

Addis Ababa University
School of Graduate Studies
Department of Civil Engineering

SOFTWARE DEVELOPMENT FOR DESIGN OF SHALLOW FOUNDATIONS

By

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B.Sc. in Civil Engineering

A Thesis Submitted to School of Graduate Studies in
Partial Fulfillment of the Requirement for Degree of
Master of Science
in
Geotechnics

Advisor

Dr. Hadush Seged

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Addis Ababa, Ethiopia

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ABSTRACT

The most commonly used types of shallow foundations are isolated footings, strap footings and combined footings. A team of expertise involving engineers, draftspersons, quantity surveyors, and others frequently do the tasks of designing, drawing, and quantifying shallow foundations. Design of shallow foundations is usually performed using spreadsheet programs. Quantity surveyors are also aided by Microsoft Excel to quantify structures. Working drawing is most of the time prepared by using the software AutoCAD.

Most of the times, information is transferred from engineers to drafts person by using sketches. And quantity surveyors use the drawings developed to quantify structures.

AutoCAD can be manipulated programmatically by using macros. Macros which can produce working drawings for isolated, strap, and combined footings can be developed. And the input data for these macros can be in EXCEL format.

The purpose of this thesis is to develop EXCEL spreadsheet programs and AutoCAD macros which aid the engineer, the draftsperson and the quantity surveyor design, draw and quantify isolated or strap or combined footings.

Three spreadsheet programs named “Isolated.xls”, “Combined.xls” and “Strap.xls” are developed to analyze and design shallow foundations. As a final product, brief design report can be printed from these spreadsheets and take off sheet is automatically produced in a separate sheet. Besides, three AutoCAD macros named “Isolated.dvb”, “Combined.dvb” and “Strap.dvb” are developed to produce working drawings. The input data for the AutoCAD macro can be simply copied from the Excel spreadsheet programs.

LIST OF SYMBOLS

D	-	Depth of foundation
B	-	Width of foundation
f_{ctk}	-	Characteristic tensile strength of concrete
f_{ctm}	-	Mean value of axial tensile strength of concrete
f_{ctd}	-	Design of axial tensile strength of concrete
f_{ck}	-	Characteristic compressive strength of concrete
f_{yk}	-	Characteristic yield strength of reinforcement
f_y	-	Yield strength of reinforcement
f_d	-	Design strength
f_k	-	Characteristic strength
$f_{0.2}$	-	Yield strength of reinforcement at 0.2% offset
f_{bd}	-	Design bond strength
l_b	-	Basic anchorage length
l_{bnet}	-	Required anchorage length
l_{bmin}	-	Minimum anchorage length
γ_m	-	Partial safety factor for materials
γ_c	-	Partial safety factor for concrete
γ_s	-	Partial safety factor for steel
DL	-	Dead load
LL	-	Live load
M_{sd}	-	Design value of the applied internal bending moment
d	-	Distance from extreme compression to centroid of tension reinforcement
b	-	Actual flange width in a T or L beam
b_w	-	Width of the web on T, I, or L beams
ρ	-	Geometrical ratio of reinforcement
ρ_{min}	-	Minimum geometrical ratio of reinforcement
ρ_{max}	-	maximum geometrical ratio of reinforcement
A_s	-	The cross-sectional area of the longitudinal reinforcement
A_{sef}	-	Area of reinforcement actually provided
A_{scal}	-	Theoretical area of reinforcement required by the design

S	-	Shear reinf. spacing in the direction of the longitudinal reinforcement
V_{rd}	-	Shear resistance of a section
V_c	-	Shear carried by the concrete
V_{sd}	-	Shear acting along the periphery" of the critical section
V	-	Punching shear
$K1, K2$	-	Margin of strength
S_{max}	-	Maximum spacing between stirrups
β	-	Ratio of long side to short side of footing
ϕ	-	diameter of reinforcement

1 INTRODUCTION

1.1 Background

Foundations are used to spread the load from superstructure so that the pressure transmitted to the ground is not of a magnitude such as to cause the ground to fail.

The various types of foundations are grouped into two broad categories:

1. Shallow foundations which are further grouped into
 - a) Strip footing
 - b) Spread or isolated footing
 - c) Combined footing
 - d) Strap or cantilever footing
 - e) L footings
 - f) Mat foundations
2. Deep foundations which are mostly pile foundations

Designs of foundations involve:

- checking for bearing capacity failure
- checking for excessive settlement
- checking for shear failure
- designing for flexure

1.2 Problem Statement

Analysis and design of foundations involve rigorous calculations to be performed. The advent of the computer and development of sophisticated and yet simple to use design software have enabled structural engineers to be very precise in the analysis and design of foundations.

In Ethiopia numerous spreadsheet programs have been developed to aid the analysis and design process. These spreadsheet programs are developed by interested individuals and not by organized group of expertise. Therefore, these programs are very much liable to various types of errors and most of the times lead to unsafe or uneconomical design of foundations.

1.3 Aim and Objectives

The objective of the thesis is to develop a standard, public domain computer program which can:

- i. Perform structural design of shallow foundations according to EBCS
- ii. Produce a working drawing
- iii. Prepare bill of quantities
- iv. Prepare a design report

1.4 Scope of Study

The types of shallow foundations to be studied here are

1. Isolated rectangular footing
2. Combined footings which support two columns
3. Strap footings

This thesis also studies on how to group isolated square footings.

Limitations of the thesis are

- Only rigid method of analysis is discussed here.
- Stepped footings are not discussed here.

1.5 Thesis Outline

This thesis is divided into five chapters. The first chapter gives the basic introduction to the research background, outlines the scope, objectives of the research and structure of the thesis.

The basic principles of foundation design are discussed in the Second Chapter. Chapter Two also presents the detail review of the Ethiopian Building Code of Standards (EBCS).

Methodology for design of isolated footings is discussed in the third chapter. In this chapter the theoretical background and formulas that are used in the development of the spreadsheet program for design of isolated footings are discussed in detail.

Methodology for design of combined footings is discussed in the fourth chapter. In this chapter the theoretical background and formulas that are used in the development of the spreadsheet program for design of combined footings are discussed in detail.

Methodology for design of strap footings is discussed in the fifth chapter. In this chapter the theoretical background and formulas that are used in the development of the spreadsheet program for design of strap footings are discussed in detail.

Appendix 1 solves an actual problem of isolated footings by using the programs developed by this thesis. A typical problem of isolated footings includes grouping, analysis and design, report writing, quantifying, and producing detailed drawings.

Appendix 2 solves an actual problem of combined footing by using the programs developed by this thesis. A typical problem of combined footing includes analysis and design, report writing, quantifying, and producing detailed drawings.

Appendix 3 solves an actual problem of strap footing by using the programs developed by this thesis. A typical problem of strap footing includes analysis and design, report writing, quantifying, and producing detailed drawings.

2 LITERATURE REVIEW

2.1 INTRODUCTION

Foundations: Definition

Foundation is the part of an engineered system that transmits the loads supported by the foundation and its' self-weight to, and into, the underlying soil or rock.

Foundations: Classification

Foundations may be classified based on where the load is carried by the ground, producing:

Shallow foundations are termed bases, footings, spread footings, or mats and the depth is generally $D/B < 1$ but may be somewhat more [7].

Deep foundations—piles, drilled piers, or drilled caissons and, $D/B > 4+$ [7].

Foundations: General Requirements

Foundations are structural members used to support columns and walls and to transmit and distribute their loads to the soil in such a way that the load bearing capacity of the soil is not exceeded, excessive settlement, differential settlement, and rotations are prevented, and adequate safety against overturning or sliding is maintained.

Shallow Foundations: Types

The most commonly used types of shallow foundations are

1. Spread(Isolated) footing
2. Combined footing
3. Strap footing
4. Mat foundation

Except mat foundations, the other three shallow foundations are discussed in this thesis.

2.2 REVIEW OF EBCS

2.2.1 UNIT WEIGHT OF CONCRETE

The unit weight of normal weight reinforced concrete is 25 kN/m³.

2.2.2 CLASSIFICATION OF CONCRETE WORKS

Concrete works are classified as either Class I or II depending on the quality of workmanship and the competence of the supervisors directing the works. Works carried out under the direction of appropriately qualified supervisors ensuring the attainment of level of quality control envisaged in EBCS 2 1995, Chapter 9 are classified as Class I works.

2.2.3 GRADES OF CONCRETE

Concrete is graded in terms of its characteristic compressive cube strength. The grade of concrete to be used in design depends on the classification of the concrete work and the intended use. Table 2.1 gives the permissible grades of concrete for the two classes of concrete works. The numbers in the grade designation denote the specified characteristic compressive strength in MPa.

Table 2.1: Grades of Concrete.

Class	Permissible Grades of Concrete							
1	C5	C15	C20	C25	C30	C40	C50	C60
2	C5	C15	C20					

Grade C5 shall be used only as lean concrete

2.2.4 CHARACTERISTIC COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength of concrete is determined from compression tests on 150mm cubes at the age of 28 days in accordance with Ethiopian Standards. The characteristic compressive strength is defined as that strength below which 5% of all possible strength measurements may be expected to fall. In practice, the concrete may be regarded as complying with the grade specified for the design if the results of the tests comply with the acceptance criteria laid down in Chapter 9 of EBCS 2, 1995. Cylindrical or cubical specimens of other sizes may also be used with conversion factors determined from a comprehensive series of tests. In the absence of such tests, the conversion factors given in Table 2.2 may be applied to obtain the equivalent characteristic strength on the basis of 150mm cubes.

Table 2.2: Conversion Factors for Strength

Size and Type of Test Specimen	Conversion Factor
Cube (200 mm)	1.05
Cylinder (150 mm diameter 300 mm height)	1.25

Therefore the characteristic compressive strength of concrete cylinder f_{ck} is calculated as:

$$f_{ck} = \frac{\text{Grade of concrete}}{1.25} \quad \text{Eq.2. 1}$$

2.2.5 CHARACTERISTIC TENSILE STRENGTH OF CONCRETE

The characteristic tensile strength refers to the axial tensile strength as determined by tests in accordance with standards issued or approved by Ethiopian Standards. In the absence of more accurate data, the characteristic tensile strength f_{ctk} may also be determined from the characteristic cylinder compressive strength according to the equation below.

$$f_{ctk} = 0.7 * f_{ctm} \quad \text{Eq.2. 2}$$

Where f_{ctm} is the mean value given by the equation below

$$f_{ctm} = 0.3 * f_{ck}^{2/3} \quad \text{Eq.2. 3}$$

2.2.6 CHARACTERISTIC PROPERTIES OF REINFORCING STEEL

The characteristic strength f_{yk} is defined as the 5% fractile of the proof stress f_y or 0.2 % offset strength, denoted as $f_{0.2}$. The density of steel is 7850 kg/m³.

2.2.7 DESIGN STRENGTH

The design strength, f_d , for a given material property and limit state is obtained, in principle, by dividing the characteristic strength, f_k , by the appropriate partial safety factor for the material property, γ_m . Tables 2.3 and 2.4 can be used to determine the partial safety factor for material property.

$$f_d = f_k / \gamma_m \quad \text{Eq.2. 4}$$

Table 2.3: Partial Safety Factor for Materials -Class I Works

Design Situations	Concrete γ_c	Reinforcing Steel, γ_s
Persistent and Transient	1.5	1.15
Accidental	1.3	1

Table 2.4: Partial Safety Factor for Materials -Class II Works

Design Situations	Concrete γ_c	Reinforcing Steel, γ_s
Persistent and Transient	1.65	1.2
Accidental	1.45	1.1

Design Strength for Concrete

(1) The design strength of concrete, f_{cd} , is defined by:

(a) In compression

$$f_{cd} = 0.85 * f_{ck} / \gamma_c \quad \text{Eq.2. 5}$$

(b) In tension

$$f_{ctd} = 0.85 * f_{ctk} / \gamma_c \quad \text{Eq.2. 6}$$

Where, γ_c is the partial safety factor for concrete.

Design Strength for Steel

(1) The design strength of steel in tension and compression, f_{yd} , is defined by:

$$f_{yd} = f_{yk} / \gamma_s \quad \text{Eq.2. 7}$$

Where, γ_s is the partial safety factor for steel.

2.2.8 ACTIONS ON STRUCTURES

Actions are classified by their variation in time as:

- (I) Permanent actions dead load (*DL*) e.g. self-weights of structures, fittings ancillaries and fixed equipment.
- (II) Variable actions live load (*LL*) e.g. imposed loads or wind loads.
- (III) Accidental actions (*EQ*), e.g. explosions or impact from vehicles.

