Stresses Beneath Pads Under Eccentric Loads, Shears and Moments

Escaped

Sheet	Analysis Options
1	Analyse Pads Subjected to Eccentric Loads, Shears & Moments
2	Select & Auto Analyse/Print Pads in the "STORE" Worksheet
3	Go to Pad Data in "STORE" Worksheet
4	Clear Enitre Data for all Pads in the "STORE" Worksheet

Documentation

5	Features of EccPad
6	User Notes for EccPad
7	Notations
8	Terms and Conditions of Use
9	Revision History

EccPadPad20071003

Company:	DGP International	© 2007 Techno Consultants	
Address:	Brunel House, 54 Princesses Street	EccPadPad20071003	
	Manchester M1 6HS	Non-registered copy	
	Tel : 0161 907 3500	Made by / Date / Page No	
Project:			
Client:		Checked / Job No / Revision	
Element:			

Stresses Beneath Pads Under Eccentric Loads, Shears and Moments **Pad Data Store No: 1001**

Title: Example 1

Stress Variation Analysis: Linear: No-tension

Pad Dimensions

Xp, m	Yp, m	Zp, m
2.6	2.2	2.296

Pad Weight & its cg Location

Sw, kN	Cx, m	Cz, m
315.1949	1.3	1.148

Analysis Units:	
Force:	kN
Length:	m

Load No	Staad Node	Load Case No	Reactions from Staad Analysis Fx, kN	Fy, kN	Fz, kN	Mx, kNm	My, kNm	Mz, kNm	Reaction Position x, m	y, m	z, m
1.01	142	24 1.0 (DL+	0.021	-69.085	0.73	0	0	0	2.3	2.2	1.996
1.02	146	24 1.0 (DL+	-0.06	69.979	24.485	0	0	0	2.3	2.2	0.3
1.03										2.2	
1.04	150	24 1.0 (DL+	7.793	-35.845	1.555	0	0	0	0.3	2.2	1.996
1.05	154	24 1.0 (DL+	19.205	121.856	16.528	0	0	0	0.3	2.2	0.3
1.06										2.2	
1.07											
1.08											
1.09											
1.10										2.2	
1.11	11			200					0.66	2.2	0.6
	Sum of Applied Loads:		26.959	286.905	43.298	0.000	0.000	0.000			

Resultant Vertical Load Ry & its Location

RFy	ex - axial	ez - axial	Quadrant	Region
602.100	-0.452	-0.758	3	C

Induced Stresses at 4 Corners

F1at A	F2 at B	F3 at C	F4 at D
0.000	0.000	676.567	179.431

Maximum Stress: 676.567

Stress Variation Constants & Lengths:

K1= 0.2652086		K2= NA	
L1 -Right	L2- Bottom	L3- Left	L4-Top
0.408	0.000	1.538	3.538

Loss of contact in compression: 57.63%

Overturning Factors

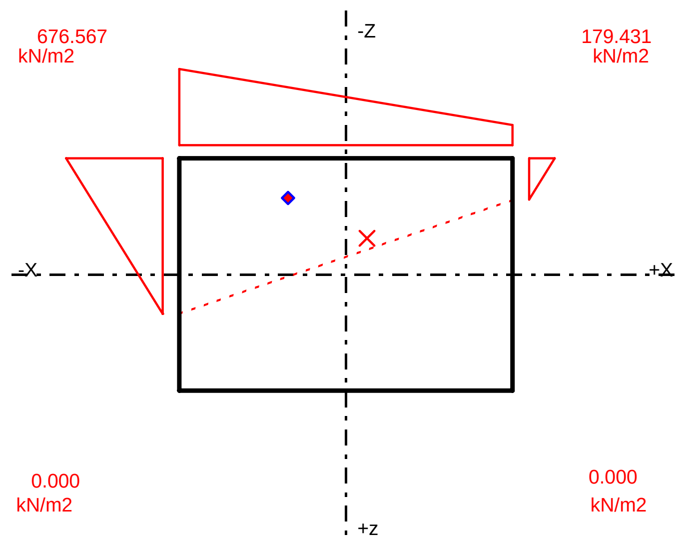
Along X-X	2.873	Along Z-Z	1.514

Resultant Lateral Shears & Eccentricities

RFx	ez'- shear	RFz	ex'- shear
26.959	-0.356	43.298	0.165

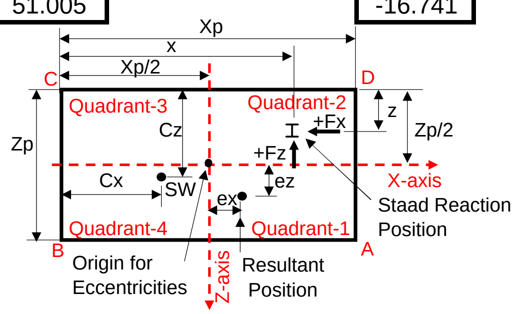
Total Sliding Shear & Rotational Moment

RFxz	RMy
51.005	-16.741



Plan Showing Linear: No-tension Stress Variation Along 4 Edges of the Pad, Zero-Stress Line & Symbols

◆ - Vertical Resultant, RFy x - Horizontal Resultant, RFxz



Sign Convention:

x, y, z, Cx and Cz are values from the lower-top-left corner-C of the Pad.
All positive Axial and Moment reactions cause Compression at the Top-Right corner D of the pad. Acting on to the foundation base:

Mx, My & Mz are +ve clockwise, when viewed looking into the origin.
Fx is +ve Left (opposite to x-direction)
Fz is +ve upwards (opposite to z-direction)
Fy is +ve acting down (opposite to y-direction)

The calculated eccentricities ex & ez of the resultant RFy are relative to the origin at Xp/2 and Zp/2 from the top-left corner-C of the pad, +ex is towards right and +ez is towards bottom.

Stresses Beneath Pads Under Eccentric Loads, Shears and Moments

Features of EccPad

EccPad is an Excel spreadsheet for the calculation of pressure induced beneath rectangular pads subjected to eccentric loads, shears & moments. The pressure distribution can be linear no-tension, linear tension allowed or uniform no-tension.

Using its analysis, pads can be sized to limit the induced vertical pressures and to have adequate safety factors against overturning in two orthogonal directions.

EccPad helps reduce design time by avoiding cumbersome hand calculations. In a design process, pad data can be saved and retrieved for repeated optimisation.

