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TECHNICAL NOTE

Angle Shaped Footing under Eccentric Vertical Load

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Key words
Model tests, Cohesion less soil, Square Footings, Eccentric load, Angle shaped footing, Eccentricity width ratio.

Abstract: The paper presents a new type of foundation very much useful under the eccentric loading conditions. The Angle Shaped Footing was introduced in 2000 and in this paper studies the effectiveness by varying the angle of projection has been observed. Due to the inclination of footing projection, the earth pressure is increased which gives a little more resistance to the tilting. In the normal conventional footing due to eccentric loading the footing tilts and produces tension when the eccentricity exceeds 1/6 the footing width. After conducting a series of experiments and verified the experimental results by readymade software, 'ANSYS', which is based on Finite Element Technique. It has been observed that the angle shaped footing (Footing projection perpendicular to footing) becomes more effective when the angle of projection with vertical is in the range of 15° - 30°. The horizontal displacements in the footing due to vertical eccentric loading have been found to be almost zero.

Introduction

The load on the footing may be 1) vertical only, 2) Vertical with horizontal load, due to wind or earthquake resulting in inclined loading. 3) Inclined loading and 4) vertical load with moment. The loads of the structure are transmitted to the underlying soil through the base of foundation. The load transmitted to the soil, moves the soil particles in horizontal and vertical direction. The design of a foundation normally requires that both settlements and bearing capacity be evaluated.

Due to eccentric loading the footing tilts and pressure below the footing does not remain uniform. The tilt of the footing depends upon the value of eccentricity width ratio.

The conventional method of footing design requires that footing must possess sufficient safety against failure and settlement must be kept within the allowable value. These requirements are dependent on the bearing capacity. The eccentrically loaded footings can be designed by providing unequal offsets on either side of the column face so as to match the center of gravity of the footing area with the center of gravity of the column load.To avoid tensile crack eccentricity width ratio i.e. e_x/B ratio limited to 1/6.

The footing when provided with vertical projection on one side such that it is an integral part of the footing it is called angle shape footing. In such a footing the soil particles near the footing projection are prevented from moving laterally thus footing projection to tilt in direction opposite the one in which the footing has tendency to tilt thus tilt of the footing can be reduced to zero by providing a downward inclined footing projection of required depth toward the loading side. The idea of angle as well as suitable length of projection has been used here by giving the footing an angle shape of variable projection angle.

Review of Previous Work

a) Rao and Narhari (1979) conducted model and field studies on foundation with skirted-soil plug,

b) Ranjan Gopal and Rao B.G. (1983) present the use of granular piles for reinforcing loose cohesionless deposit.

c) Mahiyar H.K. and Patel A.N. (1997) studied the depth of confinement of circular footings on sand and found that the bearing capacity increases with increase in the depth of confinement. The effectiveness of the confinement reduces with an increase in the diameter of the confinement.

d) Mahiyar H.K and Patel A.N. (2000) studied performance of angle shape footing under vertical load using finite element analysis of. The analysis has been done by considering the parameters as depth of footing (D) and eccentricity width ratio (e_x/B). The depth of projection was varies from 0.25B to 2.0B and eccentricity width ratio from zero to 0.30. He observed that the Angle shape footing is a good alternative of resisting the eccentric loading. The depth of projection depends upon the e_x/B value. The relation between e/B and L/B is third degree polynomial. Result shows the zero tilt occurs at L/B ratio is 2.00, ex/B ratio is 0.30. The relation is independent of material of the footing and properties of sand.

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Objective of Work

In the design of angle shaped footing under uniaxial eccentric vertical loading, the tilt of footing can be brought equal to zero by providing particular of angle of footing projection (β) of required depth depending upon the ex/B value.

The objectives of the research study described in this paper are

> To prevent tilt and shift of footing due to eccentric loading by providing downward footing projection of a particular angle and depth at the edge near the loading.

> To establish a relationship between the eccentricity width ratio, angle of projection and depth of projection such that the tilt is nearly zero for a particular load.