Note seismic design of footings is not included in this study. Therefore only dead and live loads are used for the design.

2.2.9 COMBINANTION OF ACTIONS

- a) Footing sizes are determined for unfactored service loads and soil pressures.

$$F_D = DL + LL \quad \text{Eq.2. 8}$$

Where, F_D is design load.

- b) The strength design of reinforced concrete members (depth and reinforcement calculation) are determined for factored service loads and soil pressures.

$$F_D = 1.4 * (DL + LL) \quad \text{Eq.2. 9}$$

2.2.10 DESIGN OF FLEXURAL REINFORCEMENT

- The geometrical ratio of reinforcement ρ at any section of a beam is calculated by:

$$\rho = \left[1 - \sqrt{1 - \frac{2 * M_{sd}}{b * d^2 * f_{cd}}} \right] * \frac{f_{cd}}{f_{yd}} \quad \text{Eq.2. 10}$$

Where M_{sd} is the design bending moment at a section

b is the width of the section

d is effective depth of the section

f_{cd} is the design strength of concrete

f_{yd} is the design strength of reinforcing steel

- The minimum geometrical ratio of reinforcement ρ is calculated by:

$$\text{For beams} \quad \rho_{\min} = \frac{0.6}{f_{yk}} \quad \text{Eq.2. 11}$$

$$\text{For slab} \quad \rho_{\min} = \frac{0.5}{f_{yk}} \quad \text{Eq.2. 12}$$

Where, f_{yk} is the characteristic strength of steel.

- Area of steel

$$A_s = \rho b d \quad \text{Eq.2. 13}$$

Where, b is width and d is effective depth of member.

- Spacing of reinforcement

$$S = \frac{b * \pi * \phi^2}{A_s} \quad \text{Eq.2. 14}$$

Where, Φ is diameter of reinforcement.

2.2.11 DESIGN OF SHEAR REINFORCEMENT

Critical section for shear is at a distance d from the face of supports as shown in figure 2.1.

Sections closer than d shall be designed for the shear at d .

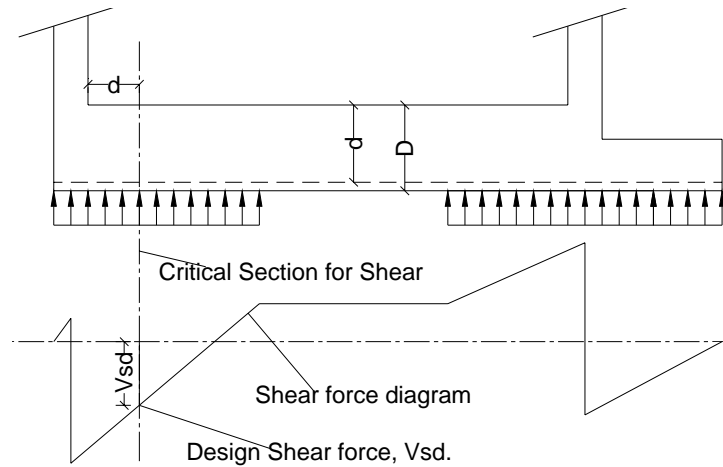


Figure 2. 1: Critical section for shear.

Limiting Value of Ultimate Shear Force

In order to prevent diagonal compression failure in the concrete, the shear resistance V_{RD} of a section given by the equation below shall not be less than the applied shear force V_{sd} .

$$V_{RD} = 0.25 * f_{cd} * b_w d \quad \text{Eq.2. 15}$$

Where, b_w is the minimum width of the web.

Shear Resistance of Concrete in Beams and Slabs

The shear force V_c carried by the concrete in members without significant axial forces shall be taken as:

$$V_c = 0.25 * f_{ctd} * k_1 k_2 b_w d \quad \text{Eq.2. 16}$$

Where

$$K_1 = 1 + 50\rho < 2.0$$

$$K_2 = 1.6 - d > 1 \text{ (d in meters)}$$

$$\rho = \frac{A_s}{b_w d}$$

A_s is the area of the tensile reinforcement anchored beyond the intersection of the steel and the line of a possible 45° crack starting from the edge of the section.

Spacing of stirrup

$$S = \frac{A_v * d * f_{yd}}{V_{SD} - V_C} \quad \text{Eq.2. 17}$$

Where

A_v is the area of shear reinforcement within distance S .

V_{sd} = design shear force

V_c = shear resistance of concrete

Minimum Reinforcement

1. All beams, except joists of ribbed slabs, shall be provided with at least the minimum web reinforcement given by:

$$\rho_{\min} = \frac{0.4}{f_{yk}} \quad \text{Eq.2. 18}$$

Where f_{yk} is in MPa.

2. The maximum spacing S_{max} between stirrups, in the longitudinal direction, shall be given as below:

$$S_{max} = 0.5d < 300 \text{ mm if } V_{sd} < 2/3V_{RD}$$

$$S_{max} = 0.3d < 200 \text{ mm if } V_{sd} > 2/3V_{RD} \quad \text{Eq.2. 19}$$

3. The transverse spacing of legs of stirrups shall not exceed d , or 800 mm, whichever is the smaller.

2.2.12 PUNCHING**General**

This section applies to the punching of slabs and footings that are provided with the necessary flexural reinforcement. The ultimate limit state in punching is characterised by the formation of a truncated punching cone or pyramid around concentrated loads or reactions.

Loaded Area

The provisions of this section are applicable to the following types of loaded area:

1. Shape (d denotes the average effective depth of the slab or footing):
 - rectangular, with perimeter not exceeding $11d$ and the ratio of length to breadth not exceeding 2.
 - circular, with diameter not exceeding $3.5d$
 - any shape, with perimeter not exceeding $11d$.
2. The loaded area is not so close to other concentrated forces that their critical perimeters intersect, nor in a zone subjected to significant shear forces of a different origin.

If the conditions in (a) above are not satisfied for wall or rectangular column supports, the critical reduced perimeters according to figure 2.2 shall be taken into account, since the shear forces in wall-shaped supports are concentrated in the corners.

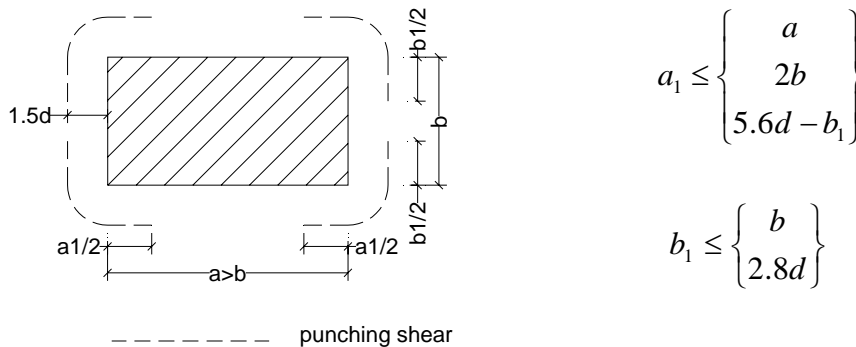


Figure 2. 2: Application of Punching Provisions in Non-Standard Cases

Critical Section

The critical section is perpendicular to the middle plane of the slab. It extends along the effective depth d and its outline is defined below.

Loaded Area Remote from an Opening or a Free -Edge

The outline of the critical section is the closed outline of the minimum perimeter surrounding the loaded area. However, it need not approach closer to the loaded area than lines located at a distance $1.5d$ from that area and parallel to its boundaries (see Fig. 2.3).

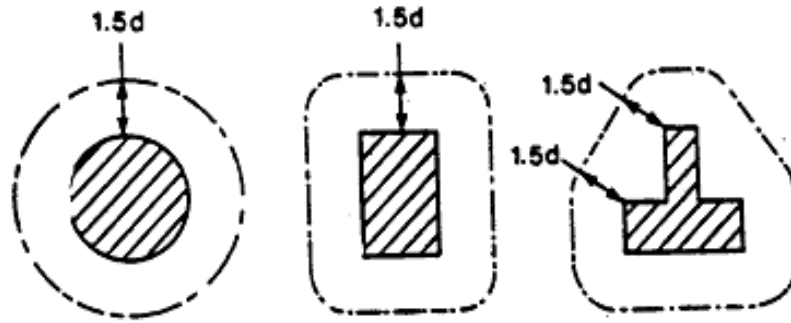


Figure 2. 3: Critical Section Remote from a Free Edge [3]

Loaded Area Close to an Opening

When openings in slabs and footings (see Figure 2.4) are located at a distance less than $6d$ from the edge of the concentrated load, then that part of the perimeter which is enclosed by radial projections from the centroid of the loaded area to the openings is considered ineffective.

Where a single hole is adjacent to the column and its greatest width is less than one quarter of the column side or one half of the slab depth, whichever is the lesser, its presence may be ignored.

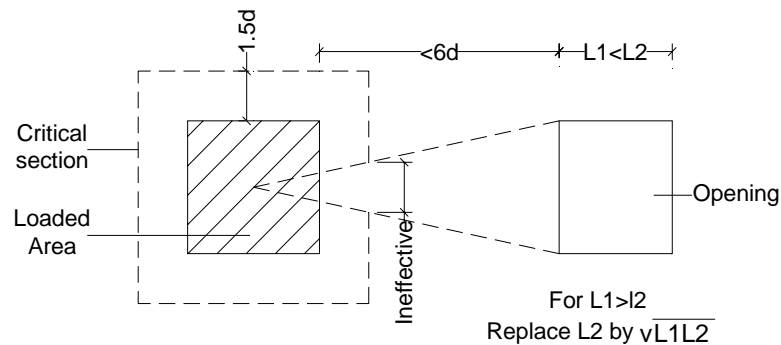


Figure 2. 4: Critical Section in a vicinity of an opening [3]

Loaded Area Close to Free Edge

In the vicinity of a free edge certain parts of the outline defined for the case of remote opening or free edge shall be replaced by perpendicular lines to those edges if the resulting length developed this way, excluding the free edges, is smaller than the length of the closed outline wholly enclosing the loaded area (see Fig. 2.5).

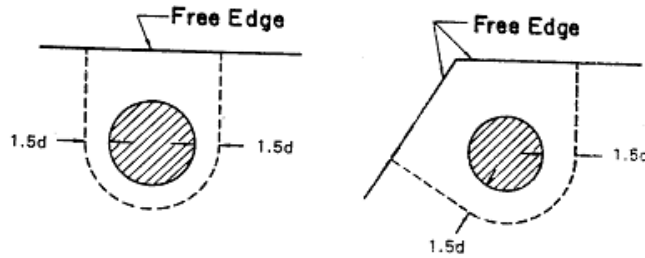


Figure 2. 5: Critical Section near free edges

[3]

Applied Load Effect

In the case of a concentric load or reaction, the punching shear force V_{sd} shall not exceed the punching shear resistance V_{Rd} . In the case of an eccentric load or reaction, the applied load effect of the punching shear force V_{sd} with eccentricity e shall be taken to be equal to that of an equivalent concentric load V_{eq} given by

$$V_{eq} = \beta V_{sd} \quad \text{Eq.2. 20}$$

Where, $\beta = 1 + \eta e u d / Z$

e is the eccentricity of the load or reaction with respect to the centroid of the critical section, always positive

Z is the section modulus of the critical section, corresponding to the direction of the eccentricity

η denotes fraction of moment which is considered transferred by eccentricity of the shear about the centroid of the critical section

$$\eta = \frac{1}{1 + \sqrt{b_2/b_1}}$$

b_1 and b_2 are sides of the rectangle of outline u , b_1 being parallel to the direction of the eccentricity e .

Conservatively, the following values may be used for flat slabs with approximately equal spans and for footings:

- (a) Interior column: $\beta = 1.15$
- (b) Edge column: $\beta = 1.40$
- (c) Corner column: $\beta = 1.50$

Resistance of Slabs or Footings without Punching Shear Reinforcement

The punching resistance V_{RD} shall be given by the equation below

$$V_{RD} = 0.25f_{ctd}K_1K_2Ud \quad \text{Eq.2. 21}$$

where $k_1 = (1 + 50\rho) < 2.0$

$k_2 = 1.6 - d > 1.0$ (d in meters- For members where more than 50% of the bottom reinforcement is curtailed, $k_1 = 1$)

$$d = (d_x + d_y)/2$$

$$\rho = (\rho_{ex} + \rho_{ey})^{1/2} < 0.015$$

ρ_{ex} , ρ_{ey} correspond to the geometric ratios of longitudinal reinforcement parallel to x and y , respectively

d is the average effective height in the x and y directions.