Features

- The pressure distribution beneath the pad can be Linear-Tension-permitted or Linear-No-tension or Uniform-No-Tension. A pull down menu allows a selection from these three analysis options.
- Analysis can be in any consistent units of force and length e.g. kN m, lb ft, etc.
- A diagram displays pressure distribution at corners and along edges of the pad on the screen display. This allows comprehension of the induced pressure distribution at a glance when meeting design and commercial requirements.
- The diagram also displays positions of both the axial and the shear resultants.
- Overturning factors in the x-x and the z-z direction are calculated and shown in the screen display and output. This allows a check of pad stability at a glance.
- Percent loss of soffit area in compression is calculated and displayed when the analysis is non-tension. This helps sizing of pads and improve their stability.
- Reactions from Staad Pro or similar programs can be copied to the clipboard and pasted into EccPad. This reduces input errors and expedites the design process. No sign adjustments are required when the input is from Staad Pro.
- Induced pressures are calculated at all four corners of the pad and noted in the screen display.
- The distribution of mass in the rectangular pad can be non-uniform. To this end, self weight of the pad and its centroid is input as data.
- In addition to the self weight, eleven other loads can be applied in each EccPad analysis.
- Each applied load can have 8 components i.e. Fy, Fy, Fz, Mx, My, Mz as magnitudes and x, y, z as their position from top lower left corner of the pad.
- The induced pressures are calculated at soffit level of the pad. As applied loads act on top of the pad, the additional moments equal to horizontal loads multiplied by the pad depth are taken into account in the analysis.
- When the analysis is non-tension, the full lengths of pad edges may not be in compression. To show extent of the compression zone, the lengths of pad edges in compression are calculated and shown in the diagram display.
- An easy to use database facility is included within the EccPad file. Data for up to 200 pads can be stored in a single EccPad file.
- An Auto-analysis option allows analysis as well as printing of all or selected pads at the click of a button.
- The pad data is kept in the worksheet STORE that is visible to the user. Using spreadsheet features of Excel, new data can be generated and the existing one examined and or modified.
- The template has virtually no user interface. The printed Output matches the Screen Display. Knowing how to use Excel and the ability to verify results as a designer is sufficient for using EccPad.
- Green shaded cells in the spreadsheet signify User-Input and un-shaded cells signify Spreadsheet-Results. This permits easy checking at a glance by the users and the checkers of EccPad output.

User Notes for EccPad

by
Dr Shaiq U.R. Khan
BEng (Civil), MEng, PhD, PE, CEng, FIStructE
August 2007
Techno Consultants Ltd
www.technouk.com

CONTENTS

1- Introduction

EccPad is a stress analysis tool to help design rectangular pads under eccentric loading. These pads can be foundations or piers of reinforced concrete, mass concrete, masonry or blocks of any other material subjected to resist loads primarily in compression.

EccPad has initially been developed for analysis using support reactions obtained from Staad Pro. These reactions are copied to the clipboard from Staad and then ported into EccPad as input data. As long as the sign convention of applied loads is adhered to, however, EccPad can be used for reactions obtained from any other application or loads input manually.

EccPad calculates resultant of the applied loads and its location relative to centre of the pad area in plan. Self weight of the pad is also included in the resultant.

EccPad also calculates factors of safety against overturning in two orthogonal directions. In addition, loss of contact under compression is also calculated as some designers limit its value in their design.

The pressures induced beneath the pads can be linear or uniform. The magnitudes of these pressures are calculated at all four corners of the pad. When calculating these pressures, three analysis options are available. These options are Linear tension not-permitted, Linear tension-allowed and Uniform Tension not-permitted. The option selection is via drop down menu.

Interactive operation of EccPad facilitates the sizing of pads so that the resultant reactions lie within their footprint, the induced ground pressures remain within permissible limits and that there is an acceptable margin of safety against overturning in two orthogonal directions.

EccPad is a stress analysis tool to help design rectangular pads under eccentric loading. These pads can be foundations or piers of reinforced concrete, mass concrete, masonry or blocks of any other material subjected to resist loads primarily in compression.

EccPad has initially been developed for analysis using support reactions obtained from Staad Pro. These reactions are copied to the clipboard from Staad and then ported into EccPad as input data. As long as the sign convention of applied loads is adhered to, however, EccPad can be used for reactions obtained from any other application or loads input manually.

EccPad calculates resultant of the applied loads and its location relative to centre of the pad area in plan. Self weight of the pad is also included in the resultant.

EccPad also calculates factors of safety against overturning in two orthogonal directions. In addition, loss of contact under compression is also calculated as some designers limit its value in their design.

The pressures induced beneath the pads can be linear or uniform. The magnitudes of these pressures are calculated at all four corners of the pad. When calculating these pressures, three analysis options are available. These options are Linear tension not-permitted, Linear tension-allowed and Uniform Tension not-permitted. The option selection is via drop down menu.

Interactive operation of EccPad facilitates the sizing of pads so that the resultant reactions lie within their footprint, the induced ground pressures remain within permissible limits and that there is an acceptable margin of safety against overturning in two orthogonal directions.

2- Using EccPad

The use of the EccPad is self explanatory. The contents of green shaded cells represent data input and can be changed to suit the design needs. Non-green cells represent results i.e. EccPad output.

EccPad allows storing data for up to 200 Pads. A data store number in the range 1001 to 1200 is used for each pad data. The data for any pad can be recalled later, amended and re-stored to suit of pad design developments.

The data store facility also allows analysis for more than one loading case. To this end, relevant buttons at the top of the spreadsheet can be clicked to store, retrieve, display-next or display-previous retaining wall data.

An Auto-analysis option allows analysis and optional printing of all or selected pads. To use this facility, take option-2 of the Home page. This leads to the Store worksheet for setting up and starting the Auto-analysis. EccPad analyses all selected pads having "Y" typed in the analysis column and also prints all pads having "Y" typed in the print column.

3- Input of Data

All green shaded cells signify invitation to data input. The basic items of input are:

- Analysis type - tension permitted or not
- Pad size Xp, Yp & Zp
- Self weight SW and its location Cx & Cz,
- Up to 11 separate reactions acting on the pad.

Each reaction on the pad can have 6 components Fx, Fy, Fz, Mx, My, Mz and 3 location coordinates x, y & z from left-lower- top corner of the pad.

EccPad does not calculate self weight and centroid of the pad. This data input is required to allow for possible variation in the distribution of mass within the pad volume.

The origin for eccentricities and soffit pressure calculations is taken at Xp/2 and Zp/2 from the pad top left corner. As mass of the pad may be irregular, the SW coordinates Cx and Cz do not necessarily lie at the at this origin i.e. may be eccentric.

Acting on to the foundation, all reaction values and their signs are as obtained from the Staad Output.

When giving x, y and z position of applied loads (Staad Reactions) on top of the pad, the reference origin is at left-lower-top corner of the pad and axes directions are:

X-axis +ve Left to Right.
Z-axis +ve Top to Bottom
Y-axis +ve Pointing up out of the paper.

EccPad keeps data within its file for up to 200 pads and or load cases. Each load case and or pad data is stored in the STORE worksheet for storage and retrieval at a later stage.

Caution:
Using copy and paste commands of Excel, data can be pasted into green-shaded cells as input. When doing so, however, a straight use of PASTE command erases the format and colour settings of input cells. To avoid this eraser of format and colour settings, please use COPY and then PASTE-SPECIAL->VALUES command to retain original format settings.

