings on sloping ground, design charts have been introduced by Meyerhof (1957)[2]. These charts utilize the concept of stability number to adjust the bearing capacity factors (Nc and Nγ) for slope effects.

Since the lack of soil on the slope side tend to reduce the stability of the footing, Bowles (1988)[3] developed a table for adjusted factors (Nc and Nq) based on the reduction in slip surface length and surcharge area, respectively.

The objective of this work is to explore the combined effect of loading eccentricity and the slope on bearing capacity and to provide the geotechnical engineer with useful design charts.

BEARING CAPACITY BY FINITE ELEMENT METHOD

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]

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

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: weightless cohesive soil with no surcharge; weightless, 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;

$$q_u = c.N_c + 0.5\gamma BN_\gamma \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

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

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

DESCRIPTION OF PROBLEM

A concrete strip footing resting on the surface of a clayey soil is analyzed. The geometric configuration of the problem is illustrated in figure (1). Material properties of both concrete [Winter and Nilson (1979)][5] and soil [Bowles (1988)][3] are listed in table (1).

The finite element method is utilized to predict the ultimate bearing capacity. The general matrix equations for a deformable solid under external loading can be found in many texts [e.g. Bathe (1996)][6]. A computer program using eight-node quadrilateral elements is drawn from Smith and Griffiths (1998)[7] and modified by the authors to account for the difference in element properties and the mesh generation of distorted geometry due to the presence of slope. It employs the visco-plastic method to compute the response to loading of elastic-plastic von Mises material.

RESULTS AND DISCUSSION

Footings at different distances from the edge of a slope, with variable slope angle and subjected to a range of eccentricities are analyzed. The results are shown in table (2). It is clear that the slope effect vanishes at a distance ratio (b/B = 1.5).

In order to isolate the effect of slope from that of eccentricity, table (3) is prepared for the case of (e/B = 0 and D/B = 0). The reduction factor of slope effect alone (Rs) represents the ratio between the bearing capacity of footing adjacent to slope and that of the same footing on flat ground. The results are compared to their (available) counterparts calculated using Bowles approach. It can be realized that Bowles approach gives higher values of (Rs). It should be mentioned that Al-Jubair (2004)[8] proved that the principle of effective width gives conservative values for the load carrying capacity of footings on cohesive soils compared to the finite element method.

Figures (2 through 7) show the variation of the reduction factor, due to slope and eccentricity effects (Rse), with the eccentricity ratio (e/B) for different values of slope angle (β) and distance ratio (b/B). It can be deduced that the reduction factor decreases with the increase of eccentricity ratio. The effect of slope angle is more pronounced at low values of distance ratio.

It is apparent from figures (8 through 10) that the reduction factor reduces as the slope angle increases. The effect of distance ratio increases with the eccentricity ratio increase.

It can be observed from figures (11 through 13) that the reduction factor is proportional with the variation of distance ratio. The effect of slope angle is greater for high values of eccentricity ratio.

CONCLUSIONS

1. For the studied values, which cover the practical ranges, it can be noted that the effect of slope diminishes as the distance ratio approaches (1.5).
2. Bowles approach overestimates the load carrying capacity of the concentrically loaded footings on slopes, compared to the finite element method.
3. Negative eccentricity reduces the bearing capacity to a lesser degree than its counterpart, since it deflects the failure zone away from the slope.
4. It is clearly demonstrated that the load carrying capacity is decreased as the footing becomes closer to a steeper slope and subjected to larger eccentricity.

5. The reduction in bearing capacity is more sensitive to the variation in eccentricity ratio, slope angle and distance ratio, respectively.