U is perimeter of critical region.

2.2.13 FOOTINGS

Moment in Footings

The external moment on any section of a footing shall be determined by passing a vertical plane through the footing, and computing the moment of the forces acting over the entire area of the footing on one side of that vertical plane.

The critical section for moment shall be taken as follows:

- At the face of column, pedestal, or wall, for footings supporting a concrete column pedestal or wall
- Halfway between middle and edge of wall, for footings supporting a masonry wall.
- Halfway between face of column and edge of steel base for footings supporting a column with steel base plates.

Flexural Reinforcement

- Distribution: In one-way footings and two-way square footings, reinforcement shall be distributed uniformly across the entire width of footing.

2. In two way rectangular footings, reinforcement shall be distributed as follows:
 - a) Reinforcement in long direction shall be distributed uniformly across the entire width of footing.
 - b) For reinforcement in the short direction, a portion of the total reinforcement given by the equation below shall be distributed uniformly over a band width (centered on center line of column or pedestal) equal to the length of the short side of footing. The remainder of the reinforcement required in the short direction shall be distributed uniformly outside the center band width of the footing.

$$\frac{\text{Reinforcement in band width}}{\text{total reinforcement in short direction}} = \frac{2}{\beta + 1} \quad \text{Eq.2. 22}$$

where β is the ratio of long side to short side of footing.

3. Anchorage: If the projection of the footing from the critical section for moment does not exceed the effective depth d at that section, the bottom reinforcement shall be provided with full anchorage length measured from the end of the straight portion of the bars.
4. If the projection exceeds d , the anchorage length may be measured from a section situated at a distance d from the above defined critical section for moment.

Shear in Footings

Design of footings for shear shall be in accordance with provisions for slabs in Section 4.5. of EBCS2 1995

The location of the critical section for shear in accordance with Section 4.5 of EBCS2, 1995 shall be measured from face of column, pedestal or wall for footings supporting a column, pedestal, or wall.

For footings supporting a column or pedestal with steel base plates, the critical section shall be measured from the location defined in Section 6.5.1. of EBCS2, 1995.

Bearing

All forces and moments applied at the base of a column or pedestal shall be transferred to the top of the supporting pedestal or footing by bearing on concrete and

by reinforcement. The design bearing strength on concrete shall not exceed the design compressive strength f_{cd} except as follows:

- a) When the supporting surface is wider on all sides than the loaded area, the design bearing strength on the load area may be multiplied by $\sqrt{(A_2/A_1)}$ but not more than 2.
- b) When the supporting surface is sloped or stepped, A_2 may be taken as the area of the lower base of the largest frustrum of a right pyramid or cone contained wholly within the support and having for its upper base the loaded area, and having side slopes of 2 vertical to 1 horizontal.

In the above A_1 is the loaded area, and A_2 is the maximum area of the portion of the supporting surface that is geometrically similar to and concentric with the loaded area.

Minimum Footing Depth

The depth of footing above bottom reinforcement shall not be less than 150 mm for footings on soil.

2.2.14 DETAILING PROVISIONS

Concrete Cover to Reinforcement

The concrete cover is the distance between the outer surface of the reinforcement (including links and stirrups) and the nearest concrete surface. The minimum concrete cover to all reinforcement including links and stirrups should not be less than the appropriate values given in Table 2.5.

Table 2. 5: Minimum Cover Requirements for Concrete Members (3)

Type of exposure	Dry environment: Interior of buildings of normal habitation or offices (Mild)	Humid environment: Interior components (e.g. laundries); exterior components; components in non aggressive soil and/or water (Moderate)	Seawater and/or aggressive chemical environment: Components completely or partially submerged in seawater; components in saturated salt air; aggressive industrial atmospheres (Severe)
Minimum Cover (mm)	15	25	50

Anchorage to reinforcement

All reinforcement shall be properly anchored at each end with due consideration for the effect of arch action and shear cracks. To prevent bond failure, the tension or compression in any bar at any section due to ultimate loads shall be developed on each side of the section by an appropriate embedment length or end anchorage or a combination thereof. Hooks may be used in developing bars in tension.

Design Bond Strength

The design bond strength f_{bd} depends on the type of reinforcement, the concrete strength and the position of the bar during concreting. The bond conditions are considered to be good for:

- (a) All bars which are in the lower half of an element
- (b) All bars in, elements whose depth does not exceed 300 mm
- (c) All bars which are at least 300 mm from the top of an element in which they are placed
- (d) All bars with an inclination of 45^0 to 90^0 to the horizontal during concreting.

For good bond conditions the design bond strength of plain bars, f_{bd} , may be obtained from the equation below.

$$f_{bd} = f_{ctd} \quad \text{Eq.2. 23}$$

For deformed bars twice the value for plain bars may be used.

$$f_{bd} = 2f_{ctd} \quad \text{Eq.2. 24}$$

For other bond conditions, the design bond strength may be taken as 0.7 times the value for good bond conditions.

$$f_{bd} = 0.7 * 2 * f_{ctd} = 1.4f_{ctd} \quad \text{Eq.2. 25}$$

Basic Anchorage Length

The basic anchorage length is the embedment length required to develop the full design strength of a straight reinforcing bar.

The basic anchorage length l_b for a bar of diameter ϕ is:

$$l_b = \frac{\phi f_{yd}}{4 f_{bd}} \quad \text{Eq.2. 26}$$

Required Anchorage Length

The required anchorage length l_{bnet} depends on the type of anchorage and on the stress in the reinforcement and can be calculated as:

$$l_{bnet} = a l_b \frac{A_{s,cal}}{A_{s,ef}} \geq l_{bmin} \quad \text{Eq.2. 27}$$

where $A_{s,cal}$ is the theoretical area of reinforcement required for the design

$A_{s,ef}$ is the area of reinforcement actually provided

$a = 1.0$ for straight bar anchorage in tension or compression

$= 0.7$ for anchorage in tension with standard hooks

$l_{b,min}$ is the minimum anchorage length

For bars in tension,

$$l_{b,min} = 0.3l_b > 10\phi > 200mm \quad \text{Eq.2. 28}$$

For bars in compression,

$$l_{b,min} = 0.6l_b > 10\phi > 200mm \quad \text{Eq.2. 29}$$

3 DESIGN OF RECTANGULAR ISOLATED FOOTINGS

3.1 INTRODUCTION

A footing carrying a single column is called a spread footing, since its function is to "spread" the column load laterally to the soil so that the stress intensity is reduced to a value that the soil can safely carry. These members are sometimes called single or isolated footings. In plan, single-column footings are usually square. Rectangular footings are used if space restrictions dictate this choice or if the supported columns are of strongly elongated rectangular cross section.

3.2 ASSUMPTIONS AND LIMITATIONS

The basic assumptions for the design of rectangular isolated footings are:

- Footings must be rigid, so that the soil pressure distribution is linear.
- Stepped footings are not discussed here.
- Horizontal loads and torsional moments transferred from columns must be very small.

3.3 LIST OF SYMBOLS SPECIFIC TO SECTION 3

P	-	Superstructure load
F_{CD}	-	design strength of concrete
M_X	-	moment in x direction
M_Y	-	moment in y direction
C_X	-	column width in x direction
C_Y	-	column width in y direction
FD	-	foundation depth
BC	-	bearing capacity
L_X	-	footing dimension in x direction
L_Y	-	footing dimension in y direction
D_E	-	total depth of footing
D_{EFF}	-	effective depth of footing
GS	-	unit weight of soil
P_{TOT}	-	total load on footing
MO_X	-	design moment in x direction
MO_Y	-	design moment in y direction

- F_{YDX} – yield design strength of steel in x direction
- F_{YDY} – yield design strength of steel in y direction
- DI_X – diameter of steel in x direction
- DI_Y – diameter of steel in y direction

3.4 PROCEDURES

- Step 1:** Proportioning of footings
- Step 2:** Determination of footing thickness
- Step 3:** Reinforcement calculation
- Step 4:** Determination of development length

3.5 PROPORTIONING OF FOOTINGS

It should be noted that footing sizes are determined for unfactored service loads and soil pressures, in contrast to the strength design of reinforced concrete members, which utilizes factored loads and factored nominal strengths.

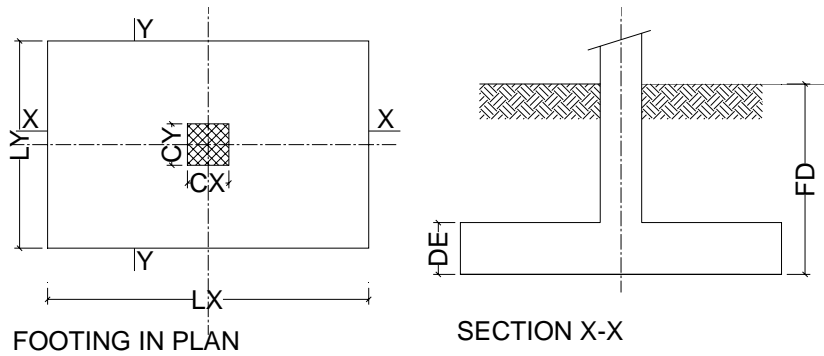


Figure 3. 1: Rectangular isolated footings

Loads acting on the foundation are:

1. Super structure loads : P
2. Weight of backfill soil SO_{wt} with unit weight of soil GS and is given by:

$$SO_{wt} = (Lx * Ly - C_x * C_y) * (FD - DE) * GS \quad Eq.3. 1$$

3. Own weight of footing O_{wt} :

$$O_{wt} = DE * L_x * L_y * 25 \quad Eq.3. 2$$

Hence the total vertical load acting on footing, P_{tot} , is the sum of superstructure load, own weight of footing and weight of backfill soil.

$$P_{tot} = P + O_{wt} + SO_{wt} \quad \text{Eq.3.3}$$

Where GS is unit weight of backfill material. For other notations see figure 3.1.

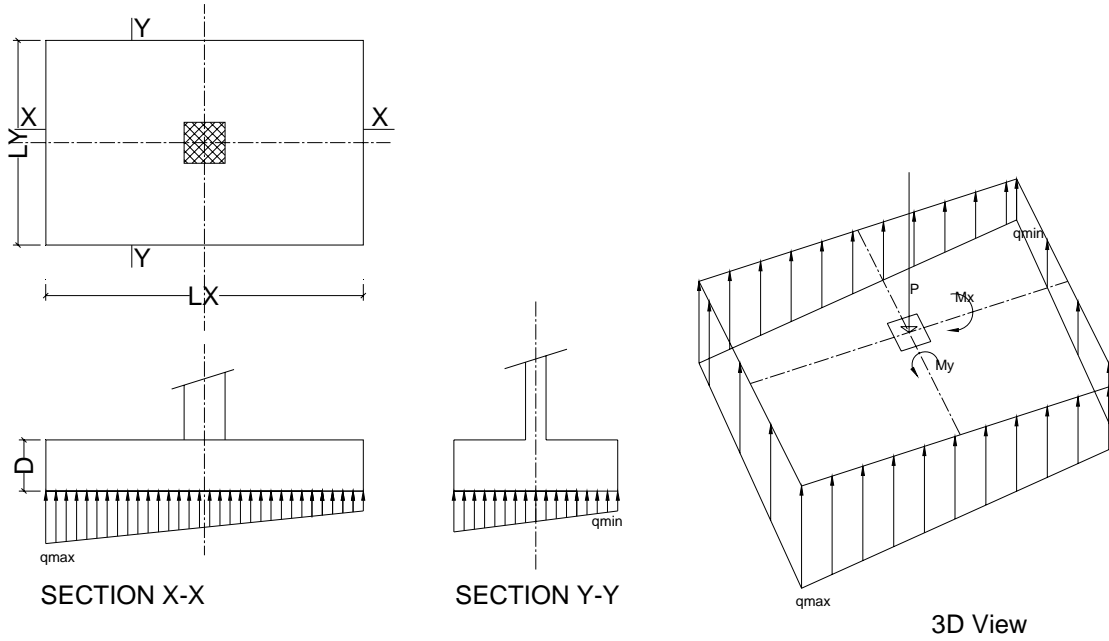


Figure 3. 2: Pressure distributions under isolated footing

The column transmits, at its juncture with the footing, not only a vertical load but also a bending moment. In either case, the load effects at the footing base can be represented by the vertical load P and a bending moment M . The resulting bearing pressures are again assumed to be linearly distributed. As long as the resulting eccentricity $e = M/P$ does not exceed the kern distance k of the footing area, the usual flexure formula permits the determination of the bearing pressures at the two extreme edges, as shown in figure 3.2.

$$Q_{\max,\min} = \frac{P}{A} \pm \frac{M_x C_x}{I_x} \pm \frac{M_y C_y}{I_y}$$

$$Q_{\max} = \frac{P_{tot}}{L_x L_y} + \frac{6|M_y|}{L_y L_x^2} + \frac{6|M_x|}{L_x L_y^2} \leq BC \quad \text{Eq.3.4}$$

$$Q_{\min} = \frac{P_{tot}}{L_x L_y} - \frac{6|M_y|}{L_y L_x^2} - \frac{6|M_x|}{L_x L_y^2} \geq 0 \quad \text{Eq.3.5}$$

3.6 DETERMINATION OF FOOTING THICKNESS

Once the required footing area has been determined, the footing must then be designed to develop the necessary strength to resist all moments, shears, and other internal actions caused by the applied loads. For this purpose, the load factors of the EBCS Code apply to footings as to all other structural components.