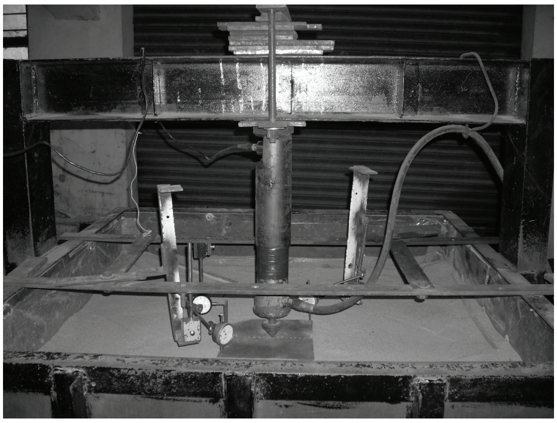
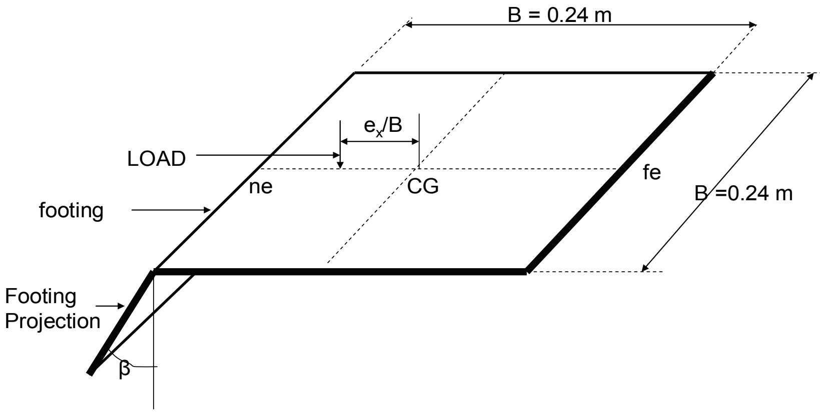


Fig.1 Experimental Setup

Laboratory Model Tests

Model Test Tank

Model tests were conducted in a test tank, having inside dimensions of 1.20 m x 1.20 m x 1.20 m deep. The size of the tank was decided by the size of the footing and the zone of influence. The test tank is made of steel and has arrangement to fix the load cell with specially fabricated load device for applying the axial load to the footing as shown in Figure 1.



B = Width of footing projection, ex/B = Eccentricity width ratio
ne= Near end, fe = Far end
α = Load inclination with vertical, β = Angle of footing projection with vertical

Fig. 2 Angle Shaped Square Footing, 0.24m X 0.24 m X 0.01 m thick

Angle Shaped Footing

As shown in Figure 2, the experiments were carried out on the footings made of mild steel square plate of size 0.24 m x 0.24 m x 10mm thick .On the top of these plates small holes were drilled in such a way that the eccentricity width ratios are 00, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45 and 0.50 from centre to both extreme edges of angle of projection (β) = 0°, 15°, 30°, 45°, 60°and 75°). The lengths of footing projection (L) were taken as 0.2 B, 0.4 B and 0.6 B. The thickness of footing projection is 0.01m.The footing without any projection has also been studied

Test Material: Soil, Narmada sand as filled by rainfall technique. The gradation of the sand bed is as given in Table 1.

Experimental Setup and Test Program

The point load was applied to the plate with the help of a hydraulic jack at a particular eccentricity width ratio and measured with load cell arrangement. The load was increased until the failure. Each load increment was maintained constant until the footing settlement had stabilized. Settlements of two diagonally opposite edges were observed by fixing three dial g auges (two placed diagonally opposite to measure vertical settlement and one placed horizontally to measure horizontal displacement). The procedure was repeated with different eccentric width ratio and different angle of footing projection at various ex/B values. The length of the projection was also varied.

The load settlement characteristics of the angle shaped footing were analyzed by the various parameters such as length of angle of

Table 1 Textural Composition

Particulars	Size in mm	Percentage
Gravel	> 4.75	00
Sand; Coarse	between 4.75 & 2.00	00.07
Medium	between 2.00 & 0.425	13.92
Fine	between 0.425 & 0.075	81.27
Silt & Clay	< 0.075	04.74
Total		100.00

projection, eccentricity width ratio and angle of projection. In all 288 no. of tests have been conducted. The displacement values obtained experimentally have been compared with the Finite Element Analysis using ready-made software package, Ansys. Each series of the tests were carried out under axial as well as eccentric load to study the effect of one parameter while the other variables were kept constant.

