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Finite Element Analysis for Bearing Capacity of Rectangular Footing Resting Near Sloped Cohesive soil

Dr. Jawdat K. Abbas — **Assistant Professor**
Ayad S. Sabbar — **Engineer**
Civil Engineering Department -University of Tikrit

Abstract

Finite element method is used to investigate the ultimate bearing capacity of rectangular footing resting on cohesive soil near slope. The effect of footing aspect ratio (L/B), distance ratio (b/B), and slope angle (β) on the bearing capacity are calculated. A new reduction factor (R_s) is proposed to compute the ultimate bearing capacity for rectangular footing adjacent to slope of cohesive soil from ultimate bearing capacity for similar rectangular footing resting on ground level of cohesive soils. This study shows that the ultimate bearing capacity for rectangular footing adjacent to slope of cohesive soils decreases when slope angle (β) and aspect ratio (L/B) increases. Also the ultimate bearing capacity increases when the distance ratio (b/B) increases. Finally The effect of slope diminishes as the distance ratio (b/B) equal, or exceeds 0.75.

Key words: Bearing capacity, finite element, slope, rectangular footing.

التحليل بطريقة العناصر المحددة لحساب قابلية التحمل للأساس المستطيل المجاور لمنحدر طيني

الخلاصة

في هذا لبحث استخدمت طريقة العناصر المحددة لحساب قابلية التحمل القصوى لأساس مستطيل مستند إلى تربة طينية ومجاور لمنحدر. تم التحري عن تأثير تغير،نسبة طول الأساس إلى عرضه ،بعد الأساس عن حافة المنحدر إلى عرضه وزاوية ميل المنحدر على قابلية التحمل .تم اقتراح معامل جديد يدعى معامل التقليل (Reduction Factor Rs) لغرض حساب قابلية التحمل القصوى للأساس المستطيل المجاور لمنحدر طيني بالاعتماد على قابلية التحمل لنفس الأساس موضوع على ارض مستوية. أظهرت النتائج إن قابلية التحمل للأساس المستطيل المجاور لمنحدر طيني تقل مع زيادة زاوية ميل المنحدر وزيادة نسبة طول الأساس إلى عرضه.كما بينت النتائج إن قابلية التحمل تزداد بزيادة المسافة التي يبعد بها الأساس عن قمة المنحدر. وان تأثير زاوية الميل يتلاشى عندما تكون نسبة المسافة التي يبعد بها الأساس عن قمة المنحدر إلى عرض الأساس تساوي أو تتجاوز (0.75).

الكلمات الدالة:قابلية تحمل التربة، العناصر المحددة،المنحدرات ،أساس مستطيل.

Notations

b distance between footing edge and slope.(m)
B : footing width (m)
c : soil cohesion (kN/m^2)
E : modulus of elasticity (kN/m^2)
N_c, N_q, N_γ : bearing capacity factors
q_u : ultimate bearing capacity
R_s : reduction factor
γ : unit weight of soil ($kN \backslash m^3$)
φ : friction angle of soil (degree)
μ : Poisson’s ratio
β : slope angle (degree)

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Introduction

Foundations are sometimes placed on slopes, adjacent to slopes or near a proposed excavation. Presently, in the case of bridges, footings are usually not placed within the fill and instead, pile support or other deep foundations are considered, which may not be the most economical solution. Foundations are also sometimes situated near the open section of the underground railways. In such situation, the problem becomes that of obtaining the minimum value of the bearing capacity from the point of view of (i)foundation failure and (ii)over all stability of the slope. For footing in the case of non-cohesive soil, the bearing capacity will always be governed by the foundation failure, while in cohesive materials, the bearing capacity of the foundation may be limited by the stability of the whole slope(Sud 1984)[1]. Several theories are available to compute the ultimate bearing capacity of foundations on slopes. However, the best estimation of both bearing capacity and settlement is possible only if the pressure settlement characteristics of the foundation soil are known.

Meyerhof (1957)[2] had studied the problem of the ultimate bearing capacity of foundation on slopes. He extended his classical theory of bearing capacity of foundation on level ground and combined with theory of the stability of slopes to cover the stability of foundations on slopes. The slip lines were constituted by taking into account the slope angle, the distance from the edge of the slope and the angle of shearing resistance.