4- EccPad Axes

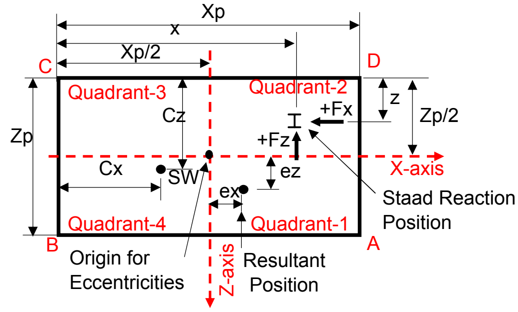
EccPad uses 3-dimensional axes for its analysis. In its plan view, +ve X-axis is to the right, +ve Y-axis is upwards out of the paper/screen and +ve Z-axis is down towards the bottom. The axis layout relative to the pad in plan is shown in the sketch below.

5- Sign Convention

When describing loads and moments,
X, Z, Cx and Cz are distances from the top-left corner-C of the Pad.
All positive Staad Axial and Moment reactions cause compression at the Top-Right corner-D of the pad.
Acting on to the foundation pad:

- Mx, My & Mz are +ve clockwise, when viewed looking into the origin.
- Fx is +ve Left (opposite to x-direction)
- Fz is +ve upwards (opposite to z-direction)
- Fy is +ve acting down (opposite to y-direction)

The calculated eccentricities ex & ez of the resultant Ry are relative to the origin at Xp/2 and Zp/2 from top-left corner C of the pad, +ex is towards right and +ez is towards bottom.



6- Resultants & Eccentricity Calculations

The resultant axial reactions in the x, y and z directions are given by:

Rfy = SUM(Fy) + SW
RFx = SUM (Fx)
RFz = SUM (Fz)

Eccentricity ex of Resultant RFy is given by:

ex = [+ SUM (MZ) + SUM (Fy*x) -SUM (Fx*y) + SW * Cx] / RFy -Xp/2

Eccentricity ez of Resultant RFy is given by:

ez = [- SUM (Mx) + SUM (Fy*z) -SUM (Fz*y) + SW * Cz] / RFy -Zp/2

Eccentricity ex' of Resultant RFx is given by:

ez' = SUM (Fx*z) / RFx - Zp/2

Eccentricity ex' of Resultant RFz is given by:

ex' = SUM (Fz*x) / RFz - Xp/2

The total resultant shear RFxz is given by:

RFxz = SQRT (RFx^2 + RFz^2)

The total torsional moment RMy is given by:

RMy = SUM (My) + RFx*ez' - RFz*ex'

7- Stress Diagram Display

To assist comprehension of its analysis results at a glance, EccPad displays a live and interactive diagram to show the following information:

- Magnitudes of stresses induced at 4 corners
- Distribution of stress along 4 pad edges
- Line of zero stress when passing beneath the pad
- Position of vertical resultant indicated by a diamond shape
- Position of horizontal resultant indicated by a x-mark
- X and Z axes with their +ve directions

The stress distribution at each edge of the pad is shown in a plan of the pad with stress plots along each of its 4 sides.

8- Resultant not within the Pad Footprint OR Compression

Whenever the resultant vertical load on the pad is

- not a compression load i.e. a -ve value representing tension, or
- it lies at edges of the pad, or
- outside the pad footprint.

EccPad opts to carry out a Linear - Tension Allowed analysis.

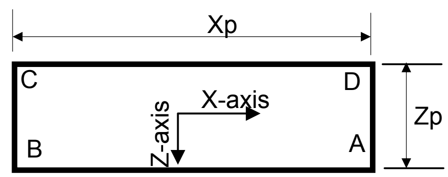
This ride out takes place even when the analysis specified is Linear: No-tension or Uniform: No-tension. EccPad indicates the selection of this analysis by adjusting the calculated stress values, the stress diagram display and the appearance of an Attention-Message to left of the diagram in red italics.

9- Overturning Check

EccPad calculates two overturning factors, one along X-axis and the other along Z-axis. When the resultant eccentricity is very small, the values of these factors may approach infinity.

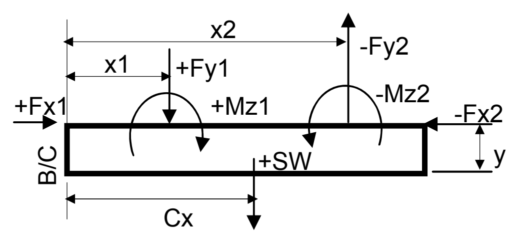
A conventional overturning check comprises calculations of the restoring and overturning moments. For a given set of reactions
shown in the sketch:

The Restoring moment about edge B/C is:
RM = SW Cx + Fy1 x1 + Mz1 + Fx1 y



Plan Showing Axes

The corresponding overturning moment about the edge B/C is:
OM = Fy2 x2 + Mz2 + Fx2 y



Pad Elevation Showing Forces

The factor of safety against overturning is therefore given by:
FOS = RM / OM,
which needs to be less than a permissible value of say 1.5

In the above procedure, it is necessary to identify loads which are either resist or cause overturning. This process becomes tedious and manual when there are multitude of loads acting on the pad. Moreover, at times, there may not be any loads causing the pad to overturn. This occurs when all applied loads act vertically within the pad foot print. The overturning factor in such cases becomes infinity or large when the resultant eccentricity approaches a zero or near zero value.

To avoid complexity, the values of eccentricities ex and ez already calculated for the stress analysis are used to check the overturning moment factors as follows:

OTMF = 0.5 Xp / ex the factor along x-axis
OTMF = 0.5 Zp / ez the factor along z-axis

10- Loss of Contact in Compression

When a part of the pad soffit is in non-tension it carries no compression. The part of the pad is considered as having lost contact with the ground. Some designers and codes of practice limit the extent to which this loss is acceptable. This requirement is similar to or in-lieu of having an adequate factor of safety against overturning.

EccPad calculates the % loss of contact whenever a part of the pad is under non-tension.

11- Sliding & Rotational Resistance of Pad

EccPad calculates the resultant shear RFxz and the resultant torsional moment RMy. In addition, location of the shear resultant RFxz is also calculated and indicated in the diagram display. This location of RFxz, however, may not be the same as that of the vertical resultant RFy.