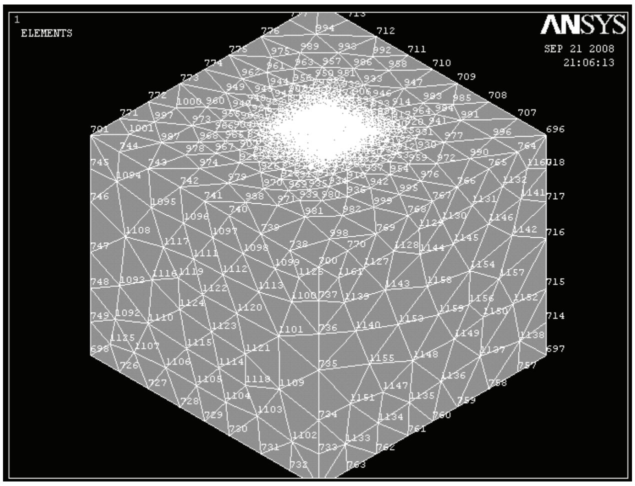


Fig. 3 Free Meshing to Discretise the Model

Finite Element Analysis

For large deformation or large strain analysis, it is well known that the two main approaches are the Eulerian and Lagrangian formulations. Large deformation problems in solid mechanics have been solved numerically by the finite element method using a Lagrangian method, as the governing equations in this method are relatively simple and the material properties, boundary conditions, and stress and strain states can be accurately defined.

- Finite Element Analysis is a way to simulate loading conditions on a design and determine the design's response to those conditions.
- The design is modeled using discrete building blocks called elements.
- Each element has exact equations that describe how it responds to a certain load.
- The "sum" of the response of all elements in the model gives the total response of the design.
- The elements have a finite number of unknowns, hence the name finite elements

The experimental results are verified by using finite element technique. For the analysis and solution finite element programme ANSYS 10 has been used. Solid six nodded triangle isoperimetric elements were chosen which have three degree of freedom i.e. displacement along the x, y and z axis. The soil parameters of this model were derived from a series of laboratory tests.

The angle of internal friction ϕ and cohesion c has been determined by direct shear test as 31^0 and 0.01 N/mm^2, respectively. The Young's modulus of elasticity E for sand has been determined as 10,000 kN/m^2 and that for steel as 2.1 x 10^8 kN/m^2. The boundary conditions were chosen such that the vertical boundary was constrained horizontally and the horizontal boundary at the base of the tested tank was constrained in both the horizontal and the vertical direction.

Free meshing was applied to discretise the model as shown in Figure 3. The point load at particular e_x /B values was applied and a sufficient number of iterations were done so that convergence was reached. Under this load, the displacement at various points was noted. The analysis was carried out for various eccentricity width ratios and various depths of footing projection. From ANSYS Programme, outputs such as settlement in the vertical direction at various points of footing, displacements at different points of the footing projection and maximum lateral displacements anywhere in the model were recorded.

Results and Discussion

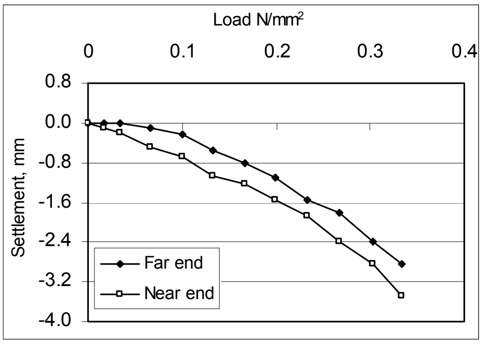
The analysis has been done by Considering following parameters,(i) the length of footing projection (L), (ii) Eccentricity width ratio (e_x / B) and (iii) Angle of footing projection (β). The length footing projections was varied from 0.0B, 0.2B, 0.4B and 0.6B. The eccentricity width ratios are 00, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 and 0.5 from center to both extreme edges of the footing.

From the observations of load and settlements, few load settlement curves are presented in Figures 4(a), 4(b), 4(c) and 4(d). It is observed that for axial loading at particular angle of footing projection, the near end settle more and far end settle less, i.e. the tilt is clockwise. As the e_x/B values increases the magnitude of this clockwise tilt reduces and after cetratin ex/B, the far end starts settling more that the near end.