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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)Ultimate Bearing Capacity (kN/m^2) for strip footing near slope under for different values of (b/B, e/B, ß)

b/B =0.0

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10	240	292	237	200	170	142	110
20	225	275	220	185	165	130	100
30	215	262	205	170	145	115	90
40	200	245	185	150	125	110	80
50	180	228	165	135	110	90	70
60	165	215	145	115	195	75	60

b/B =0.25

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10	250	300	245	210	175	145	120
20	245	290	235	195	170	140	112
30	230	270	215	180	150	125	100
40	215	255	192	160	135	110	90
50	200	245	175	145	120	95	80
60	190	235	165	135	105	90	70

b/B =0. 5

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10	255	305	250	215	185	150	125
20	250	300	242	205	175	145	120
30	242	282	225	195	162	132	105
40	232	265	205	170	145	120	95
50	215	252	180	155		105	85
60	205	2452	175	142	115	95	75

b/B =0.75

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10	255	310	255	215	185	15	125
20	250	305	250	212	180	150	125
30	245	295	240	200	170	145	115
40	240	282	220	185	155	130	100
50	235	265	200	165	140	115	90
60	225	255	185	155	125	105	85

b/B =1.00

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10	255	310	255	215	185	150	125
20	255	310	255	215	185	150	125
30	255	300	250	210	180	150	125
40	245	290	232	195	165	140	115
50	242	275	210	175	150	125	100
60	232	265	200	165	135	115	900

b/B =1.25

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10	255	310	255	215	185	150	125
20	255	310	255	215	185	150	125
30	255	310	255	215	185	150	125
40	255	300	250	210	180	150	125
50	250	290	240	195	165	140	110
60	245	280	220	185	155	135	105

b/B =1. 5

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10	255	310	255	215	185	150	125
20	255	310	255	215	185	150	125
30	255	310	255	215	185	150	125
40	255	310	255	215	185	150	125
50	255	310	255	215	185	150	125
60	255	310	255	215	185	150	125

b/B =2.00

e/B ß	-0.1	0.0	0.1	0.2	0.3	0.4	0.5
0.0	255	310	255	215	185	150	125
10							
20							
30							
40							
50							
60							

Table (3) The Values of slope reduction factor (Rs) for different slope angles (β) And distance ratios (b/B) [(e/B = 0) , (D/B = 0)].

β (deg) / b/B	0	10	20	30	60	Approach
0	1	0.942	0.887	0.845	0.694	F.E.M.
	1	0.951	0.901	0.852	0.704	Bowles
0.75	1	1	0.984	0.952	0.823	F.E.M.
	1	1	1	1	1	Bowles