Shear stresses usually control the footing thickness D . And there are two modes of shear failure.

1. One way shear also known as wide beam shear or diagonal compression shear
2. Two way shear also known as punching shear or diagonal tension shear

It should be noted that footing thicknesses are determined for factored service loads and soil pressures.

Calculation of effective depth D_E :

$$DE = D - 0.05 - \phi / 1000 \quad \text{Eq.3. 6}$$

Where, D is thickness of footing and Φ is diameter of reinforcement.

3.6.1 CHECKING FOOTING THICKNESS FOR PUNCHING SHEAR

Various investigators have suggested different locations for the idealized critical shear surfaces for punching. EBCS 2, 1995 specifies that they be located at $1.5d$ distance from the face of the column. The footing design is satisfactory for punching shear when it satisfies the condition, $P_{RESI} > P_{SF}$, on all critical surfaces, where, P_{RESI} is the punching shear capacity on the critical surface and P_{SF} is the factored shear stress on critical surface.

3.6.1.1 CALCULATION OF PUNCHING SHEAR CAPACITY

The nominal two-way shear stress capacity on the critical section P_{RESI} is:

$$P_{RSI} = 0.25 * F_{CTD} * K_1 * K_2 \quad \text{Eq.3. 7}$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_1 = \min (1 + 50\rho, 2)$$

$$\rho = \min (0.015, \sqrt{\rho_x * \rho_y})$$

$$K_2 = \max (1.6 - D_e, 1)$$

Where, ρ_x and ρ_y are geometric ratios of reinforcement in x and y directions. CS is grade of concrete.

3.6.1.2 CALCULATION OF PUNCHING SHEAR STRESS ON CRITICAL SURFACES

The footing may be subject to applied normal force and bending moment i.e. P , M_x , M_y , all of which produce shear forces on the critical shear surfaces. The design shear is the algebraic sum of all design ultimate vertical loads acting on one side or outside the periphery of critical section.

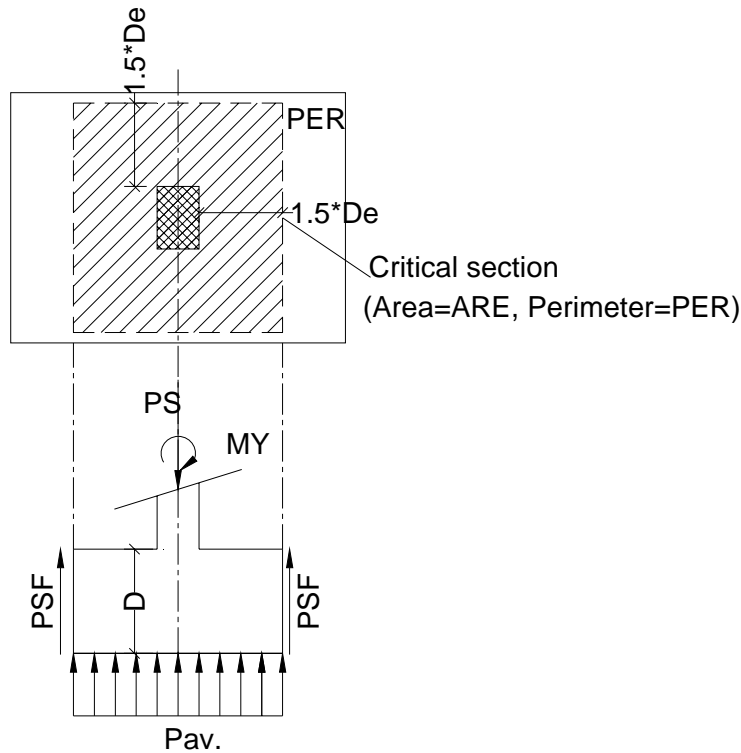
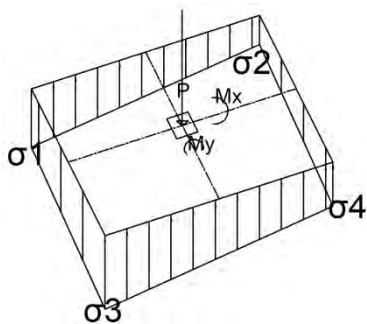


Figure 3. 3: critical areas for punching

- Calculation of punching shear stress acting on the critical area see figure 3.3.

$$P_{SF} = \frac{1.4 * (PS - PAV * ARE)}{PER * DE} \leq P_{RSI} \quad Eq.3. 8$$

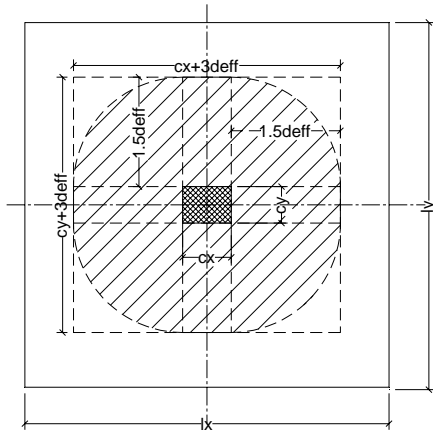
- Calculation of Average pressure acting on the critical area see figure 3.4.



$$PAV = \frac{\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4}{4} = \frac{P_{tot}}{lx * ly} \quad Eq.3. 9$$

Figure 3. 4: Average pressures acting on the critical area

- Calculation of punching area and perimeter involves four different cases



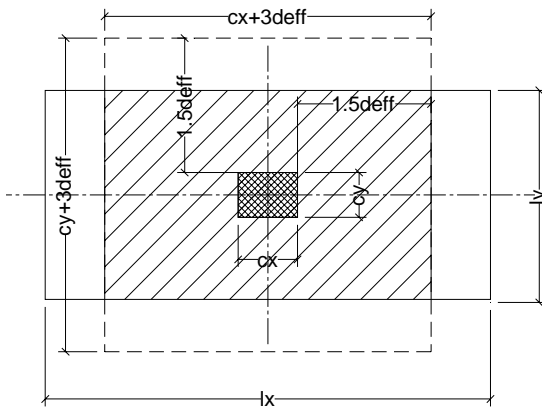
CASE 1 Critical section is within the footing area on all sides.

Case: $cx + 3d_{eff} < lx \ \& \ cy + 3d_{eff} < ly$

Perimeter: $2cx + 2cy + 3\pi d_{eff}$ *Eq.3. 10*

Area: $(cx + 3d_{eff})cy + (cy + 3d_{eff})cx - cxcy + \pi(3d)^2 / 4$ *Eq.3. 11*

Figure 3. 5: critical areas for punching (Case-1)



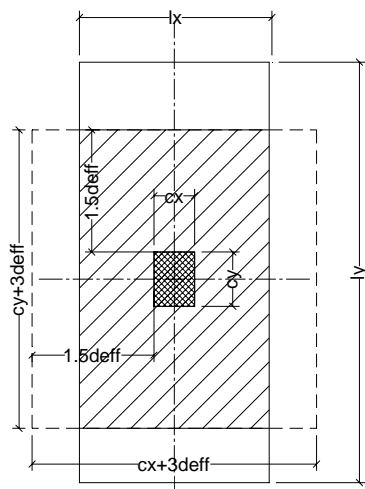
CASE 2 Critical Section is outside the footing area on top & bottom side.

Case: $cx + 3d_{eff} < lx \ \& \ cy + 3d_{eff} > ly$

Perimeter: $2 * ly$ *Eq.3. 12*

Area: $(cx + 3d_{eff}) * ly$ *Eq.3. 13*

Figure3. 6 critical areas for punching (Case-2)



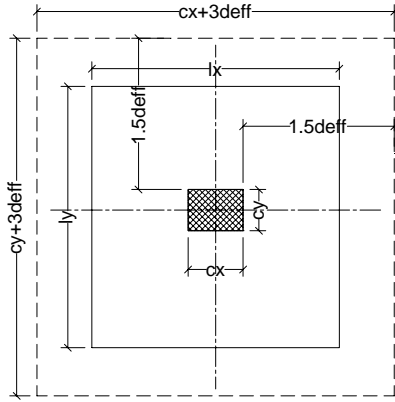
CASE 3 Critical Section is outside the footing area on left & right side.

Case: $cx + 3d_{eff} > lx \ \& \ cy + 3d_{eff} < ly$

Perimeter: $2 * lx$ *Eq.3. 14*

Area: $(cy + 3d_{eff}) * lx$ *Eq.3. 15*

Figure 3. 7: critical areas for punching (Case-3)



CASE 4 Critical section is outside the footing area on all sides.

Case: $cx + 3d_{eff} \geq lx \text{ \& } cy + 3d_{eff} \geq ly$

Perimeter: 0 *Eq.3.*

Area: $lx * ly$ *Eq.3. 17*

Figure 3. 8: critical areas for punching (Case-4)

3.6.2 CHECKING FOOTING THICKNESS FOR WIDE BEAM SHEAR

Various investigators have suggested different locations for the idealized critical shear surfaces for wide beam shear. EBCS 2, 1995 specifies that they be located at d distance from the face of the column. The footing design is satisfactory for wide beam shear when it satisfies the condition, $P_{RESI} > W_{SF}$, on all critical surfaces, where, P_{RESI} is the wide beam shear capacity on the critical surface and W_{SF} is the factored shear stress on critical surface.

3.6.2.1 CALCULATION OF WIDE BEAM SHEAR RESISTANCE

The nominal one-way shear stress capacity on the critical section is:

$$P_{RSI} = 0.25 * F_{CTD} * K_1 * K_2 \tag{Eq.3. 18}$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_1 = \min (1 + 50\rho, 2)$$

$$\rho = \min (0.015, \sqrt{\rho_x * \rho_y})$$

$$K_2 = \max (1.6 - D_e, 1)$$

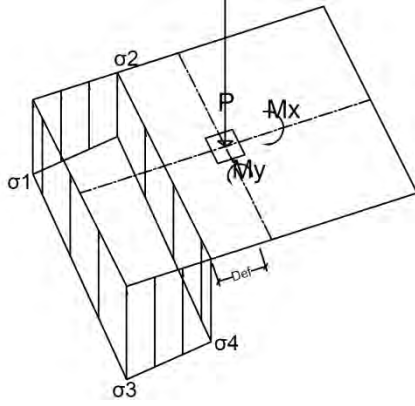


Figure 3. 9: critical areas for wide beam shear

3.6.2.2 CALCULATION OF WIDE BEAM SHEAR FORCE ON THE CRITICAL SURFACE

- Calculation of average pressure acting on the critical area

$$\sigma_{avx} = \frac{P_{tot}}{lx * ly} + \frac{3 * My * (2 * deff + cx + lx)}{ly * lx^3} \quad Eq.3. 19$$

$$\sigma_{avy} = \frac{P_{tot}}{lx * ly} + \frac{3 * Mx * (2 * deff + cy + ly)}{lx * ly^3} \quad Eq.3. 20$$

- Calculation of wide beam shear, τ , stress acting on the critical area

$$\tau_{widebeamx} = \frac{1.4 \sigma_{avx} * ly * (lx / 2 - deff - cx / 2)}{deff * ly} \leq \tau_{all} \quad Eq.3. 21$$

$$\tau_{widebeamy} = \frac{1.4 \sigma_{avy} * lx * (ly / 2 - deff - cy / 2)}{deff * lx} \leq \tau_{all} \quad Eq.3. 22$$

3.7 REINFORCEMENT CALCULATIONS

The footing is designed as reinforced concrete beam and critical sections for bending are at the face of the columns. There will only be negative bending steel in the bottom of the footing running in both directions.