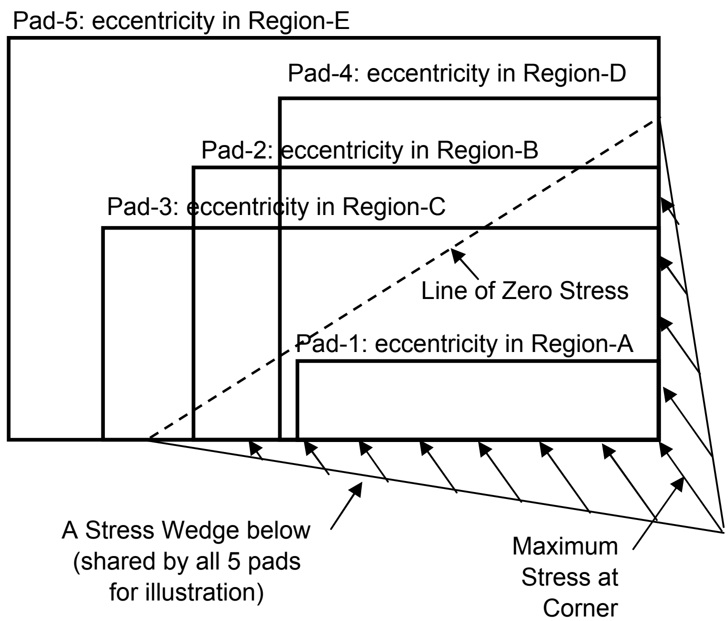
Under resultant shear and torsional moment, a pad may not only slide but also rotate in plan. The sliding & rotational resistance of a pad may comprise frictional resistance and or lateral passive earth pressure of the surrounding ground. EccPad does not estimate this resistance. Using the calculated values of RFxz & RMy, the user needs to ensure that the pad has adequate sliding and rotational resistance.

12- Linear Stress Distribution Beneath Pads

The linear stress variation beneath the pad forms part of a triangular wedge of stress. At one of its corner, two sides of this wedge are always at right angle to each other in plan. The maximum stress in this wedge occurs at this right angle corner. The stress along its two perpendicular edges varies from a maximum at one end to zero at the other. The stress along its entire diagonal edge remains zero. A wedge of stress common to 5 rectangular pads is shown below to illustrate possible stress variations beneath these pads.

When finding stress distribution beneath a pad, one corner of the pad always coincides with the right-angle corner of the triangular stress wedge. By calculating the two perpendicular lengths of the stress wedge, stresses at all corners of the rectangular pad can be worked out by linear interpolation. The induced stress is maximum at right angle corner and zero at the other two corners of the stress wedge.

When the applied loading happens to be concentric, the stress distribution beneath the pad is uniform. In this case, the two right angled lengths of the stress wedge become infinity.



13- Uniform Stress Distribution Beneath Pads

The basis of this stress distribution is essentially the same as for the limit-state design of concrete sections. The load capacity is determined from a consideration of the stress distribution at failure. If a vertical force is eccentric and the load is increased until failure of the soil/material, the contact stress distribution ultimately becomes uniform. As described in Ref 2, the pad may tilt towards the direction of the eccentricity but at the instant of failure the net ultimate capacity of one or both materials materialises at their surface of contact.

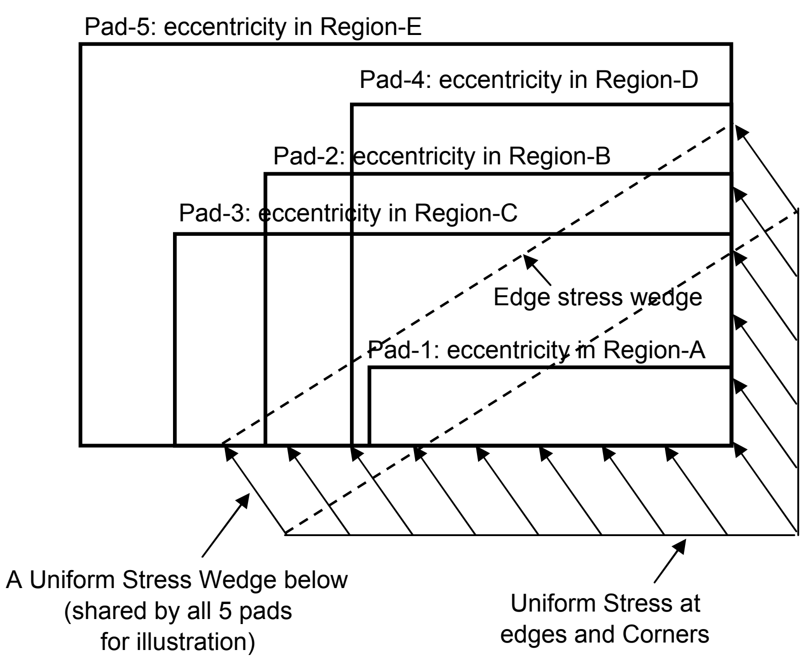
The size of the contact area is found by making centroid of the resulting stress block to coincide the position of resultant reaction acting on the pad.

When the resultant is eccentric in only one direction, the pressure distribution is given by:

RFy / (Xp*(Zp-ez)) for eccentricity in the z direction, and
RFy / (Zp*(Xp-ex)) for eccentricity in the -x direction.

When the resultant is doubly eccentric, the calculations becomes tedious and it is necessary to derive and use equations based on equilibrium. These equations are described in a later section.

Under eccentric loading, the shape of stress distribution beneath the pads is a wedge of uniform stress. In order to illustrate various stress distributions, a wedge of uniform stress common to 5 rectangular pads is shown below .

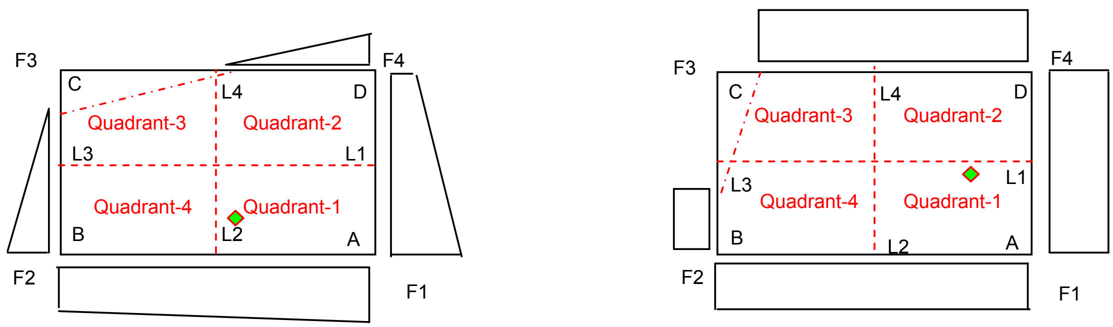


14- Eccentricity Quadrants in Plan Area of Pad

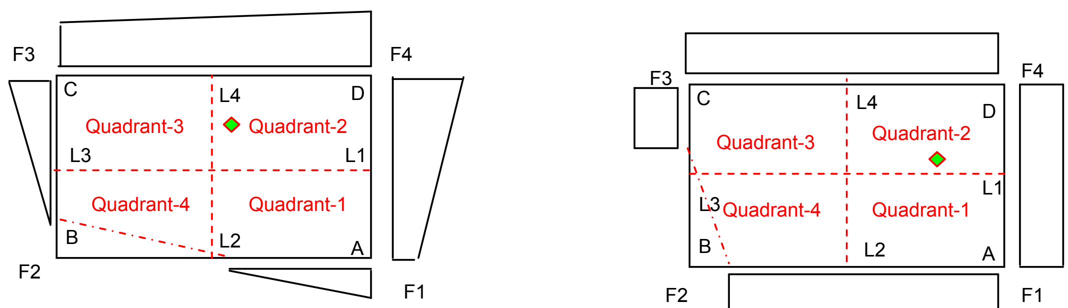
There are four quadrants in plan of the pad where the vertical resultant of applied loads can occur. The quadrant in which a given resultant lies depends upon the relative magnitude and position of constituent loads and moments acting on the pad i.e. eccentricity values ex and ez of the resultant. The criteria for establishing the quadrant of a given resultant is as follows:

Quadrant 1: ex>=0 & ez >=0
Quadrant 2: ex>=0 & ez <=0
Quadrant 3: ex<=0 & ez <=0
Quadrant 1: ex<=0 & ez >=0 .

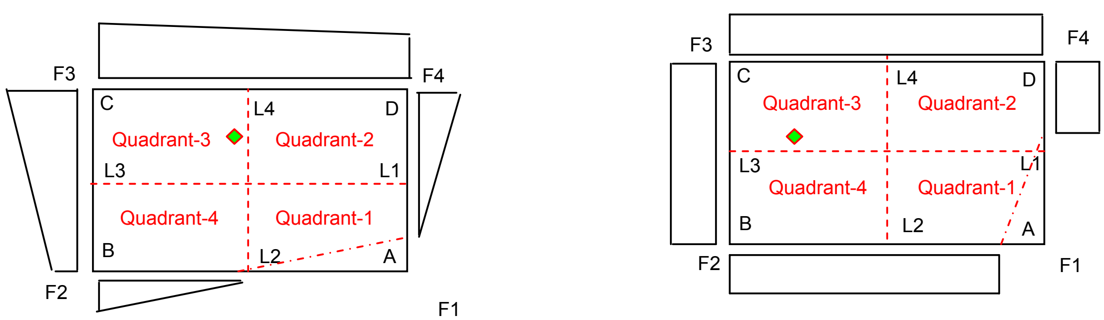
EccPad adjusts the display of stress distribution diagram and magnitudes of the induced stresses according to the quadrant in which the resultant occurs. The diagrams below shows various stress patterns and lines of zero stress when the resultant position varies in each of the four quadrants.



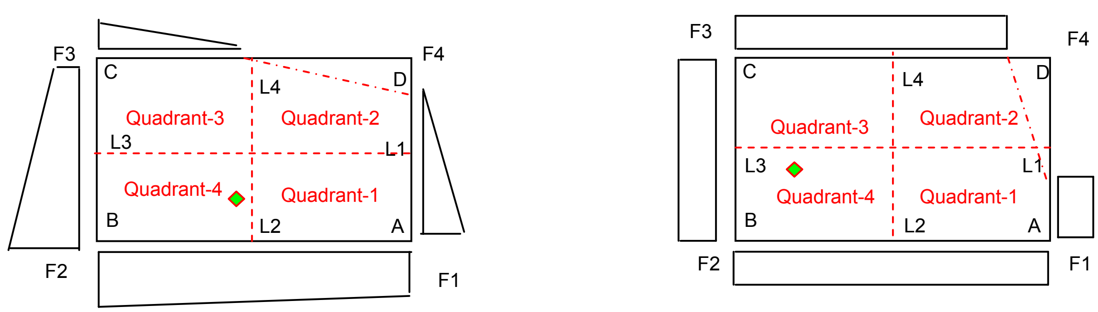
Resultant in Quadrant-1 & Stress Distributions



Resultant in Quadrant-2 & Stress Distributions



Resultant in Quadrant-3 & Stress Distributions



Resultant in Quadrant-4 & Stress Distributions

15- Regions of Eccentricity in a Pad Quadrant Under Linear Stress Variation

In each quadrant of a pad there are 5 eccentricity regions which produce differing stress patterns beneath the pad. These regions of eccentricity are A , B, C, D and E . The five regions in quadrant 1 and their corresponding stress patterns are shown in the sketch below as following:

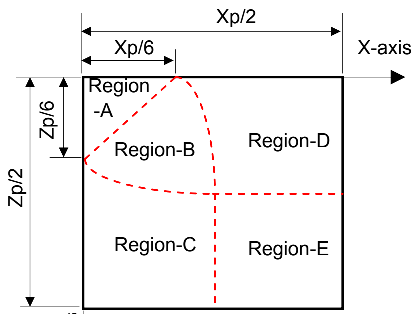
Region-A: 4 Corners A, B, C & D are in compression. Length of edges in compression are:
L1= Zp, L2=Xp, L3=Zp and L4=Xp

Region-B: 3 Corners A, B & D are in compression. Length of edges in compression are:
L1=Zp, L2=Xp, L3<Zp & L4< Xp.

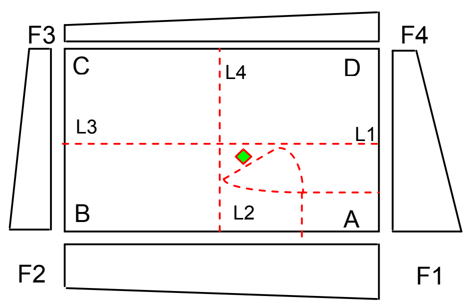
Region-C: 2 Corners A & B are in compression. Length of edges in compression are:
L1<Zp, L2=Xp, L3 <Zp & L4=0

Region-D: 2 Corners A & D are in compression. Length of edges in compression are:
L1=Zp, L2<Xp, L3 =Zp & L4<Xp

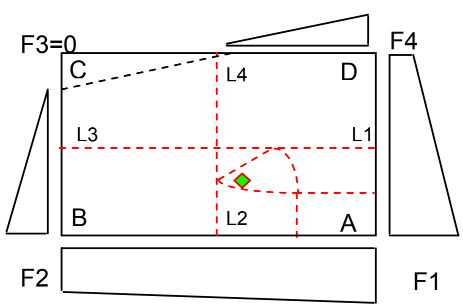
Region-E: 1 Corners A in compression. Length of edges in compression are:
L1<Zp, L2<Xp, L3 =0 & L4=0



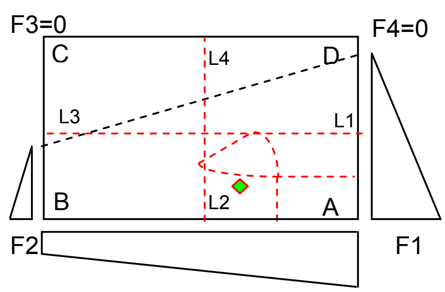
Eccentricity Regions A to E in Quadrant-1