A few approaches by 3-D analysis of slope stability have been proposed in the past decade or so. The method proposed by Hovland (1977)[3] and Chen (1982)[4] seems to be an explicit extension of the plain strain slice method, to account for the spatial failure mechanism the slice replaced by columns, and equilibrium of the columns was required. The 3-D column method inherits the approximate nature of slice analysis, and questions as to relevance of assumption and accuracy of results cannot be answered easily. Another approach to 3-D analysis was proposed by [Baligh and Azzouz (1975)][5]. They used a slice technique in order to evaluate limit loads or safety factor of slope. No exact solution for ultimate bearing capacity for rectangular footing adjacent to cohesive slope was found. In this research the 3-D analysis by finite element method used to estimate ultimate bearing capacity for rectangular footing adjacent to slope cohesive soil.

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)[6]

$$q_u = cN_c + qN_q + 0.5\gamma BN_\gamma \ldots\ldots (1)$$

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)[7] adopted

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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;

$q_u = cN_c + 0.5\gamma BN\gamma$ ……….. (2)

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

$q_u = cN_c$ …..……………….. (3)

Finite Element Formulation and Material Modeling

The finite element method is utilized to predict the ultimate bearing capacity of rectangular footing resting on the surface of a clayey soil adjacent to slope. The typical finite element mesh is illustrated in figure (1). Material properties are listed in table (1). The general matrix equations for a deformable solid under external loading can be found in many texts (e.g. Bathe 1996)[8] . A computer program using twenty node brick elements is drawn from Smith (1998)[9] and modified by the authors. In this program the main procedure for reading the coordinate and dimensions of the problem are divested to enable the program to generate a suitable mesh for analysis of rectangular footing adjacent to slope.(Al-Hamadany(2008))[10].The program before modification deals with elements that have constant dimensions (no change in one direction) and read from main program, it was modified to deal with element that have variable dimensions through modification of subroutine for problem geometry and node numbers by adding the equations and matrices.(Al-Hamadany(2008))[10]

It employs the visco-plastic method to compute the response to loading of elastic-plastic von Mises material. In this study, the finite element method used to compute reduction factor (R_s) which is used to determine the ultimate bearing capacity for rectangular footing adjacent to cohesive slope from ultimate bearing capacity for rectangular footing on normal level ground.

Results and Discussion

In the present analysis, the finite element method through the modified computer program is used to compute ultimate bearing capacity of rectangular footing adjacent to cohesive slope with different values of aspect ratio (L / B) (0.75,1 and 1.25) .The soil properties are listed in table (1). The computations of ultimate bearing capacity takes in account the effect of distance ratio (b / B) and slope angles (β).

Figures (2to7) show the soil pressure-settlement relationships of rectangular footing with various aspect ratio (L/B) and for different slope angles (β)and distance ratio (b/B). It is clear that the soil pressure –settlement curves are similar in behavior and shape for different slope angle (β) and distance ratio(b/B).

Figures (8 through 10) show the variation of ultimate bearing capacity due to slope angle (β) for different value of distance ratio (b/B) and aspect ratio (L/B). From these figures it can be noted that the ultimate bearing capacity decrease when slope angle increase, this behavior is due to the lack of soil on the slope side of footing tend to reduce the stability of the footing, and this lake of soil increase with increasing slope angle (β). Also the length of the shear failure surface under footing is reduced with increasing slope angle (β). The effect of slope angle (β) is more pronounced at low value of distance ratio(b/B).

The effects of distance ratio (b/B) on ultimate bearing capacity and as for different slope angle values (β) and aspect ratios (L/B) are shown in Figures

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(11to13). From these figures it can be noted that, the ultimate bearing capacity increase when distance ratio increase and the effect of slope diminishes as (b/B) approaches 0.75 or exceed. This behavior is due to the increase in length of the shear failure surface under footing with increasing distance ratio (b/B).

The effects of aspect ratio (L/B) on ultimate bearing capacity for different (β) values and (b/B) values are shown in Figures(14-16). From figures it can be noted that, the change in the ultimate bearing capacity follows different modes as a function of the change of aspect ratio (L/B), this behavior is due to interaction effect of others tow factors (b/B) and (β).