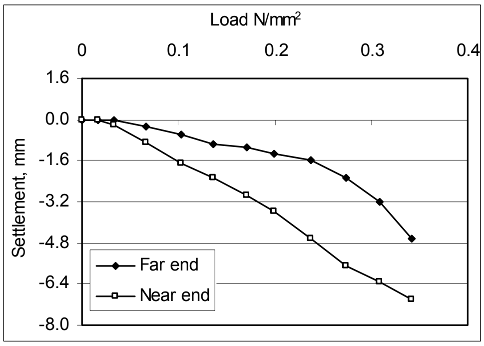
At any angle as well as for any length of the footing projection, the load first increases with increase in eccentricity up to certain limit. As the eccentricity width ratio increases further it goes on reducing. The failure load can be found at the point of rapid progressive settlement.

The tilt is positive when the near end settles more than the far end and the tilt is negative when the far end settles more than the near end. Thus these two values of tilt, there must be zero tilt at particular e_x/B value. The objective is to find e_x/B corresponding to zero tilt for all values of angle of footing projection (β).

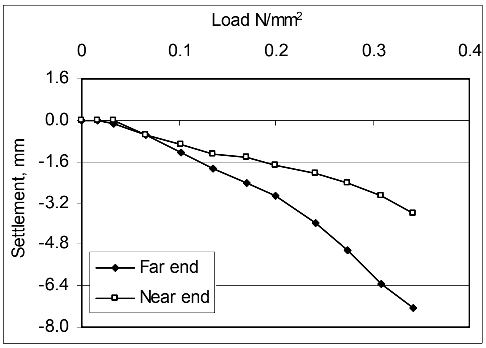
Typical outputs from the numerical analysis using ANSYS finite element programme are presented in Figure 5 (a) and (b). The maximum settlements and lateral displacements obtained from experimental and analytical methods are presented in Table 2.



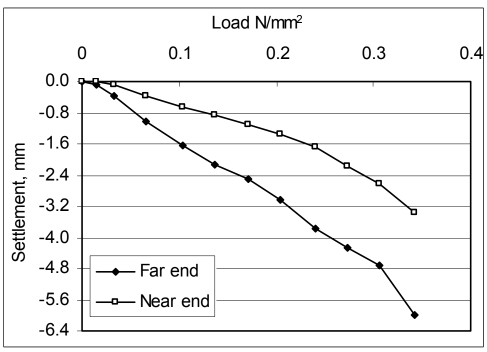
(a) Load Inclination (α) = 00^0 , Footing Projection 45^0
l/B = 0.4 (i.e. 9.6cm), e_x/B = -0.30 (Positive tilt)



(b) Load Inclination (α) = 00^0, Footing Projection 45 ^{0}
l/B = 0.4 (i.e. 9.6cm), e_x/B = -0.20 (Positive tilt)



(c) Load Inclination (α) = 00^0, Footing Projection 45 ^{0}
l/B = 0.4 (i.e. 9.6cm), e_x/B = -0.15 (Negative tilt)



(d) Load Inclination (α) = 00^0, Footing Projection 45 ^{0}
l/B = 0.4 (i.e. 9.6cm), e_x/B = -0.10 (Negative tilt)

Fig. 4 Load settlement Response for Angle Shaped Footings

Effects of Angle and Inclined Length of Footing Projection

In the previous research, as Length of footing projection is twice the width of footing i.e., l/B is 2.00 and angle of footing projection is zero degree with vertical, the zero tilt occurs at the e_x/B = 0.30 from the centre of extreme edges towards footing projection. For the zero tilt to occur at e_x/B = 0.325, the angle of footing projection is to increase to 75^0 with vertical and length of footing projection is 0.60 times the width of footing. i.e. for zero tilt of footing, as the angle of footing projection (β) increases, l/B ratio shall decrease. Table 3 presentes the zero tilt conditions as derived from the experimental results. The relation between e_x/B and l/B is third degree polynomial as presented in Table 4. The failure load of the footing plate increased with the increase of both load inclination angle and inclination angle of footing projection. The contact area and adhesion between the footing and the soil increased with the increase in angle of footing projection. Increases in angle of footing projection leads to high contact area between the footing and the soil which improves the footing stability.