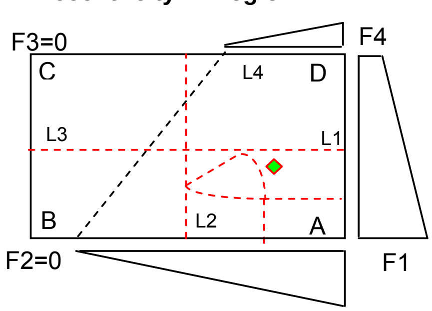
Eccentricity in Region-A



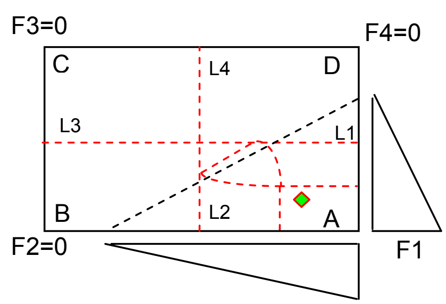
Eccentricity in Region-B



Eccentricity in Region-C



Eccentricity in Region-D



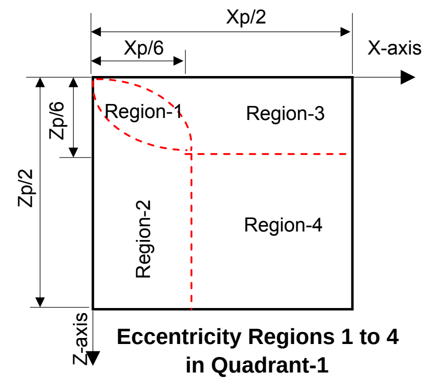
Eccentricity in Region-E

Eccentricity Regions & Linear Stress Distribution Beneath Pads

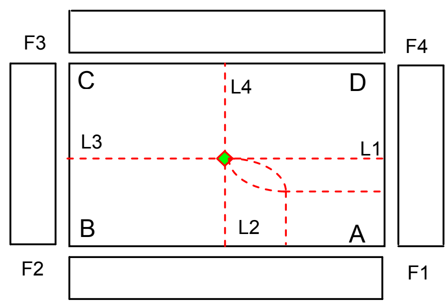
16- Regions of Eccentricity in a Pad Quadrant under Uniform Stress

In each quadrant of a pad under uniform stress distribution there are 5 eccentricity regions which produce differing stress wedge shape beneath the pad. These regions of eccentricity are 0, 1, 2, 3 and 4. The five regions in quadrant 1 and their corresponding stress shapes are shown in the sketch below as following:

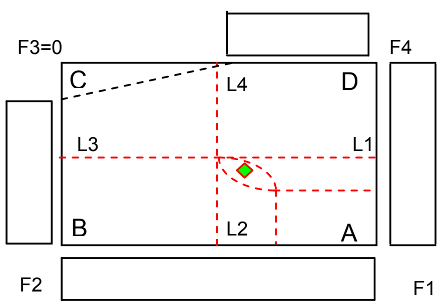
Region-0: 4 Corners A, B, C & D are in uniform compression. Length of edges in compression are:
L1= Zp, L2=Xp, L3=Zp and L4=Xp. The resultant position is concentric to the pad.
Region-1: 3 Corners A, B & D are in compression. Length of edges in compression are:
L1=Zp, L2=Xp, L3<Zp & L4< Xp.
Region-2: 2 Corners A & B are in compression. Length of edges in compression are:
L1<Zp, L2=Xp, L3 <Zp & L4=0
Region-3: 2 Corners A & D are in compression. Length of edges in compression are:
L1=Zp, L2<Xp, L3 =Zp & L4<Xp
Region-4: 1 Corners A in compression. Length of edges in compression are:
L1<Zp, L2<Xp, L3 =0 & L4=0



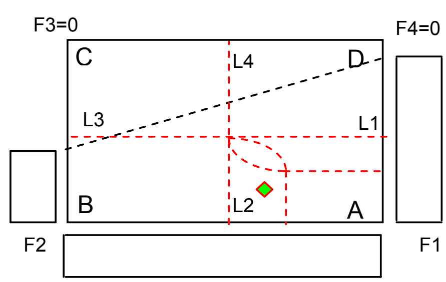
Eccentricity Regions 1 to 4 in Quadrant-1



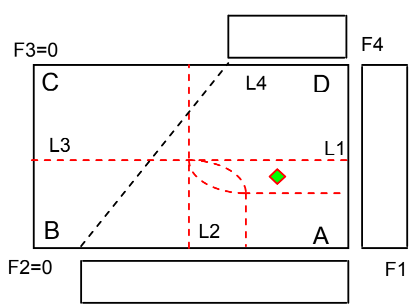
Eccentricity in Region-0



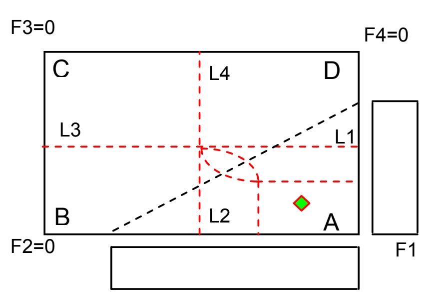
Eccentricity in Region-1



Eccentricity in Region-2



Eccentricity in Region-3



Eccentricity in Region-4

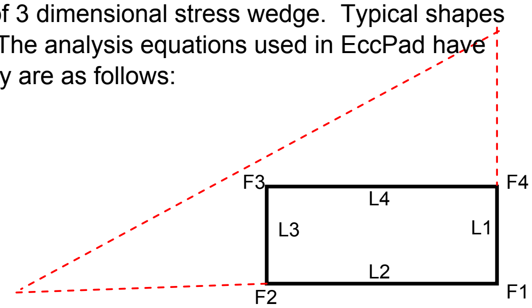
Eccentricity Regions & Uniform Stress Distribution Beneath Pads

17- Equations for Linear Stress Values & Edge Lengths Under Non-Zero Stress

As described above, each stress block is a part of 3 dimensional stress wedge. Typical shapes of this wedge for each region are shown below. The analysis equations used in EccPad have been derived from equations given in Ref 1. They are as follows:

Region-A

$L1 = Zp$
$L2 = Xp$
$L3 = Zp$
$L4 = Xp$
$F1 = RFy(1 + 6ex/Xp + 6ez/Zp) / (Xp*Zp)$
$F2 = RFy(1 - 6ex/Xp + 6ez/Zp) / (Xp*Zp)$
$F3 = RFy(1 - 6ex/Xp - 6ez/Zp) / (Xp*Zp)$
$F4 = RFy(1 + 6ex/Xp - 6ez/Zp) / (Xp*Zp)$