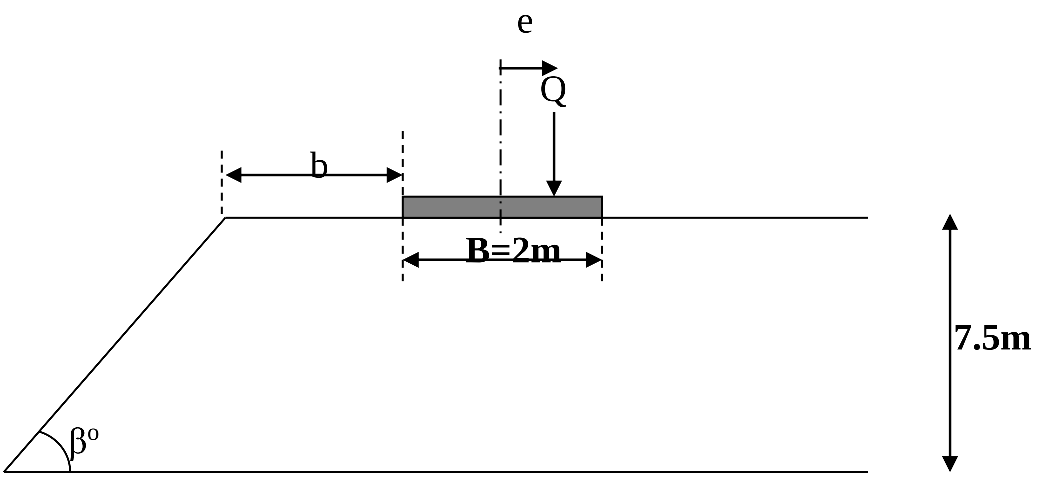

Fig.(1) The geometric configurations of the footing used in this study

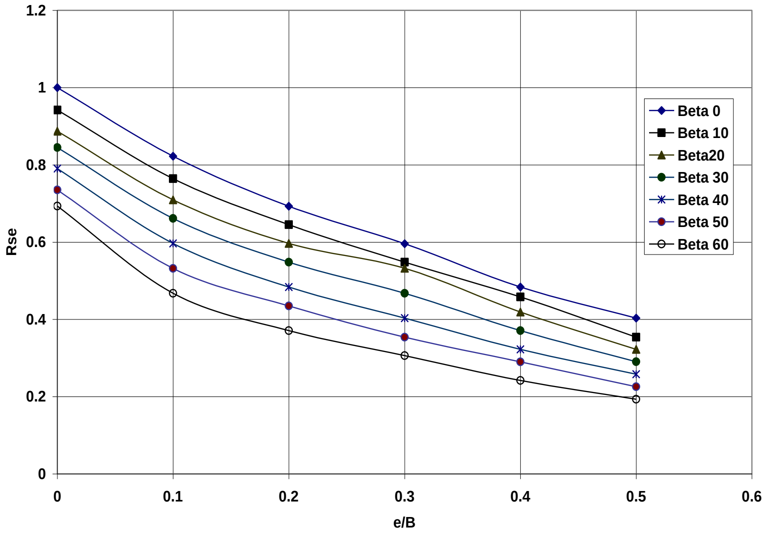

Fig.(2) Reduction factors Rse versus eccentricity ratio e/B for b/B = 0.0.