- Calculation of Average pressures

In the X direction:
$$\sigma_{avx} = \frac{P_{tot}}{lx * ly} + \frac{3 * My * (cx + lx)}{ly * lx^3} \quad Eq.3. 23$$

In the Y direction:
$$\sigma_{avy} = \frac{P_{tot}}{lx * ly} + \frac{3 * Mx * (cy + ly)}{lx * ly^3} \quad Eq.3. 24$$

- Calculation of Design Bending Moment

In the X direction:
$$M_{ox} = \frac{\sigma_{averagex} * (lx/2 + cx/2)^2}{2} * 1.4 \quad Eq.3. 25$$

In the Y direction:
$$M_{oy} = \frac{\sigma_{averagey} * (ly/2 + cy/2)^2}{2} * 1.4 \quad Eq.3. 26$$

- Calculation of reinforcement

1. Flexural reinforcement for X direction bottom

$$\rho = \frac{\sqrt{\frac{1 - 2M_{ox}}{f_{cd} * 1000 * d_{ef}^2}}}{f_{cd} * f_{yd}} \quad Eq.3. 27$$

$$\rho_{min} = \frac{0.6}{f_{yk}} \quad Eq.3. 28$$

$$As = \max(\rho, \rho_{min}) * 1000 * d_{ef} \quad Eq.3. 29$$

2. Flexural reinforcement for Y direction bottom

$$\rho = \frac{\sqrt{\frac{1 - 2M_{oy}}{f_{cd} * 1000 * d_{ef}^2}}}{f_{cd} * f_{yd}} \quad Eq.3. 27$$

$$\rho_{min} = \frac{0.6}{f_{yk}} \quad Eq.3. 28$$

$$As = \max(\rho, \rho_{min}) * 1000 * d_{ef} \quad Eq.3. 29$$

3.8 DEVELOPMENT LENGTH CALCULATION

The design bond strength f_{bd}

$$f_{bd} = 1.4 * f_{ctd}, \text{ Where } f_{ctd} \text{ is the tensile strength of concrete.} \quad Eq.3. 33$$

The basic anchorage length l_b for a bar of diameter ϕ is:

$$l_b = \frac{\Phi f_{yd}}{4 f_{bd}} \quad Eq.3. 34$$

The required anchorage length l_{bnet} depends on the type of anchorage and on the stress in the reinforcement and can be calculated as:

$$l_{bnet} = a l_b \frac{A_{s,cal}}{A_{s,ef}} \geq l_{b,min} \quad Eq.3. 35$$

where $A_{s,cal}$ is the theoretical area of reinforcement required by the design

$A_{s,ef}$ is the area of reinforcement actually provided

$a = 1.0$ for straight bar anchorage in tension or compression

$= 0.7$ for anchorage in tension with standard hooks

$l_{b,min}$ is the minimum anchorage length

$\frac{A_{s,cal}}{A_{s,ef}} \approx 1$ at the face of columns therefore,

$$l_{bnet} = a l_b = 0.7 l_b = 0.7 * \frac{\Phi}{4} * \frac{f_{yd}}{1.4 * f_{ctd}} \geq l_{b,min} \quad Eq.3. 36$$

$\frac{A_{s,cal}}{A_{s,ef}} \approx 0$ near the edges therefore $l_{bnet} = l_{b,min}$

$$l_{b,min} = 0.3 * l_b > 10\phi > 200mm \quad Eq.3. 37$$

3.9 THE SPREADSHEET PROGRAM

A spreadsheet program called “*Isolated.xls*” is developed in this study. This spreadsheet program has four worksheets named as “*Reactions*”, “*Summary*”, “*Report*”, and “*Quantity*”.

The worksheet “*Reactions*” is used to group square isolated footings. The general look of this worksheet is shown in figure 3.10. Input data (foundation reactions, number of groups needed, and average bearing capacity) are written in green font. Total area of footings which is a checkpoint is written in blue font. This sheet groups foundations so that the total area of footings is minimized thereby reducing cost. Outputs are design foundation loads for each group, and group names for each foundation reaction. Group names, written in red font, are written in front of each foundation reaction whereas, summery of group names, design loads, and number of pieces for each group is written in a separate worksheet called “*Summary*”.

The procedures for grouping square isolated footings are.

1. Click “New” to erase previous calculations.
2. Insert foundation reactions, average bearing capacity and number of groups needed.
3. Click “Sort”.
4. Click “Forward’ and “Backward” buttons alternatively until “total area” stops decreasing
5. Click “Calculate” to make final calculations and then “Ok” to write summery.

B.C.	300	Round	0.1	New		Sort		nfoot	5	Forward		Total Area	Backward		Calculate	Ok
Maximum	2.4	Minimum	0.9									642.29				
POINT	FZ	MX	MY	Length	group	Length	Number	group	group	length	Pcs	total area	P	Mx	My	
28	579.52	-5.79	0.319	1.4	5	2.4	4	1	1	2.4	9	51.84	1713.87	-0.511	-0.957	
29	1030.64	-4.104	-3.005	1.9	3	2.3	5	1	2	2.2	50	242	1451.92	2.509	-0.635	
30	942.46	-2.472	-3.289	1.8	3	2.2	35	2	3	1.9	23	83.03	1073.01	1.375	1.471	
31	855.5	-1.467	-3.268	1.7	4	2.1	11	2	4	1.7	62	179.18	857.62	4.414	-0.047	
32	843.59	-1.03	-3.158	1.7	4	2	4	2	5	1.4	44	86.24	587.42	-3.555	-0.329	
33	840.09	-1.257	-3.185	1.7	4	1.9	9	3								
34	839.12	-3.967	-3.2	1.7	4	1.8	14	3								
35	839.53	-6.288	-3.231	1.7	4	1.7	35	4								
36	844.95	-6.184	-3.135	1.7	4	1.6	16	4								
37	904.26	-4.763	-3.324	1.8	3	1.5	11	4								
38	539.71	-1.858	-5.895	1.4	5	1.4	20	5								
157	931	-3.004	1.526	1.8	3	1.3	10	5								
159	1713.87	-0.511	-0.957	2.4	1	1.2	10	5								
160	1547.54	0.061	-2.173	2.3	1	1.1	1	5								
161	1393	0.421	-2.026	2.2	2	1	2	5								
162	1379.09	0.988	-1.836	2.2	2	0.9	1	5								
163	1385.28	0.785	-1.878	2.2	2											
164	1389.26	-2.014	-1.895	2.2	2											
165	1405.32	-4.388	-1.933	2.2	2											
166	1416.29	-4.192	-1.718	2.2	2											
167	1527.02	-2.593	-2.299	2.3	1											
168	923.68	2.038	-5.076	1.8	3											

Figure 3. 10: General look of worksheet “*Reactions*”

The general look of the worksheet called “**Summary**” is shown in figure 3.11. This worksheet is used to design each footing group. Design loads, bearing capacity and number of pieces of each group is transferred from the worksheet “**Reactions**”. Additional information like foundation depth, unit weight of soil, concrete strength, and diameter of reinforcing steel has to be provided by the user on this page. After inputs data is entered, clicking the “**Run**” button designs each footing group and displays footing sizes, footing thicknesses, and spacing of reinforcement in red font as shown in figure 3.11.

SUMMARY OF FOOTING DESIGN															
Bearing Capacity=		300												Run	
Foundation Depth=		1													
Unit weight of Soil=		18													
Concrete C=		25													
Number of Groups=		5													
1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Group	P	Mx	My	Pcs	Cx	Cy	Lx	Ly	D	d _{iax}	c/c _x	d _{iax}	c/c _y		
F-1	1713.87	-0.511	-0.957	9	0.2	0.4	2.5	2.5	0.7	12	140	12	150		
F-2	1451.92	2.509	-0.635	50	0.2	0.4	2.3	2.3	0.65	12	150	12	160		
F-3	1073.01	1.375	1.471	23	0.2	0.4	2	2	0.55	12	180	12	190		
F-4	857.62	4.414	-0.047	62	0.2	0.4	1.8	1.8	0.5	12	200	10	110		
F-5	587.42	-3.555	-0.329	44	0.2	0.4	1.5	1.5	0.4	12	240	10	140		

Figure 3. 101: general look of the worksheet called “Summary”

Brief design report can be printed from the worksheet called “**Report**” shown in figure 3.13. The user first has to select the name of footing from the dropdown button and then a brief design report of the footing can be printed. This worksheet also has the input data for the drawing process.

F-1		Depth of Footing		0.70	
Footing Width		Column Width			
X-Dir	Y-Dir	X-Dir	Y-Dir		
2.50	2.50	0.20	0.4		
Reinforcement X-Dir		Reinforcement Y-Dir			
Diam	Spacing	Diam	Spacing		
12	140	12	150		

Figure 3. 112: input data for the drawing process.

Footing Design				
Footing Group	F-1	C= 25		
Super-structure load, P_s (Kn)	1713.87	$f_{cd}= 11.333$		
M_x (Kn-m)	-3.004			
M_y (Kn-m)	1.526			
Column width, a (m) * b (m)	0.20	0.4		
Foundation depth, f_d (m)	1.00			
Ultimate bearing capacity, s (Kpa)	300			
Footing Dimension, (L_x * L_y) m	2.50	2.50		
Depth, D (m)	0.65			
Footing Area, A_f (m ²)	6.25			
Effective depth, d (m)	= $D - 0.05 \cdot \text{bar dia.}$	0.588		
Own Weight of Footing, W_c (Kn)	= $A_f \cdot D \cdot g_c$	102		
Unit weight of soil, g_s (Kn/m ³)	18.00			
Soil Weight, W_s (Kn)	= $(A_f - A_c) \cdot f_d \cdot g_s$	39	Area	3.58
Total load on footing, P_t (Kn)	= $P_s + W_c + W_s$	1854	Perimeter	6.74
Checking Bearing pressure (Kpa)	= P_t / A_f	296.7		
Max. soil pressure, Q_{max} (Kpa)	$(P_t / A_f) \cdot (1 + 6 \cdot e_x / L_x + 6 \cdot e_y / L_y) < Q_{ult}$	298.4		
Min. Soil pressure, Q_{min} (Kpa)	$(P_t / A_f) \cdot (1 - 6 \cdot e_x / L_x - 6 \cdot e_y / L_y) > 0.0$	294.9		
Tensile strength of conc., f_{ctd} (Mpa)	$0.21 \cdot (f_{ck})^{0.5} / 1.5$	1.03		
Allowable punching resistance of concrete, V_{up} (Kn/m ²)	$0.25 \cdot f_{ctd} \cdot K_1 \cdot K_2 \cdot 10^3$	277.7		
Allowable wide beam shear resistance of concrete, v_{wb} (Kn/m ²)	$0.25 \cdot f_{ctd} \cdot K_1 \cdot K_2 \cdot 10^3$	277.7		
Punching Shear, V_p (kn)	$P_t \cdot (7.07d^2 + 3d(a+b) + ab) \cdot Q_{act}$	651.0		
Punching Shear Stress, V_{up} (Kpa)	$V_p / ((9.42 \cdot d^2 + 2 \cdot (a+b) \cdot d)$	164.2		
Wide beam Shear, V_{wb} (Kn/m)	$(P_s / A_f) \cdot (L_x / 2 - d - a / 2)$	385.9	317.8	
Wide beam Shear stress (Kn/m ²)	$V_{wb} / (b \cdot d)$	262.5	216.2	
Max. Design Moment, M_d (Kn-m)	$0.25 \cdot (Q_{min} + 3 \cdot Q_{max}) \cdot ((L_x - a) / 2)^2 \cdot 0.5$	181.5	151.5	
Design yield strength (Mpa)	f_{yk}	348	348	
ρ (%)	$(1 - \sqrt{1 - (2 \cdot M_d / (3000 \cdot d^2 \cdot f_{cd})})) \cdot f_{cd} / f_{yd}$	0.155	0.129	
Diameter of Steel, (mm)		12	12	
Single Area, a_s (mm ²)	$\pi \cdot \text{dia.}^2 / 4$	113.10	113.10	
Area of Steel required, A_{st} (mm ²)	$\rho \cdot b \cdot d$	909.2	755.8	
Minimum Reinforcement, $A_{s,min}$ (mm ²)	$(0.5 / f_{yk}) \cdot b \cdot d = 0.0012 \cdot b \cdot d$	735.0	735.0	
Provided Area of steel, A_s (mm ²)	MAX(required, designed)	909.2	755.8	
Spacing, S (mm)	$a_s \cdot 100 / (\rho \cdot d)$	124	150	
Allowable bond stress, F_{bd}	$2 \cdot F_{ctd}$	2.06	2.06	
Number of bars / meter length		9.0	7.7	
Actual bond stress, $F_{b,act}$	$V / (\text{perimeter} \cdot j \cdot d)$	1.75	1.88	
Bond checking		$F_{b,act} < F_{bd}$, OK	$F_{b,act} < F_{bd}$, OK	
Adjusted spacing (mm)		130	150	
Number of bars / meter length		9	8	
Actual bond stress, $F_{b,act}$		1.75	1.88	
Bond re-checking		$F_{b,act} < F_{bd}$, OK	$F_{b,act} < F_{bd}$, OK	
k_2		1.012		
k_1		1.06		
ρ provided		0.001546239	0.001285405	

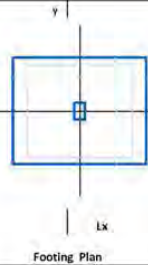


Figure 3. 123: general look of the worksheet called “Report”

Take off sheet is produced in a separate sheet called “Quantity” shown in figure 3.12. The user has to select the footing group name in order for the takeoff sheet to be displayed.