To simplified the determination of the ultimate bearing capacity of rectangular footing adjacent to cohesive slope ,in this research, the finite element method used to compute reduction factor (R_s), which is suggested to determine the ultimate bearing capacity for rectangular footing adjacent to cohesive slope from ultimate bearing capacity for rectangular footing on level ground. The reduction factor (R_s) can be computed from equation :-

$$R_s = \frac{q_{ult\,on\,slope}}{q_{ult\,on\,level\,ground}} \quad \text{………….... (4)}$$

Table (2) shows the values of reduction factor for different values of aspect ratio (L / B), slope angles (β) and distance ratio (b / B). From this table, it can be noted that the effect of slope diminishes as the distance ratio approaches 0.75 or exceed.

Conclusions

1- The ultimate bearing capacity for rectangular footing adjacent to slope is less than the ultimate bearing capacity for the same footing under same conditions when footing resting on a level ground because one side failure occurs.
2- From load- settlement curves, it can be noted that the ultimate bearing capacity decreases when the slope angles increase and settlement for footing increases when slope angle increases.
3- The ultimate bearing capacity increases when distance ratio (b/B) increases.
4- The effect of slope diminishes as the distance ratio (b/B) approaches (0.75).
5- The reduction in bearing capacity is more sensitive to the variation in slope angle(β) ,aspect ratio (L/B) and distance ratio(b/B).

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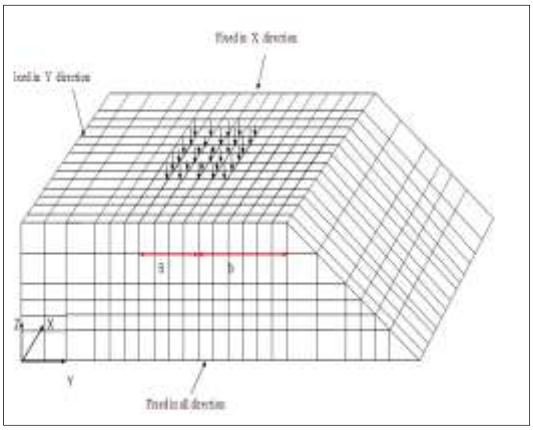
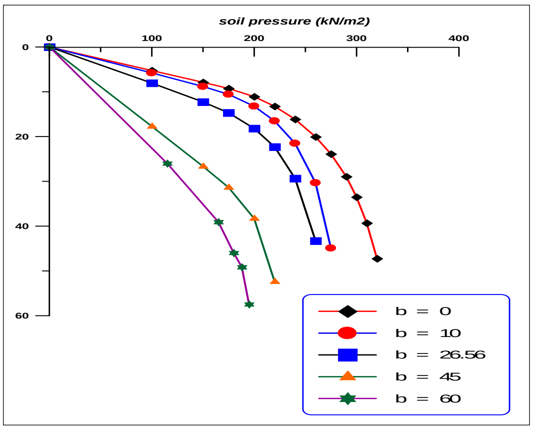
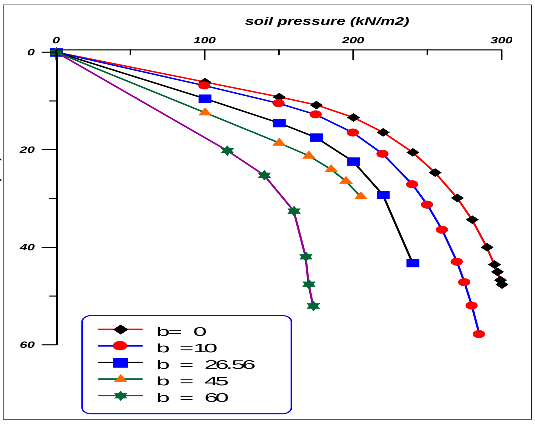


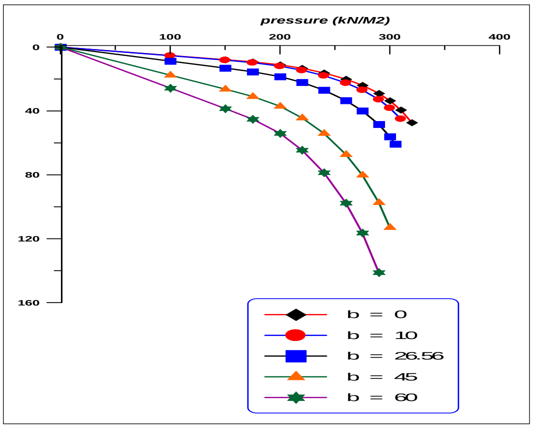
Figure (1) Typical 3-D finite element mesh (not to scale)