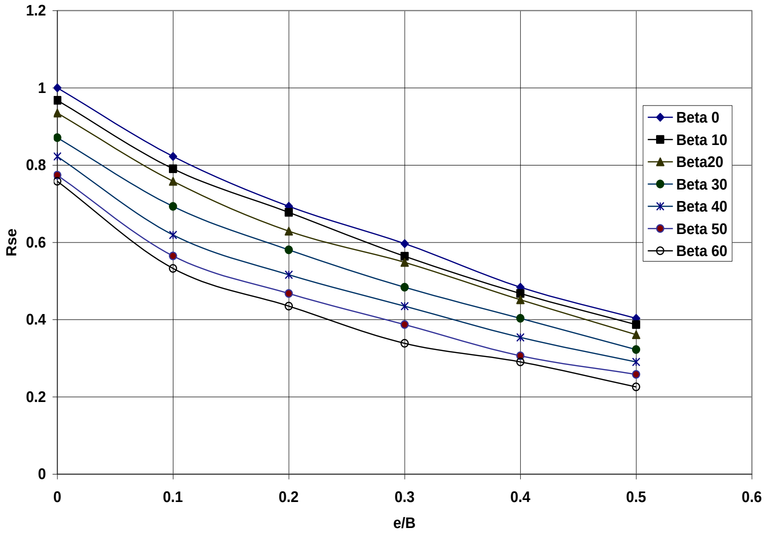

Fig.(3) Reduction factors Rse versus eccentricity ratio e/B for b/B = 0.25

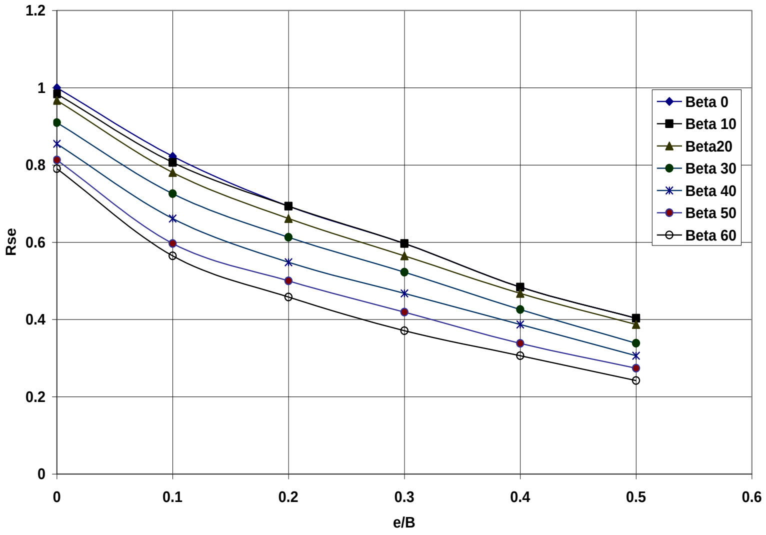

Fig.(4) Reduction factors Rse versus eccentricity ratio e/B for b/B = 0.5

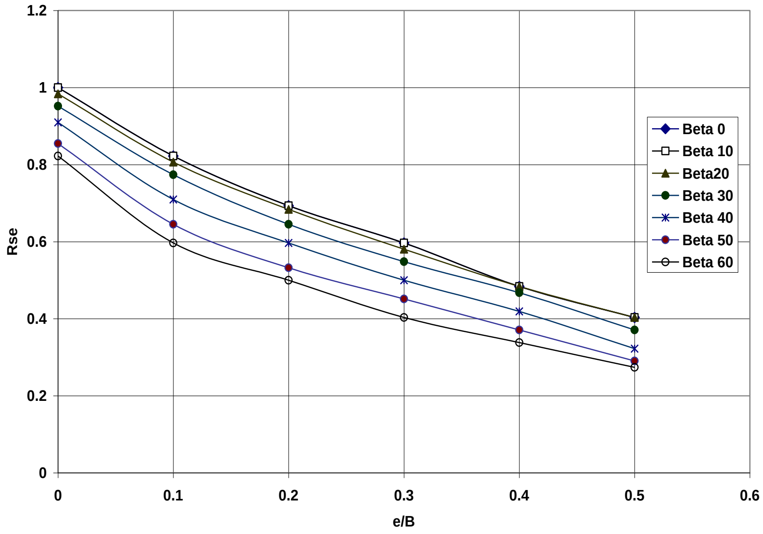

Fig.(5) Reduction factors Rse versus eccentricity ratio e/B for b/B = 0.75