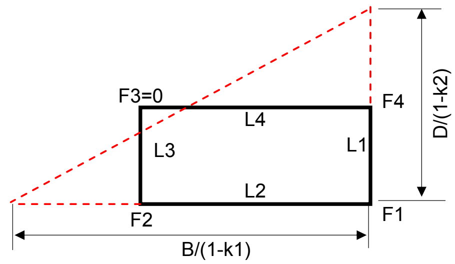
Region-A - Linear Stress Wedge in Plan

Region-B

$L1 = D / (1-k2)$; 1st side length of linear stress wedge >=Zp
$L2 = B / (1-k1)$;2nd side length of linear stress wedge >=Xp
$L3 = k1\ L1$
$L4 = k2\ L2$
$F1 = 6\ RFy / [L1*L2*(1- k1^3 - k2^3)]$
$F2 = k1\ F1$
$F3 = 0$
$F4 = k2\ F1$

In the above the values of k1 & k2 are obtained from the following two equations:

$ez/Zp = 0.5 -[\{(1 - k1^4-k2^4) / (1 - k2) - 4\ k2^3 \} / \{4*(1 - k1^3 - k2^3)\}]$
$ex/Xp = 0.5 -[\{(1 - k1^4-k2^4) / (1 - k1) - 4\ k1^3 \} / \{4*(1 - k1^3 - k2^3)\}]$



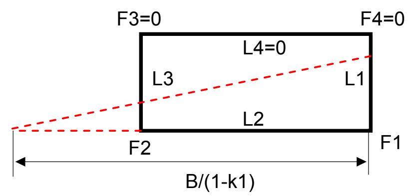
Region-B - Linear Stress Wedge in Plan

Region-C

$L1 = (2D - 4\ ey)(1+k1+k1^2) / (1+k1+k1^2+k1^3)$
$L2 = Xp / (1-k1)$; side length of linear stress wedge >=Xp
$L3 = k1\ L1$
$L4 = 0$
$F1 = 6\ RFy / [L1*Xp*(1 + k1+ k2^2)]$
$F2 = k1\ F1$
$F3 = 0$
$F4 = 0$

In the above the values of k1 are obtained from the following equation:

$ex/Xp = 0.5 -[\{(1 - k1^4) / (1 - k1) - 4\ k1^3\} / \{4*(1 - k1^3)\}]$



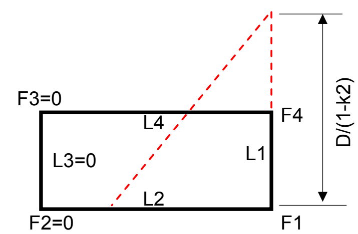
Region-C - Linear Stress Wedge in Plan

Region-D

$L1 = Zp / (1-k2)$; side length of linear stress wedge >=Zp
$L2 = (2\ Xp - 4\ ex)(1+k2+k2^2) / (1+k2+k2^2+k2^3)$
$L3 = 0$
$L4 = k2\ L1$
$F1 = 6\ RFy / [L2*Zp*(1+ k2 + k2^2)]$
$F2 = k2\ F1$
$F3 = 0$
$F4 = 0$

In the above the values of k2 are obtained from the following equation:

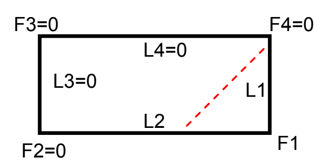
$ez/Zp = 0.5 -[\{(1 - k2^4) / (1 - k2) - 4\ k2^3\} / \{4*(1 - k2^3)\}]$



Region-D - Linear Stress Wedge in Plan

Region-E

$L1 = 2\ Zp - 4\ ez$
$L2 = 2\ Xp - 4\ ez$
$L3 = 0$
$L4 = 0$
$F1 = 0$
$F2 = 6\ RFy / (L1*L2)$
$F3 = 0$
$F4 = 0$



Region-E - Linear Stress Wedge in Plan

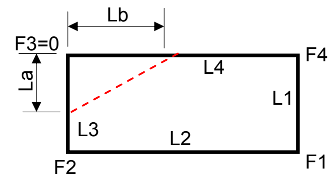
Factors k1 & k2 relate lengths of edges in the stress wedge to corresponding edges in the pad. When edges of the stress wedge are longer than the edges of the pad, equations of k1 and k2 for regions B, C and D are noted above. Where applicable, EccPad calculates and shows the values of these factors in its screen display and output. The factors k1 & k2 are useful when checking equilibrium and/or validity of EccPad results.

18- Equations for Uniform Stress Value & Edge Lengths under Non-Zero Stress

The stress variation beneath the pads is a 3 dimensional stress wedge of uniform thickness. Typical shape of this wedge for each region are shown below. The analysis equations used have been derived by taking moments of areas about the pad edges for equilibrium.. They are as follows:

Region-1 Concentric (EccPad return this value as 0 to signify that the resultant is at ex=0 & ey=0)

$L1 = Zp$; $La = 0$; $Lb = 0$
$L2 = Xp$
$L3 = Zp$
$L4 = Xp$
$F1 = F2 = F3 = F4 = RFy / (B*D)$



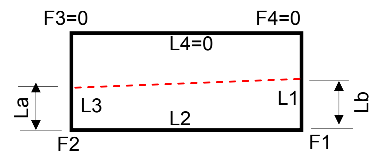
Region-1 - Uniform Stress Wedge in Plan

Region-1 Eccentric

$L1 = Zp$; 1st side length of uniform stress wedge
$L2 = Xp$; 2nd side length of uniform stress wedge
$La = 12 * Xp * Zp * ex / (Lb*(k2-2*Lb))$
In the above, Lb is given by the following cubic equation:
$4 * ez * Lb^3 + 2*(k1 * ex - 2 * k2 * ez) * Lb^2 + (ez * k2^2 - k1*k2*ex) * Lb + 24 * Xp * Zp * ex^2 = 0$
In the above, $k1 = 3*(Zp + 2*ez)$ & $k2 = 3*(Xp + 2*ex)$
$L3 = Zp - La$
$L4 = Xp - Lb$
$F1 = F2 = F4 = RFy / (Xp * Zp - La * Lb / 2)$
$F3=0$

Region-2

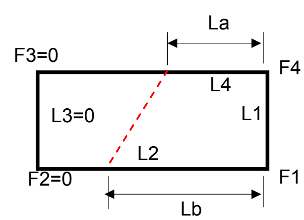
$k = (1 - 6 * ex / Xp) / (1 + 6 * ex / Xp)$
$Lb = 3 * (k+1) * (0.5 - ez/Zp) * Zp / (k^2 + k + 1)$
$La = k * Lb$
$L1 = Lb$; $L2 = Xp$; $L3 = La$; $L4 = 0$
$F1 = F2 = RFy / (Xp * (La + Lb) / 2)$
$F3 = F4 = 0$