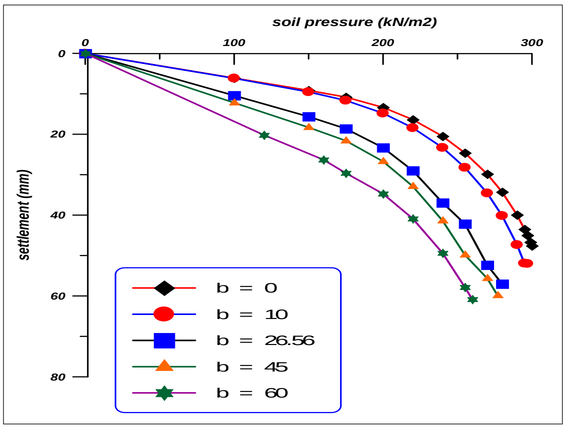
Figure(4) Soil pressure- settlement relationships for L/B=1 ,b/B=0



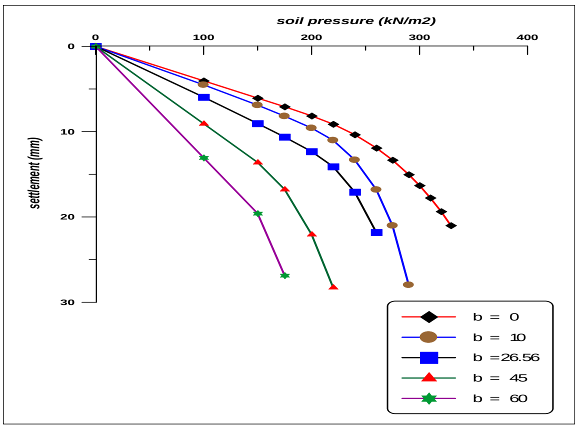
Figure(2) Soil pressure- settlement relationships for L/B=1.25 ,b/B=0



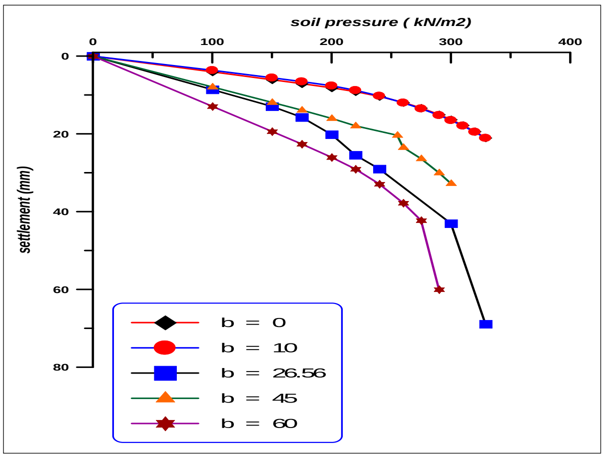
Figure(5) Soil pressure- settlement relationships for L/B=1 ,b/B=



Figure(3) Soil pressure- settlement relationships for L/B=1.25 ,b/B=0.5



Figure(6) Soil pressure- settlement relationships for L/B=0.75 ,b/B=0



Figure(7) Soil pressure- settlement relationships for L/B=0.75 ,b/B=0.5

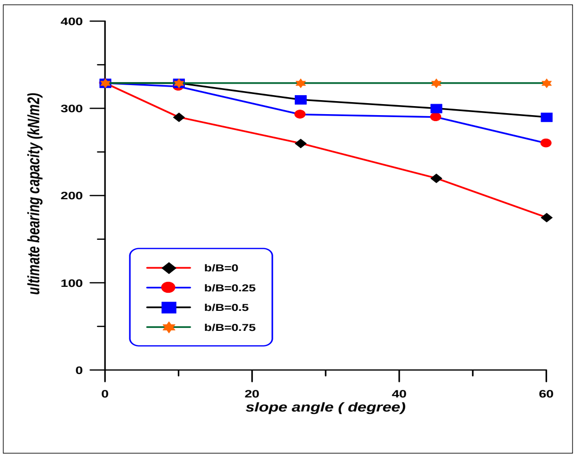


Figure (10) Ultimate bearing capacity - slope angle curves for different distance Ratio (b/B) ,L/B=0.75