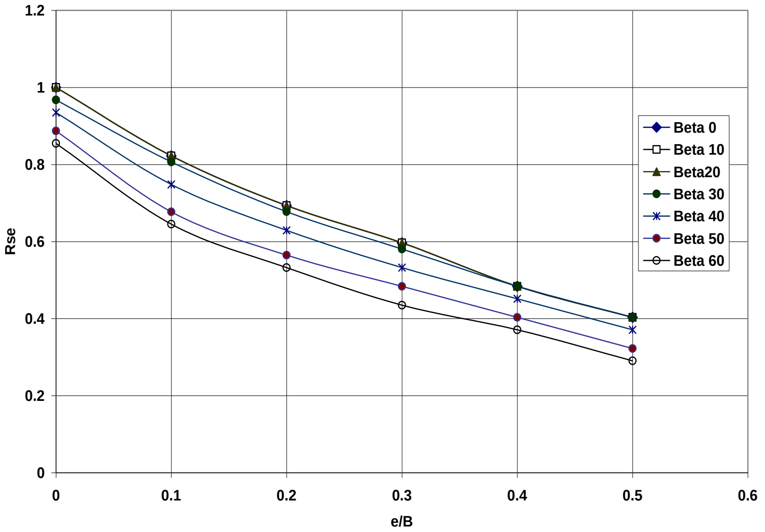

Fig.(6) Reduction factors Rse versus eccentricity ratio e/B for b/B = 1.0

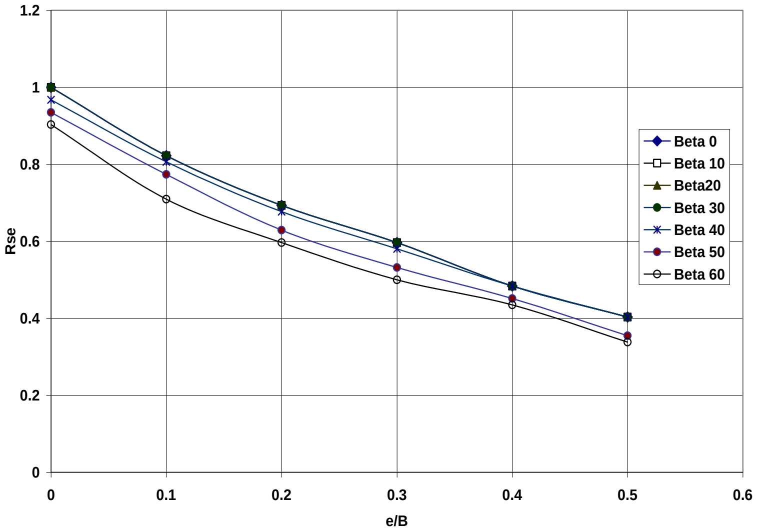

Fig.(7) Reduction factors Rse versus eccentricity ratio e/B for b/B = 1.25

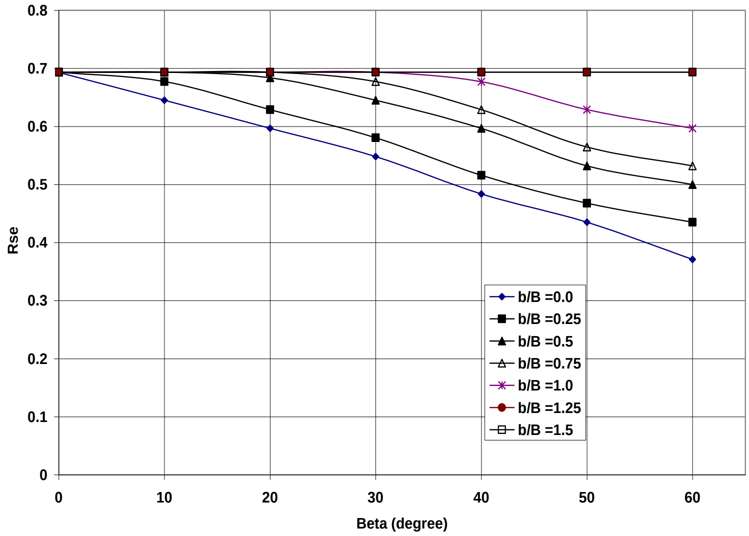

Fig.(8) Reduction factors Rse versus slope angle (β) for e/B = 0.0.