Footing	F-1		Working Space		0.5								
Concrete		Steel				Lean Concrete		Formwork		Pit Excavation		Backfill	
Grade	C-25	Pos.	Xdir	Pos.	Ydir	Grade	C-5	Pcs.	9	Pcs.	9	Pcs.	9
Pcs.	9	Pcs.	9	Pcs.	9	Pcs.	9	L	2.5	L	3.5	L	3.5
L	2.5	No	19	No	18	L	3.5	B	2.5	B	3.5	B	3.5
B	2.5	L	3.6	L	3.6	B	3.5	D	0.7	D	1	D	1
D	0.7	Dia	12	Dia	12	m ²	110.25	m ²	63.00	m ³	110.25	m ³	70.88

Figure 3. 134: general look of the worksheet called “Quantity”

After entering all the input data then click the button “Run” to design the footing.

The checkpoints which also have red font are listed below.

1. Check maximum soil pressure
2. Check minimum soil pressure
3. Check punching shear
4. Check wide beam shear

To produce working drawing first run the macro named “Isolated.dvb” on a new window of AutoCAD 2007, and then paste the input data which is copied from worksheet “Report”, and finally click the “Draw” button see figure 3.12 and figure 3.15.

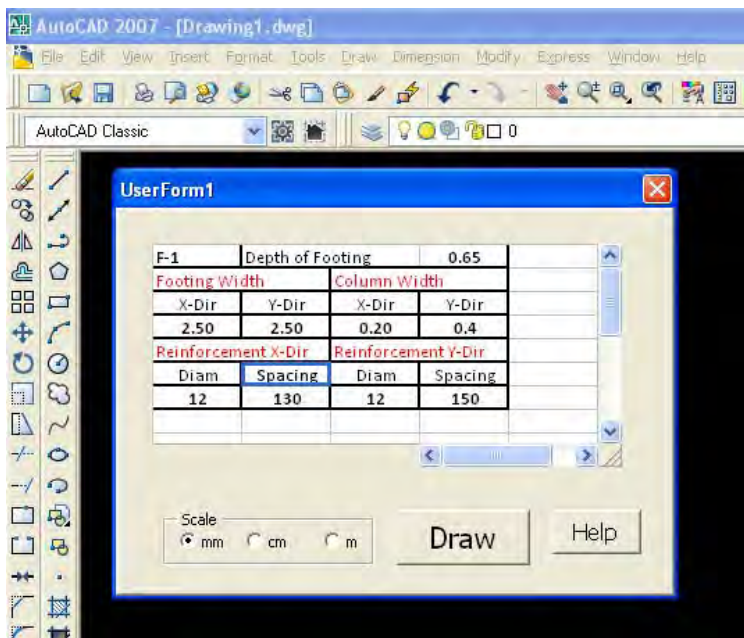


Figure 3. 145: when “isolated.dvb” is run in AutoCAD2007

3.10 CONCLUSIONS ON SECTION 3

1. The fact that this spreadsheet program can group, design, draw and quantify isolated footings considerably reduces the time needed for these processes and it also eliminates the error made during the information transfer from designer to drafts person and quantity surveyor.
2. Unlike many other spreadsheet programs available in this country, this spreadsheet program is developed according to the requirements of the recent version of Ethiopian Building Code Standards (EBCS). And little assumptions and approximations were made to the code during the spreadsheet development. This spreadsheet program considers every possible case during punching shear force calculation.
3. The user can intervene and override any result during the whole process.
4. The spreadsheet programs calculate development length of each reinforcing bars.

4 DESIGN OF RECTANGULAR COMBINED FOOTINGS

4.1 INTRODUCTION

Combined footings are shallow foundations which support more than one column. Depending upon the loading condition, combined footings may be either rectangular or trapezoidal in shape. When two columns are so close that their footings would merge or nearly touch, a combined footing extending under the two should be constructed.

Besides, when a column footing cannot project in one direction, perhaps because of the proximity of a property line, the footing may be helped out by an adjacent footing with more space; either a combined footing or a strap (cantilever) footing may be used under the two.

4.2 ASSUMPTIONS AND LIMITATIONS

The basic assumptions for the design of rectangular combined footings are:

- Footing must be rigid, so that the soil pressure distribution is linear.
- Horizontal loads and torsional moments transferred from columns must be very small.
- Rectangular combined footings which support only two columns are discussed here.

4.3 LIST OF SYMBOLS SPECIFIC TO SECTION 4

<i>BC</i>	-	Allowable bearing capacity of underlying soil
<i>GS</i>	-	Unit weight of backfill soil
<i>CC</i>	-	center to center distance between columns
<i>FD</i>	-	foundation depth
<i>CL_{x1}</i>	-	dimension of column 1 in the x direction
<i>CL_{y1}</i>	-	dimension of column 1 in the y direction
<i>CL_{x2}</i>	-	dimension of column 2 in the x direction
<i>CL_{y2}</i>	-	dimension of column 2 in the y direction
<i>PS₁</i>	-	Unfactored Superstructure axial load from column 1
<i>PS₂</i>	-	Unfactored Superstructure axial load from column 2
<i>M1_x</i>	-	Unfactored superstructure moment from column 1 in the x direction
<i>M1_y</i>	-	Unfactored superstructure moment from column 1 in the y direction
<i>M2_x</i>	-	Unfactored superstructure moment from column 2 in the x direction

M_{2y}	-	Unfactored superstructure moment from column 2 in the y direction
CS, SS	-	grade of concrete, grade of reinforcing steel
LEN_1	-	length from left edge of footing to center of column 1
LEN_2	-	length from center of column 2 to right edge of footing
L_y	-	length of footing in the y direction
L_x	-	Length of footing in the x direction
CEN	-	Centroid of superstructure loads from left edge of footing
D	-	Total depth of footing
D_e	-	effective depth of footing
OWT	-	own weight of footing
$SOWT$	-	weight of backfill above footing

4.4 PROCEDURES

- Step 1:** Proportioning of footings
- Step 2:** Determination of footing thickness
- Step 3:** Reinforcement calculation
- Step 4:** Detailing and quantifying

4.5 PROPORTIONING OF FOOTINGS

It is desirable to design combined footings so that the centroid of the footing coincides with the resultant of the two column loads. This produces uniform bearing pressure over the entire area and prevents a tendency for the footings to tilt. It should be noted that footing sizes are determined for unfactored service loads and soil pressures, in contrast to the strength design of reinforced concrete members, which utilizes factored loads and factored nominal strengths.

Loads acting on the foundation are:

1. Super structure loads P_{tot} :

$$P_{tot} = P_{s1} + P_{s2} \quad Eq.4.1$$

2. Weight of backfill soil SO_{wt} :

$$SO_{wt} = (L_x * L_y - CL_{x1} * CL_{y1} - CL_{x2} * CL_{y2}) * (FD - D) * GS \quad Eq.4.2$$

3. Own weight of footing O_{wt} :

$$O_{wt} = 25 * L_x * L_y * D \quad Eq.4.3$$

Where, GS is unit weight of backfill soil. For other notations refer to figure 4.1.

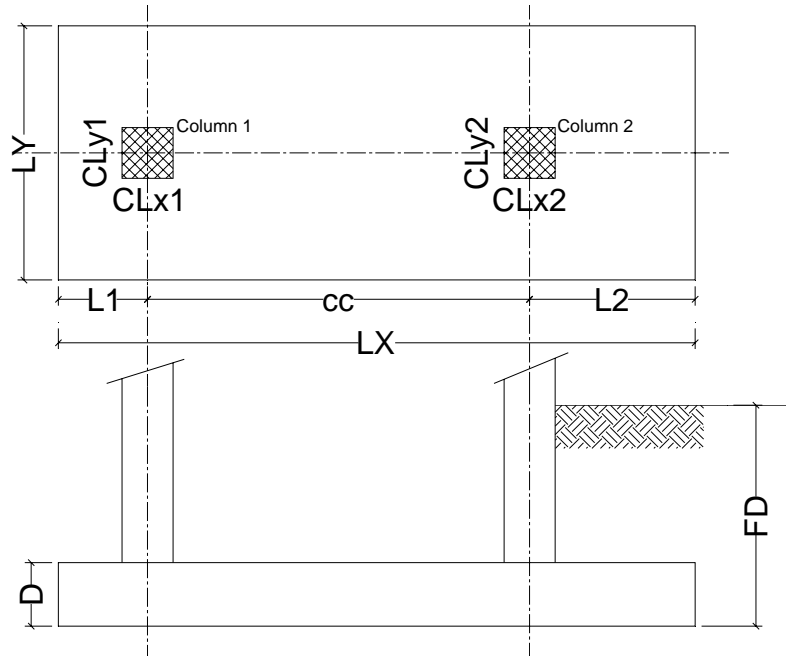


Figure 4. 1: Rectangular combined footings

The column transmits, at its juncture with the footing, not only a vertical load but also a bending moment. In either case, the load effects at the footing base can be represented by the vertical load P and a bending moment M . The resulting bearing pressures are again assumed to be linearly distributed. As long as the resulting eccentricity $e = M/P$ does not exceed the kern distance k of the footing area, the usual flexure formula permits the determination of the bearing pressures at the two extreme edges, as shown in figure 4.2.

$$Q_{\max,\min} = \frac{P}{A} \pm \frac{M_x * C_x}{I_x} \pm \frac{M_y * C_y}{I_y} \quad Eq.4.4$$

$$Q_{\max} = \frac{P_{tot} + SO_{wt} + O_{wt}}{L_x L_y} + \frac{6|M_{1x} + M_{2x}|}{L_x L_y^2} \leq BC \quad Eq.4.5$$

$$Q_{\min} = \frac{P_{tot} + SO_{wt} + O_{wt}}{L_x L_y} - \frac{6|M_{1x} + M_{2x}|}{L_x L_y^2} \geq 0 \quad Eq.4.6$$

Where, BC is allowable bearing capacity of soil. For other notations refer to figure 4.2.