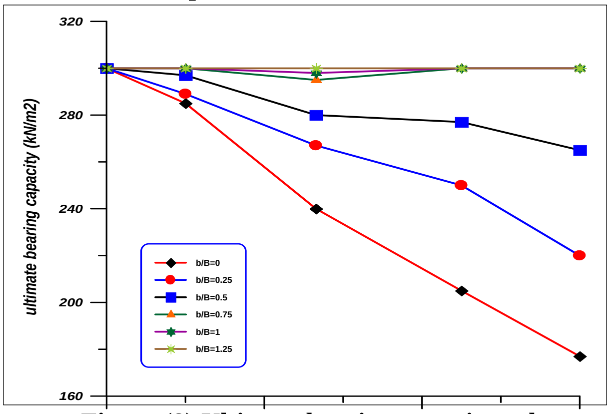


Figure (8) Ultimate bearing capacity - slope angle curves for different distance ratio(b/B) ,L/B=1.25

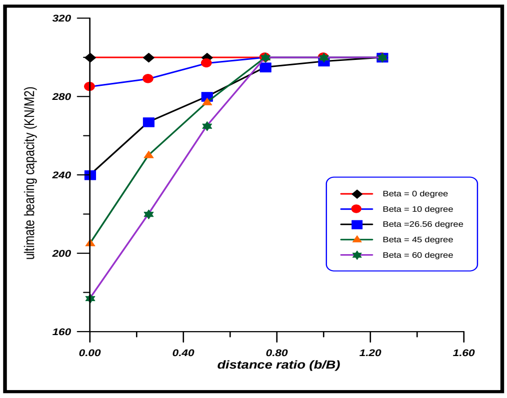


Figure (11) Ultimate bearing capacity - distance ratio (b/B) curves for different slope angle(β) and L / B = 1.25

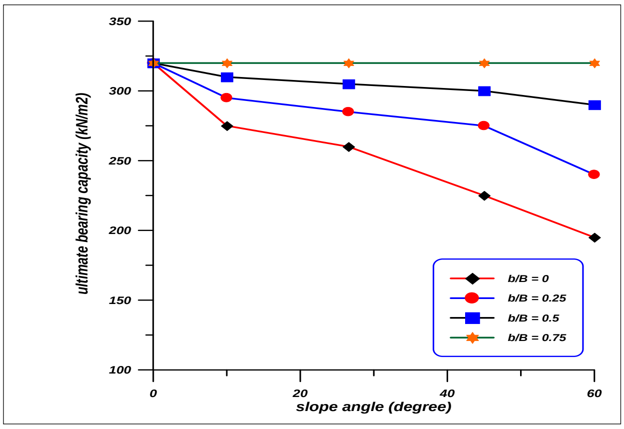


Figure (9) Ultimate bearing capacity - slope angle curves for different distance ratio(b/B) ,L/B=1

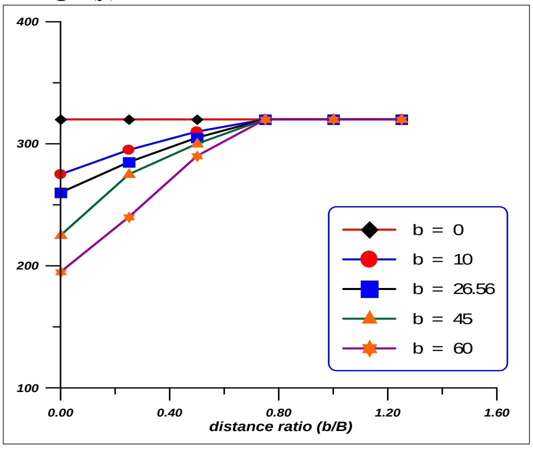


Figure (12) Ultimate bearing capacity - distance ratio (b/B) curves for different slope angle (β) and L / B =1

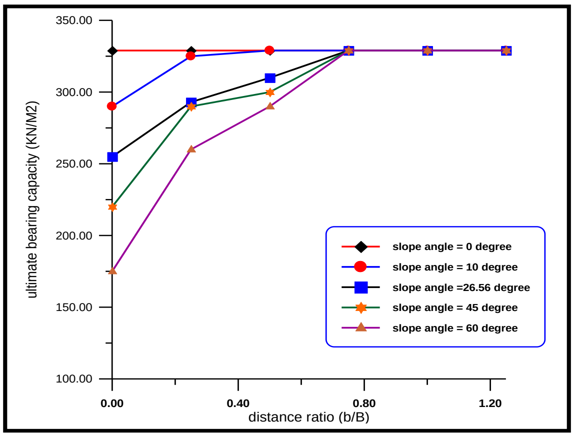


Figure (13) Ultimate bearing capacity - distance ratio (b/B) curves for different slope angle (β) and L b/ B =0.75