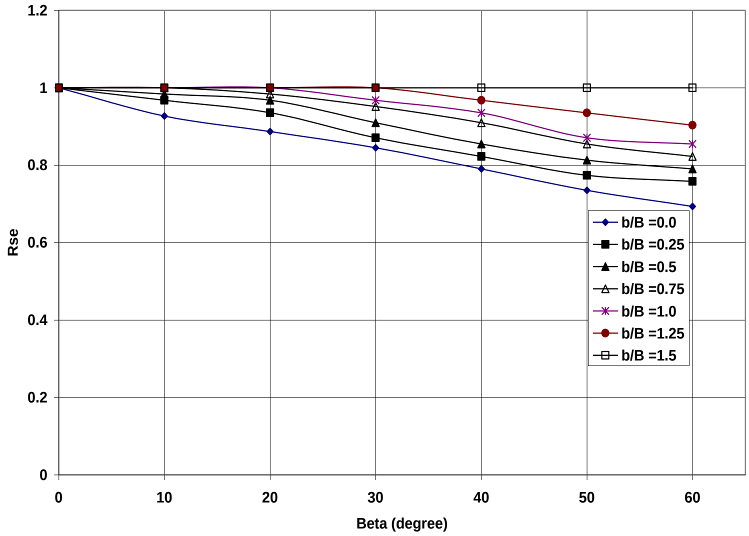

Fig.(9) Reduction factors Rse versus slope angle (β) for e/B = 0.2

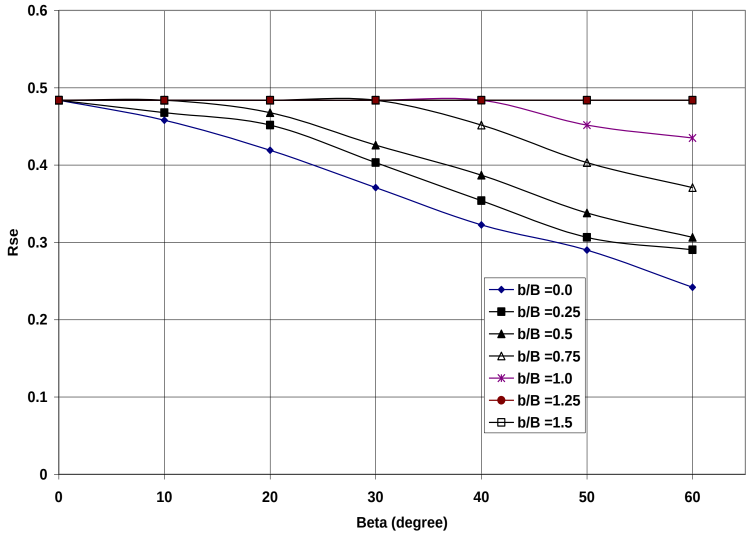

Fig.(10) Reduction factors Rse versus slope angle (β) for e/B = 0.4

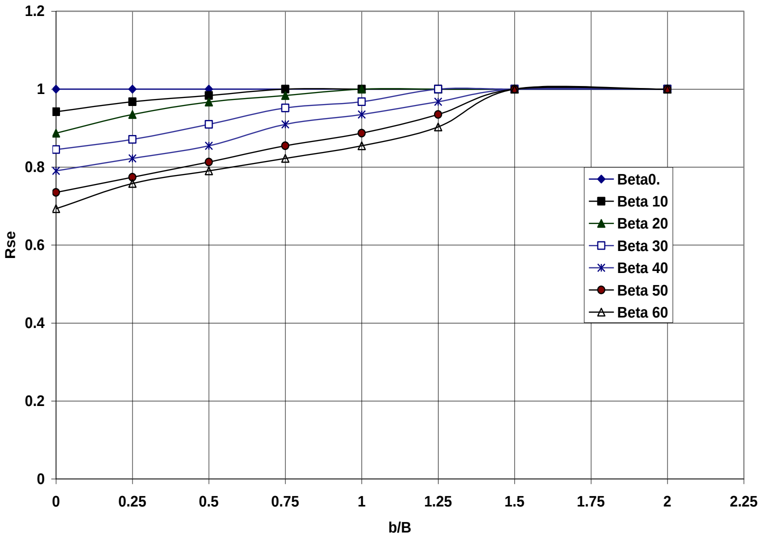

Fig.(11) Reduction factors Rse versus edge distance ratio b/B for e/B = 0.0.