Region-2 - Uniform Stress Wedge in Plan

Region-3

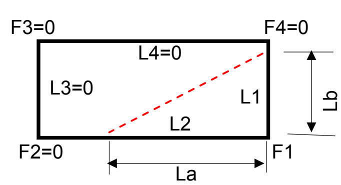
$k = (1 - 6* ez / Zp) / (1 + 6 * ez / Zp)$
$Lb = 3 * (k+1) * (0.5 - ex / Xp) * Xp / (k^2 + k + 1)$
$La = k * Lb$
$L1 = Zp$; $L2 = Lb$; $L3 = 0$; $L4 = La$
$F1 = F4 = RFy / (Zp * (La + Lb) / 2)$
$F2 = F3 = 0$



Region-3 - Uniform Stress Wedge in Plan

Region-4

$La = 3* (xp/2 - ex)$
$Lb = 3* (Zp/2 - ez)$
$L1 = Lb$; $L2 = La$; $L3 = 0$; $L4 = 0$
$F1 = 0$
$F1 = RFy / (La * Lb / 2)$
$F3 = 0$
$F4 = 0$



Region-4 - Linear Stress Wedge in Plan

19- Assumptions & Limitations

■ No sliding check is carried out. The sliding resistance of a pad may comprise the frictional resistance equal to the vertical resultant multiplied by the coefficient of friction and the passive lateral resistance of the adjacent ground.

■ The resultant torsional moment RMy is not required or used in the pressure distribution analysis. The magnitude of this resultant is however calculated and included in the output. In its overall design, the pad should have sufficient rotational resistance to prevent rotation under this moment.

■ The pressures values calculated are at soffit level of the pad. The analysis takes into account the additional moments caused by horizontal shears acting at top of the pad above its soffit level.

■ The pressure distribution is linear.

■ The pad is a rigid element and does not deform under applied loads and induced pressures below its soffit.

20- References

1 Hackman, Mike, "Bearing Pressures on Bridge Footings", Civil Engineering (London), November 1977, pp. 37-39

2 Billam, John, "The design of eccentrically loaded shallow footings", Civil Engineering (London), March 1978

Notations

A	Region-A of eccentricity in a pad quadrant; also Pad corner at its bottom right
B	Region-B of eccentricity in a pad quadrant; also Pad corner at its bottom left
C	Region-C of eccentricity in a pad quadrant; also Pad corner at its top left
D	Region-D of eccentricity in a pad quadrant; also Pad corner at its top right
E	Region-E of eccentricity in a pad quadrant
Cx	Centroid of the Pad from its top left corner in x-direction
Cz	Centroid of the Pad from its top left corner in z-direction
ex	Vertical Resultant eccentricity in x-direction (origin being at point Xp/2, Zp/2)
ex'	Shear Resultant eccentricity in x-direction (origin being at point Xp/2, Zp/2)
ey	Vertical Resultant eccentricity in z-direction (origin being at point Xp/2, Zp/2)
ez'	Shear Resultant eccentricity in z-direction (origin being at point Xp/2, Zp/2)
F1	Induced stress at bottom right corner-A of the pad
F2	Induced stress at bottom left corner-B of the pad
F3	Induced stress at top left corner-C of the pad
F4	Induced stress at top right corner-D of the pad
Fx	Applied load in X-direction (Horizontal, left to right)
Fy	Applied load in Y-direction (Vertical, bottom to top)
Fz	Applied load in Z-direction (Horizontal, top to bottom)
k1	A constant relating pad x-eccentricity to the magnitude and length of the stress wedge
k2	A constant relating pad z-eccentricity to the magnitude and length of the stress wedge
L1	Length of non-zero stress along right edge of the pad
L2	Length of non-zero stress along bottom edge of the pad
L3	Length of non-zero stress along left edge of the pad
L4	Length of non-zero stress along top edge of the pad
Mx	Applied moment about X-axis
My	Applied moment about Y-axis (ignored in the resistance check)
Mz	Applied moment about Z-axis
OM	Overturning moment
OTMF	Overturning moment factor to provide stability
Q	Resultant Quadrant, a number 1 to 4
RFx	Resultant Vertical Load in x-direction
RFxz	Resultant shear tending to slide the pad in the horizontal direction [Sqrt (RFx^2 + RFz^2)]
RFy	Resultant Vertical Load in y-direction or W
RFz	Resultant Vertical Load in z-direction
RM	Restoring moment resisting overturning of the pad
RMy	Resultant Torsional tending to spin the pad in plan (about Y-axis).
SW	Self weight of the Pad
W	Resultant Vertical Load in y-direction or RFy
x	X-position of the load from top left corner of the pad
Xp	Pad projection in X-direction (in plan)
y	Y-position of the load from soffit level of the pad.
Yp	Pad height in Y-direction (in elevation)
z	Z-position of the load from top left corner of the pad
Zp	Pad projection in Z-direction (in plan)

Terms & Conditions of EccPad Use

Disclaimer

No Liability is accepted by Techno Consultants or its software authors for any direct, indirect, consequential or incidental loss or damage arising out of the software use or any mistakes and negligence in developing this software. The organisation or person using the software bears all risks and responsibility for the quality and performance of the software.

Your Usage

The software is intended to help you save time and effort in calculations. Please check and validate all results carefully. You are responsible and liable for all consequences of its use.

Software Distribution Policy

This product is being distributed as a part of our policy to pool, share and grow technical expertise with fellow engineers. In the past we did so by using personal and direct business contacts. Availability of the Internet, now makes it possible to pool and share expertise with engineers all over the world.

You can freely use this product for your personal or business design work. This product however remains our copyright. You may also reproduce and distribute it provided that each copy shall be a true and complete copy, including all copyright and trademark notices and that such distribution shall not be for commercial purposes.

Funding and Formal Registration

We welcome funds to help our Research and Development work. You are welcome to make contributions at your discretion. As a guide and route to making a minimum payment, you can register your use of this software. Doing so shall enable you to become a formal member of our user team. Your details will be used for pooling, sharing and informing of future developments via email.

The fee for formal registration is £45.00. Add 17.5 percent VAT for registrations based in the UK and EC member states.

To register and send payments please email us your full details i.e. Name, Company, Postal Address, Telephone, Fax & Email Address. Acknowledgement will be sent via Email.

Technical Support and Contacting Us

We welcome and value all comments and suggestions via email. However, we do not provide formal technical support. As and when possible, your comments will be used to improve our software in the future. Your feedback is very important to us. You can download software and obtain the latest information from our web site. The web and email address is:

http:\\www.technouk.com
Email: shaiq@technouk.com

Stresses Beneath Pads Under Eccentric Loads, Shears and Moments

Revision History of EccPad

V20070822	1st version Issued.
V20070830	2nd version Issued. Error in storage of "Max Stress" in the "Store" sheet fixed.
V20070904	3rd version Issued. Facility carryout uniform stress analysis beneath the pads added.
V20071003	4th version Issued. Documentation improved in places.

EccPadPad20071003