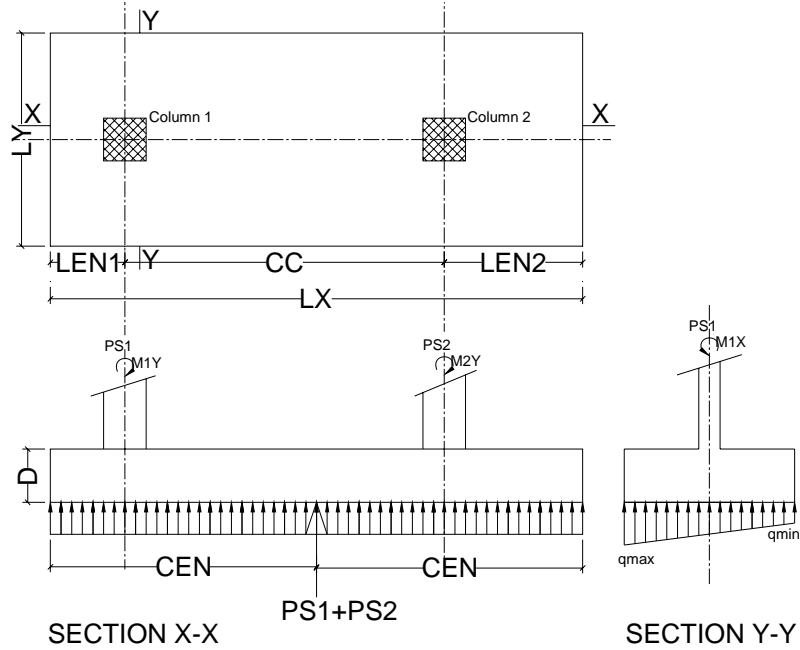


Figure 4. 2: Pressure distributions under combined footing

The basic steps in the proportioning of combined footing are:

STEP1. Assume $LEN1$

STEP2. Calculate CEN :

$$CEN = PS_1 * LEN1 + PS_2 * (LEN1 + CC) + \frac{|M1_y + M2_y|}{PS_1 + PS_2} \quad Eq.4.7$$

STEP3. Calculate L_x

$$L_x = 2 * CEN \quad Eq.4.8$$

STEP4. Calculate L_y

$$Q_{max} = \frac{P_{tot} + SO_{wt} + O_{wt}}{L_x L_y} + \frac{6|M1_x + M2_x|}{L_x L_y^2} = BC \quad Eq.4.9$$

$$P_{tot} = PS_1 + PS_2 \quad Eq.4.10$$

$$SO_{wt} = (L_x * L_y - CL_{x1} * CL_{y1} - CL_{x2} - CL_{y2}) * (FD - D) * G_s \quad Eq.4.11$$

$$O_{wt} = 25 * L_x * L_y * D \quad Eq.4.12$$

Equating... Eq.4.10, Eq.4.11 & Eq.4.12 onto Eq.4.9 gives

$$BC = \frac{PS_1 + PS_2 + 25 * L_x * L_y * D + (L_x * L_y - CL_{x1} * CL_{y1} - CL_{x2} - CL_{y2}) * (FD - D) * GS}{L_x L_y} + \frac{6|M_{1x} + M_{2x}|}{L_x L_y^2} \quad Eq.4.13$$

Rearranging and solving for L_y .

$$A * L_y^2 + B * L_y + C = 0 \quad Eq.4.14$$

Where:

$$A = L_x * (25 * D + (FD - D) * GS - BC)$$

$$B = PS_1 + PS_2 - (CL_{x1} * CL_{y1} + CL_{x2} * CL_{y2}) * (FD - D) * GS$$

$$C = 6 * |M_{1x} + M_{2x}|$$

STEP5. Chek if $Q_{min} > 0$

$$Q_{min} = \frac{P_{tot} + SO_{wt} + O_{wt}}{L_x L_y} - \frac{6|M_{1x} + M_{2x}|}{L_x L_y^2} \geq 0 \quad Eq.4.15$$

$$P_{tot} = PS_1 + PS_2$$

$$SO_{wt} = (L_x * L_y - CL_{x1} * CL_{y1} - CL_{x2} - CL_{y2}) * (FD - D) * GS$$

$$O_{wt} = 25 * L_x * L_y * D$$

Equating...

$$Q_{min} = \frac{PS_1 + PS_2 + 25 * L_x * L_y * D + (L_x * L_y - CL_{x1} * CL_{y1} - CL_{x2} - CL_{y2}) * (FD - D) * GS}{L_x L_y}$$

$$- \frac{6|M_{1x} + M_{2x}|}{L_x L_y^2} \geq 0 \quad Eq.4.16$$

4.6 SHEAR FORCE AND BENDING MOMENT DIAGRAMS

The column loads are actually distributed over the column width but should always be taken as concentrated loads. This assumption greatly simplifies the shear and moment computations, and the values at the critical locations are the same if shear force & bending moment diagram is calculated by using distributed or concentrated load.

The shear and bending moments will be determined at different sections (critical locations) along the length of the footing as described in figure 4.3.

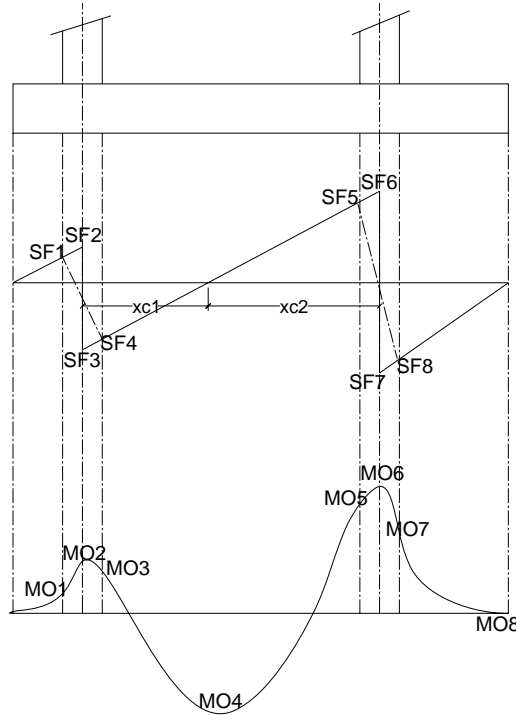


Figure 4. 3: shear force and bending moment diagram

- The distributed load from the constant pressure is

$$BCA = \frac{P_{tot}}{L_y * L_x} \quad Eq.4.17$$

- Shear force and bending moment at the left face of column 1

$$X = LEN_1 - CL_{x1} / 2 \quad Eq.4.18$$

$$SF1 = BCA * L_y * (LEN_1 - CL_{x1} / 2) \quad Eq.4.19$$

$$MO1 = 0.5 * SF1 * (LEN_1 - CL_{x1} / 2) \quad Eq.4.20$$

- Shear force and bending moment at the center of column 1

$$X = LEN_1 \quad Eq.4.21$$

$$SF2 = BCA * L_y * LEN_1 \quad Eq.4.22$$

$$SF3 = BCA * L_y * LEN_1 - PS_1 \quad Eq.4.23$$

$$MO2 = 0.5 * SF2 * LEN_1 \quad Eq.4.24$$

$$MO2' = 0.5 * SF2 * LEN_1 + M_{1y}) \quad Eq.4.25$$

- Shear force and bending moment at the right face of column 1

$$X = LEN_1 + CL_{x1} / 2 \quad Eq.4.26$$

$$SF4 = BCA * L_y * LEN_1 - PS_1 + BCA * L_y * CL_{x1} / 2 \quad Eq.4.27$$

$$MO3 = 0.5 * SF2 * LEN_1 + SF4 * CL_{x1} / 2 + (SF3 - SF4) / 2 * CL_{x1} / 2 + M_{1y} \quad Eq.4.28$$

- Maximum Bending Moment

$$XC_1 = \frac{-SF3}{SF6 - SF3} * CC \quad Eq.4.29$$

$$MO4 = MO2' + SF3 * XC_1 / 2 \quad Eq.4.30$$

- Shear force and bending moment at the left face of column 2

$$X = LEN_1 + CC - CL_{x2} / 2 \quad Eq.4.31$$

$$SF5 = BCA * L_y * (LEN_1 + CC) - PS_1 - BCA * L_y * CL_{x2} / 2 \quad Eq.4.32$$

$$MO5 = MO6 - SF5 * CL_{x2} / 2 - (SF6 - SF5) * CL_{x2} / 2 \quad Eq.4.33$$

- Shear force and bending moment at the center of column 2

$$X = LEN_1 + CC \quad Eq.4.34$$

$$SF6 = BCA * L_y * (LEN_1 + CC) - PS_1 \quad Eq.4.35$$

$$SF7 = BCA * L_y * (LEN_1 + CC) - PS_1 - PS_2 \quad Eq.4.36$$

$$MO6 = MO4 + SF6 / 2 * (CC - XC_1) \quad Eq.4.37$$

$$MO6' = MO6 + M_{2y} \quad Eq.4.38$$

- Shear force and bending moment at the right face of column 2

$$X = LEN_1 + CC + CL_{x2} / 2 \quad Eq.4.39$$

$$SF8 = BCA * L_y * (LEN_1 + CC) - PS_1 - PS_2 + BCA * L_y * CL_{x2} / 2 \quad Eq.4.40$$

$$MO7 = MO6' - SF8 * CL_{x2} / 2 + (SF7 - SF8) * CL_{x2} / 4 \quad Eq.4.41$$

- (Check) Shear force and bending moment at the right end of footing

$$X = L_x \quad Eq.4.42$$

$$SF = SF7 + BCA * L_y * LEN_2 = 0 \quad Eq.4.43$$

$$MO8 = MO6' + SF7 * LEN_2 / 2 \approx 0 \quad Eq.4.44$$

4.7 DETERMINATION OF FOOTING THICKNESS

Once the required footing area has been determined, the footing must then be designed to develop the necessary strength to resist all moments, shears, and other internal actions caused by the applied loads. For this purpose, the load factors of the EBCS Code apply to footings as to all other structural components.

Shear stresses usually control the footing thickness D . And there are two modes of shear failure.

1. One way shear also known as wide beam shear or diagonal compression shear
2. Two way shear also known as punching shear or diagonal tension shear

It should be noted that footing thicknesses are determined for factored service loads and soil pressures.

The design shear strength near concentrated loads is governed by two conditions

1. Shear along vertical section extending across the full width of the base.
2. Punching shear around the loaded area

Calculation of effective depth, D_e

$$D_e = D - 0.05 - \phi / 1000 \quad \text{Eq.4.45}$$

Where D is total depth of footing and ϕ is average diameter of reinforcement.

4.7.1 CHECKING FOOTING THICKNESS FOR PUNCHING SHEAR

Various investigators have suggested different locations for the idealized critical shear surfaces for punching. EBCS 2, 1995 specifies that they be located at $1.5d$ distance from the face of the column. The footing design is satisfactory for punching shear when it satisfies the condition, $P_{RESI} > P_{SF}$, on all critical surfaces, where, P_{RESI} is the punching shear capacity on the critical surface and P_{SF} is the factored shear stress on critical surface.

4.7.1.1 CALCULATION OF PUNCHING SHEAR CAPACITY

The nominal two-way shear stress capacity on the critical section is:

$$P_{RESI} = 0.25 * F_{CTD} * K_1 * K_2 \quad \text{Eq.4. 46}$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_1 = \min (1 + 50\rho, 2)$$

$$\rho = \min (0.015, \sqrt{\rho_x * \rho_y})$$

$$K_2 = \max (1.6 - D_e, 1)$$

4.7.1.2 CALCULATION OF PUNCHING SHEAR STRESS ON CRITICAL SURFACES

The footing may be subject to applied normal force and bending moment i.e. P , M_x , M_y , all of which produce shear forces on the critical shear surfaces.

The design shear is the algebraic sum of all design ultimate vertical loads acting on one side or outside of the periphery of critical section.

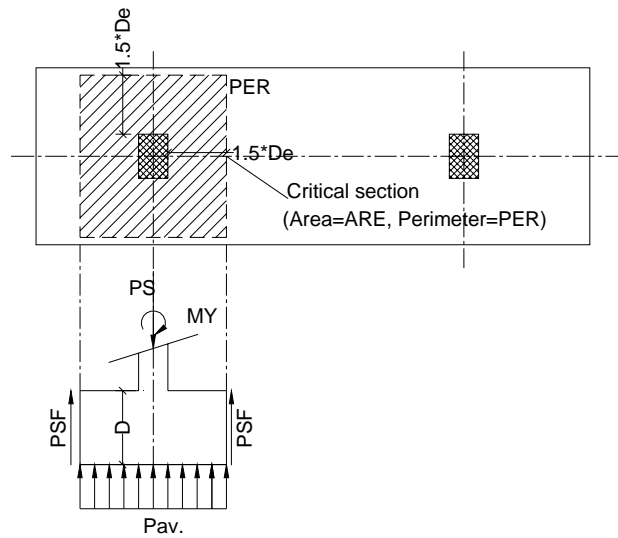


Figure 4. 4: critical areas for punching

- Taking $\sum Fz=0$, see figure 4.4.