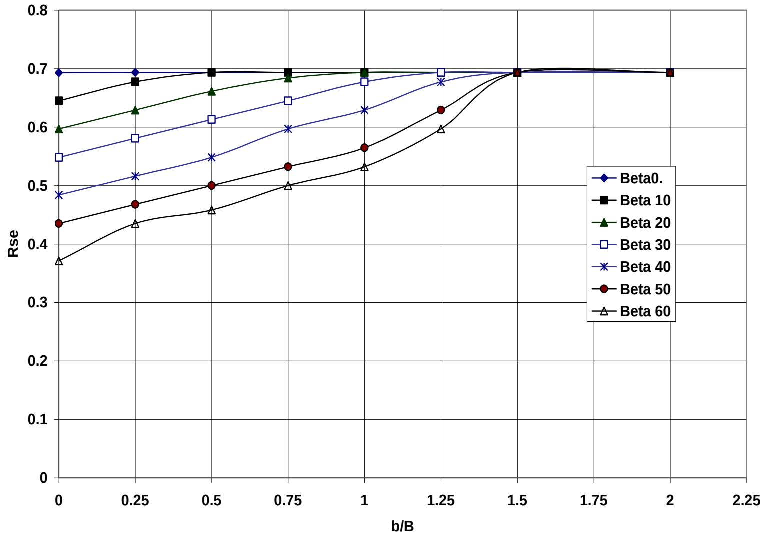

Fig.(12) Reduction factors Rse versus edge distance ratio b/B for e/B = 0.2

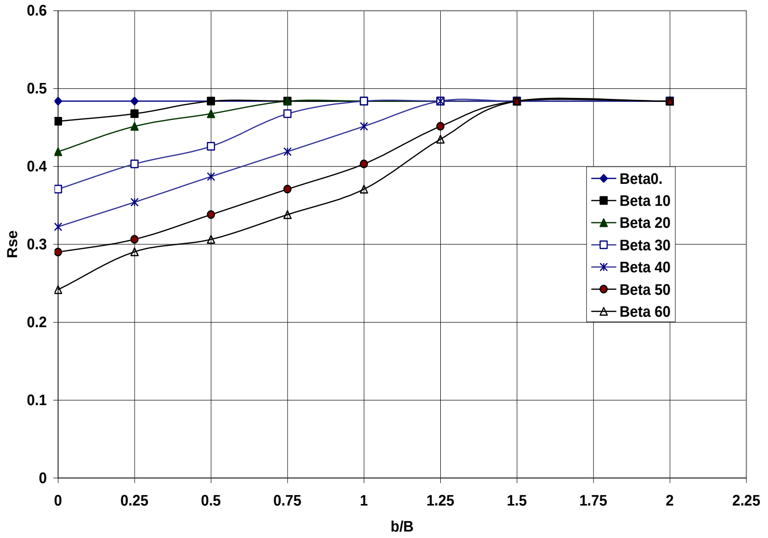

Fig.(13) Reduction factors Rse versus edge distance ratio b/B for e/B = 0.4

قابلية التحمل القصوى للاساس الشريطي المحمل مركزيا" والمجاورة للمنحدرات

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الخلاصة

في هذا البحث تم استخدام طريقة العناصر المحددة للتحري عن تصرف الأساس الشريطي المنشأ بالقرب من المنحدرات التماسكية والمعرض لأحمال عمودية غير مركزية . تأثير تغير، زاوية ميلان المنحدر ،بعد حافة الأساس عن المنحدر، و تأثير اللامركزية للأحمال المسلطة على قابلية التحمل القصوى للأساس الشريطي المحمل لامركزيا" والمجاور للمنحدرات تم التحري عنها ايضا".

أظهرت النتائج ان تناقص المسافة بين الأساس وحافة المنحدر ، وزيادة اللامركزية للحمل وزيادة زاوية ميل المنحدر تقلل من قابلية التحمل القصوى للأساس الشريطي المجاور للمنحدرات والمعرض لأحمال غير مركزية.كما أظهرت النتائج ان تأثير المنحدر يتلاشى عندما يكون بعد الأساس عن المنحدر **(1.5)** مرة بقدر عرض الأساس.

الكلمات الدالة

قابلية تحمل التربة، العناصر المحددة،المنحدرات،اساس شريطي.