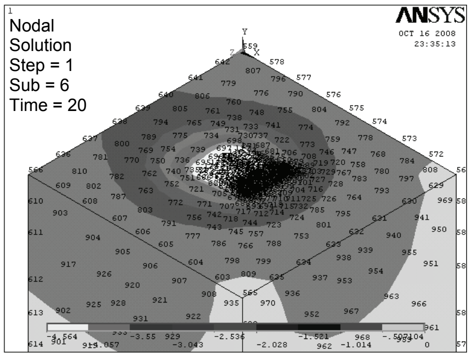


Fig. 5(a) Isometric View of Vertical Displacement

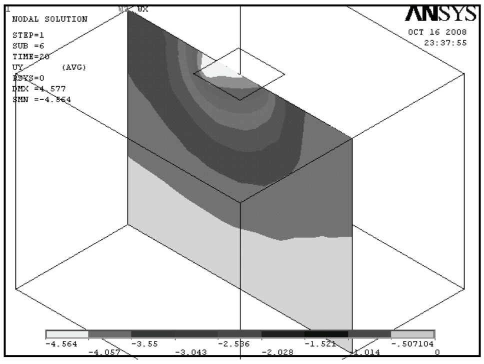


Fig. 5(b) Section - Isometric View of Vertical Displacement

Increasing length of footing projection results in a decrease in settlement and greater improvement in the bearing capacity of soil. The horizontal displacement also reduces due to confinement.

The typical curve between tilt at a settlement of 1% of the footing width and e_x/B for particular length of footing projection is drawn as shown in Figure 6. Now

Table 2 Settlement and Displacements under Maximum Load

	Experimental Results			*F E M Results*		
ex/B	Near end (mm)	Far end (mm)	Horizontal Displacement (Hd), in mm	Near end (mm)	Far end (mm)	Horizontal Displacement (Hd), in mm
α =0 deg, β = 45 deg and l/B = 0.20						
- 0.20	7.36	5.56	0.38	5.18	3.63	0.28
-0.10	7.40	5.80	0.10	5.30	5.55	0.080
-.015	5.06	6.03	0.21	5.78	5.22	0.053
0.00	6.1	7.38	0.59	4.06	5.32	0.16
α =0 deg, β = 45 deg and l/B = 0.40						
- 0.30	3.47	2.88	0.26	4.50	3.38	0.35
- 0.20	7.0	4.63	0.07	4.22	4.03	0.12
- 0.15	3.54	7.31	0.11	4.08	4.36	0.02
0.10	3.26	5.88	0.45	3.93	4.7	0.099
α =0 deg, β = 45 deg and l/B = 0.60						
- 0.40	5.00	3.27	0.16	4.04	3.23	0.40
- 0.35	4.00	3.52	0.09	3.78	3.90	0.18
- 0.30	8.20	8.7	---	3.84	4.04	0.064
0.20	5.78	10.44	0.80	3.77	4.36	0.046
α =0 deg, β = 30 deg and l/B = 0.20						
- 0.20	5.40	4.12	0.22	4.79	3.31	0.29
- 0.10	4.15	3.50	0.29	4.27	4.06	0.072
- 0.05	3.41	4.77	0.35	3.94	4.36	0.037
0.00	2.96	5.28	0.53	3.12	4.02	0.12
α =0 deg, β = 30 deg and l/B = 0.40						
- 0.30	7.25	0.93	1.16	4.46	3.18	0.41
- 0.20	7.7	2.18	0.33	5.69	5.25	0.21
- 0.15	4.17	7.54	0.11	5.47	5.7	0.17
0.10	2.62	4.9	0.24	4.55	5.22	0.11
α =0 deg, β = 30 deg and l/B = 0.60						
0.40	8.22	0.23	1.00	3.75	2.76	0.46
- 0.30	9.05	3.70	0.6	4.0	3.63	0.25
- 0.25	4.83	7.0	0.23	3.91	3.92	0.13
0.20	6.05	7.55	0.42	3.45	3.79	0.037