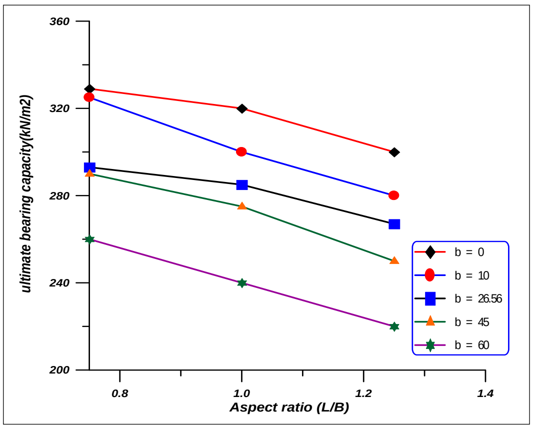


Figure (15) ultimate bearing capacity with aspect ratio curve for different slope angle and b/B =0.25

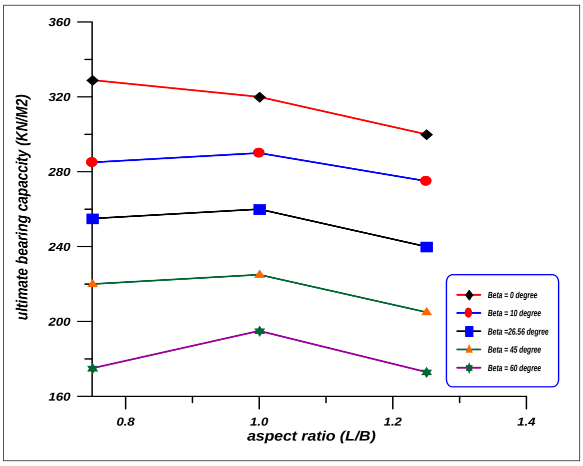


Figure (14) ultimate bearing capacity with aspect ratio curve for different slope angle and b/B = 0

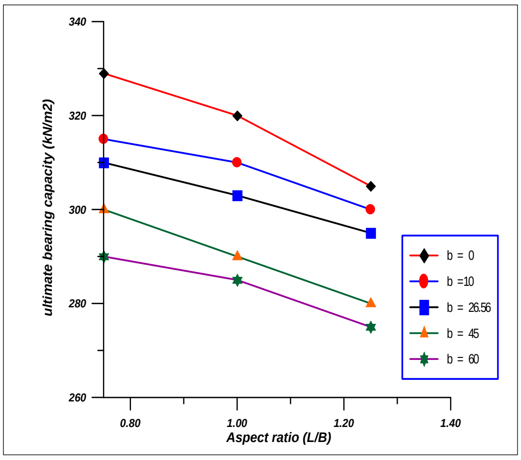


Figure (16) ultimate bearing capacity with aspect ratio curve for different slope angle and b/B =0.5

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Table (1) Material properties

Soil properties	Values
E (kN/m^2)	50*10^3
μ	0.45
φ (degree)	0
c (kPa)	50

Table(2) Reduction Factor (R_s) for Different Values of (b/B,L\B ,ß)

L\B=1.25

b/B / ß°	0	0.25	0.5	0.75	1	1.25	1.5
0.0	1	1	1	1	1	1	1
10	0.95	0.93	0.99	1	1	1	1
26.56	0.8	0.89	0.93	0.98	1	1	1
45	0.68	0.83	0.92	1	1	1	1
60	0.59	0.73	0.88	1	1	1	1

L\B=1

b/B / ß°	0	0.25	0.5	0.75	1	1.25	1.5
0.0	1	1	1	1	1	1	1
10	0.85	0.92	0.96	1	1	1	1
26.56	0.81	0.87	0.95	1	1	1	1
45	0.7	0.85	0.93	1	1	1	1
60	0.6	0.75	0.9	1	1	1	1

L\B=0.75

b/B / ß°	0	0.25	0.5	0.75	1	1.25	1.5
0.0	1	1	1	1	1	1	1
10	0.88	0.98	1	1	1	1	1
26.56	0.77	0.89	0.94	1	1	1	1
45	0.66	0.88	0.91	1	1	1	1
60	0.53	0.79	0.88	1	1	1	1