Table 3 e_x/B Values for Zero Tilt Condition

β	0	15	30	45	60	75
L/B = 0	0	0	0	0	0	0
L/B = 0.2	0.06	0.07	0.075	0.08	0.1	0.1
L/B = 0.4	0.11	0.16	0.165	0.17	0.225	0.22
L/B = 0.6	0.17	0.23	0.25	0.255	0.31	0.325

Table 4 The Relation between ex/B and l/B for Zero Tilt for Various β

β deg	Equation for l/B
0	$-71.301(e_x/B)^3 + 18.182(e_x/B)^2 + 2.4991(e_x/B) - 7X10^{-14}$
15	$34.5071(e_x/B)^3 - 11.905(e_x/B)^2 + 3.521(e_x/B) - 2X10^{-14}$
30	$13.762(e_x/B)^3 - 5.9965(e_x/B)^2 + 3.039(e_x/B) - 2X10^{-15}$
45	$9.3371(e_x/B)^3 - 3.9683(e_x/B)^2 + 2.7577(e_x/B) - 1X10^{-14}$
60	$17.301(e_x/B)^3 - 7.4005(e_x/B)^2 + 2.5667(e_x/B) - 6X10^{-15}$
75	$7.918(e_x/B)^3 - 4.0489(e_x/B)^2 + 2.3257(e_x/B) - 4X10^{-14}$

from similar curves, the e_x/B values corresponding to zero tilt for a particular length of footing projection were found out.

A typical curve between the e_x/B value for a zero tilt as obtained from above and the length of footing projection/width of footing (i.e. l/B) is drawn and presented in Figure 7.

Conclusions

> For angle shaped footing under uniaxial eccentric loading, the tilt of footing can be brought equal to zero by providing particular of angle of footing projection (β) of required depth depending upon the e_x/B value. The relationship between e_x/B and l/B for no tilt is a third-degree polynomial having different equations.

> By comparing the experimental results with those defined by ANSYS programme it has been observed that the vertical displacement at near end and far end are slightly more in the case of ANSYS programme.

> The curves between the e_x/B value for a zero tilt and length of footing projection/width of footing (i.e. l/B) show that settlements can be kept within the permissible limits by keeping the angle of footing projection between 15^0 and 30^0. The failure load is also maximum under this condition and the maximum stress occurred at a distance of 0.33 B from center to extreme edges of the footing projection.

> The failure load of footing plate is maximum at zero tilt eccentricity width ratio and depends on the angle and length of footing projection.

> The lateral displacements of the angle shaped footing are insignificant.

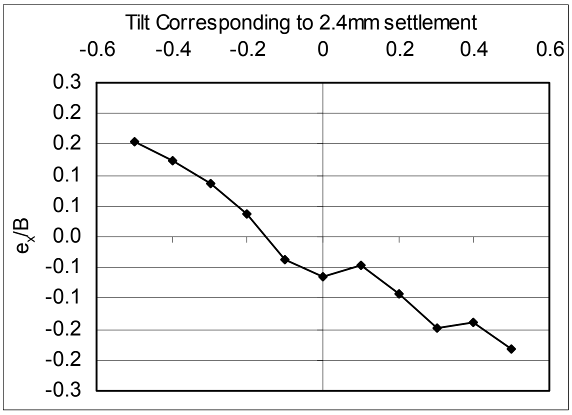


Fig. 6 Curve between e_x/B and Tilt, at 2.4 mm Settlement (l/B = 0.40 and B = 0^0)

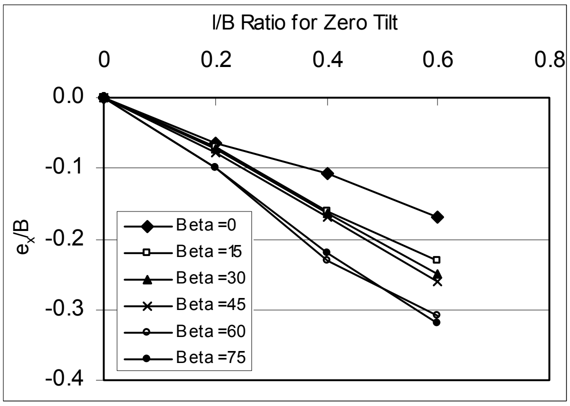


Fig. 7 Curves between e_x/B and l/B Ratio at Zero Tilt

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