$$PSF = 1.4 * \frac{(PS - BCA * ARE)}{PER * D_e} \quad Eq.4.47$$

- Calculation of punching shear stress for column1

$$PSF1 = 1.4 * \frac{(PS1 - BCA * ARE1)}{PER1 * D_e} \quad Eq.4.48$$

- Calculation of punching shear stress for column2

$$PSF2 = 1.4 * \frac{(PS2 - BCA * ARE2)}{PER2 * D_e} \quad Eq.4.49$$

- Calculation of punching shear stress for double column

$$PSF3 = 1.4 * \frac{(PS1 + PS2 - BCA * ARE3)}{PER3 * DE} \quad Eq.4.50$$

4.7.1.2.1 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION

4.7.1.2.1.1 DEFINITIONS

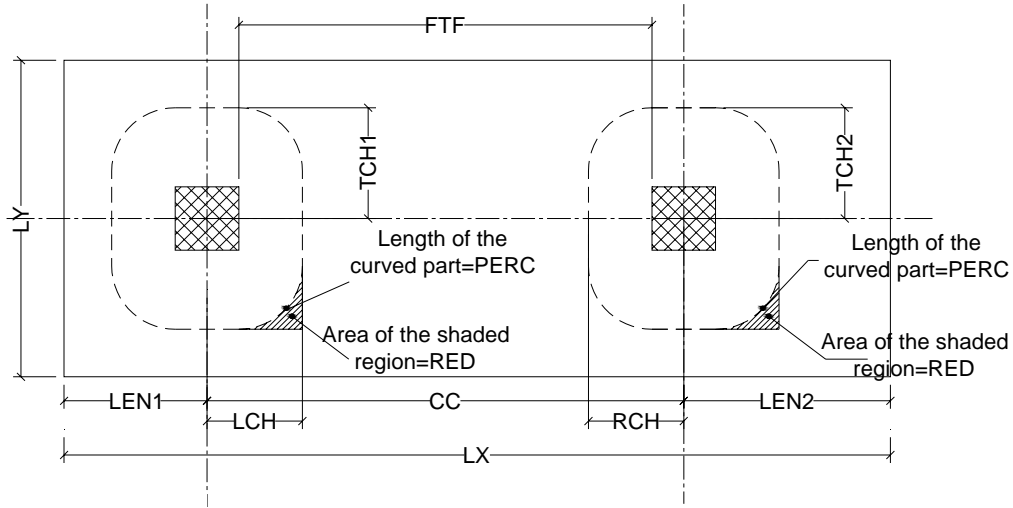


Figure 4. 5: critical areas for punching for combined footings

$$PERC = 0.75 * \pi * D_e \quad Eq.4.51$$

$$RED = (2.25 - 0.5625\pi) * D_e^2 \quad Eq.4.52$$

$$FTF = CC + CL_{x1} / 2 + CL_{x2} / 2 \quad Eq.4.53$$

$$LCH = 1.5 * D_e + CL_{x1} / 2 \quad Eq.4.54$$

$$RCH = 1.5 * D_e + CL_{x2} / 2 \quad Eq.4.55$$

$$TCH1 = 1.5 * D_e + CL_{y1} / 2 \quad Eq.4.56$$

$$TCH2 = 1.5 * D_e + CL_{y2} / 2 \quad Eq.4.57$$

$$TCH = MAX(TCH1, TCH2) \quad Eq.4.58$$

$$C_{y_{av}} = (CL_{y1} + CL_{y2}) / 2 \quad Eq.4.59$$

For notations refer to figure 4.5.

4.7.1.2.1.2 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION FOR COLUMN 1

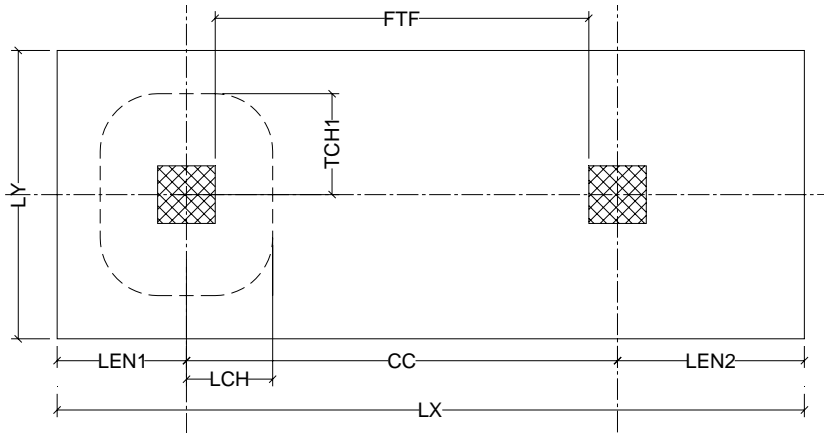


Figure 4. 6: critical areas for punching-column1- case1

Case: critical section for left column within the premise of the footing

$$LCH + TCH1 < LEN1.. \& ..LCH + TCH1 < L_y / 2 \quad Eq.4.60$$

Perimeter: $PER1 = 2 * CL_{x1} + 2 * CL_{y1} + 4 * PERC$ Eq.4.61

Area: $ARE1 = 4 * LCH * TCH1 - 4 * RED$ Eq.4.62

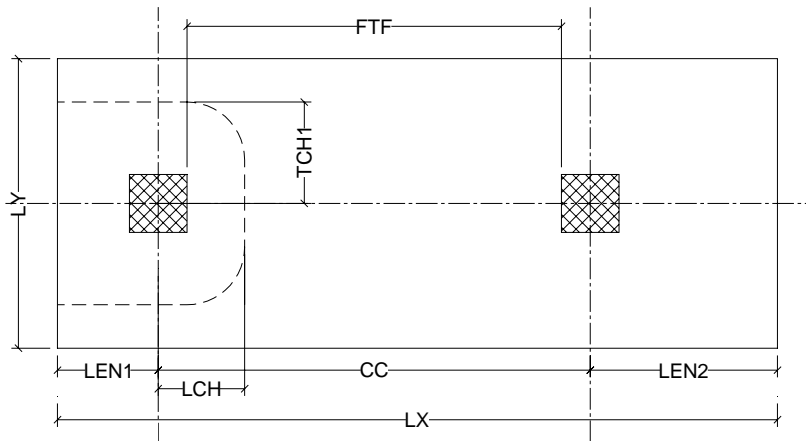


Figure 4. 7: critical areas for punching-column1- case2

Case: Critical section for left column outside the footing area on the left side & within the footing area at top and bottom.

$$LCH + TCH1 \geq LEN_1.. \& ..LCH + TCH1 < L_y / 2 \quad Eq.4.63$$

Perimeter: $PER1 = 2 * (LEN_1 + CL_{x1} / 2) + 2 * PERC + CL_{y1}$ Eq.4.64

Area: $ARE1 = 2 * (LEN_1 + LCH) * TCH1 - 2 * RED$ Eq.4.65

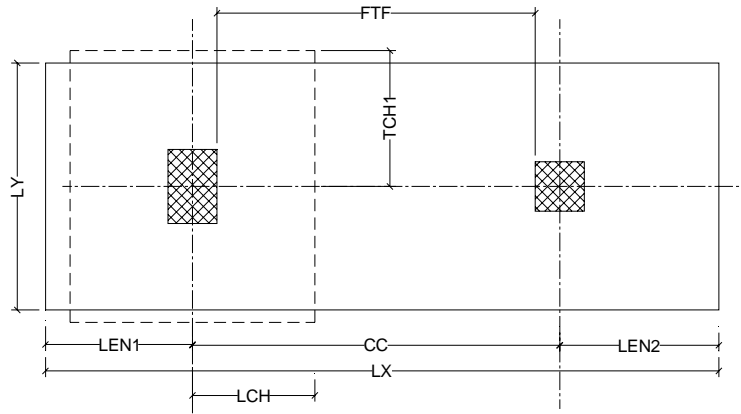


Figure 4. 8: critical areas for punching-column1- case3

Case: Critical section for left column outside the footing area at top and bottom & within the footing area on the left side.

$$LCH + TCH1 < LEN_1 \dots \& \dots LCH + TCH1 \geq L_y / 2 \quad Eq.4.66$$

Perimeter: $PER1 = 2 * L_y$ Eq.4.67

Area: $ARE1 = 2 * LCH * L_y$ Eq.4.68

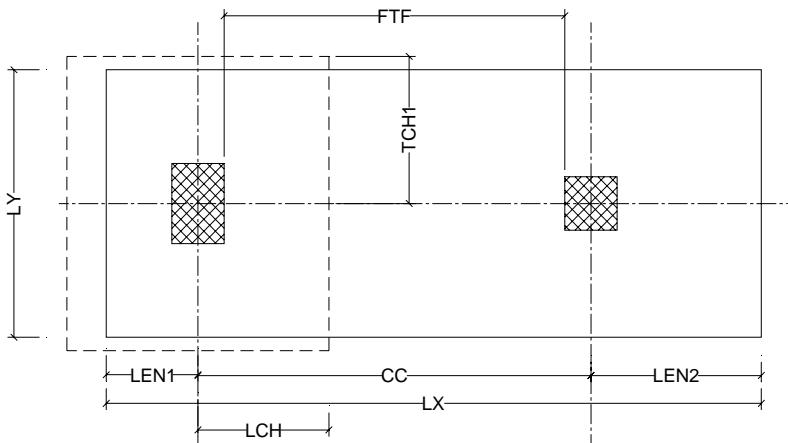


Figure 4. 9: critical areas for punching-column1- case4

Case: Critical section for left column outside the footing area on top, bottom and left side of the footing.

$$LCH + TCH1 \geq LEN_1 \dots \& \dots LCH + TCH1 \geq L_y / 2 \quad Eq.4.69$$

Perimeter: $PER1 = L_y$ Eq.4.70

Area: $ARE1 = (LEN_1 + LCH) * L_y$ Eq.4.71

4.7.1.2.1.3 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION FOR COLUMN 2

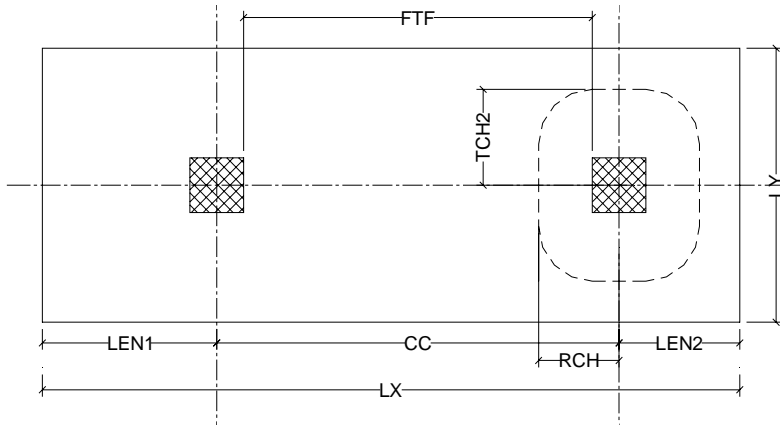


Figure 4. 10: critical areas for punching-column1- case1

Case: critical section for right column within the premise of the footing

$$RCH + TCH2 < LEN_2 \dots \& \dots RCH + TCH2 < L_y / 2 \quad Eq.4.72$$

Perimeter: $PER2 = 2 * CL_{x2} + 2 * CL_{y2} + 4 * PERC \quad Eq.4.73$

Area: $ARE2 = 4 * RCH * TCH2 - 4 * RED \quad Eq.4.74$

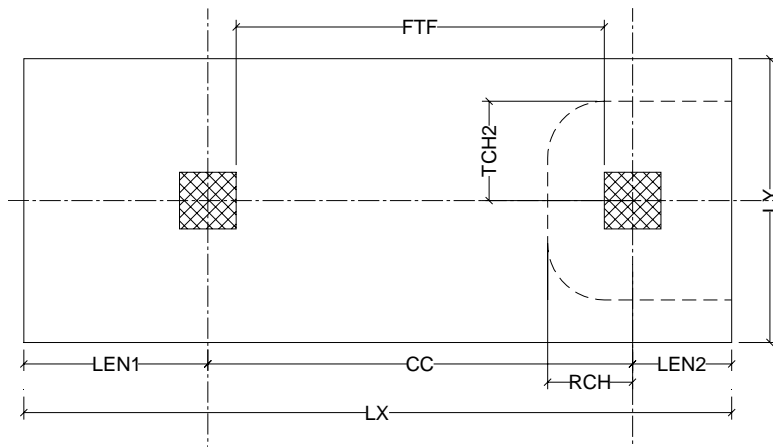


Figure 4. 11: critical areas for punching-column1- case2

Case: Critical section for right column outside the footing area on the right side & within the footing area at top and bottom.

$$RCH + TCH2 \geq LEN_2 \dots \& \dots RCH + TCH2 < L_y / 2 \quad Eq.4.75$$

Perimeter: $PER2 = 2 * (LEN_2 + CL_{x2} / 2) + 2 * PERC + CL_{y2} \quad Eq.4.76$

Area: $ARE2 = 2 * (LEN_2 + RCH) * TCH2 - 2 * RED \quad Eq.4.77$

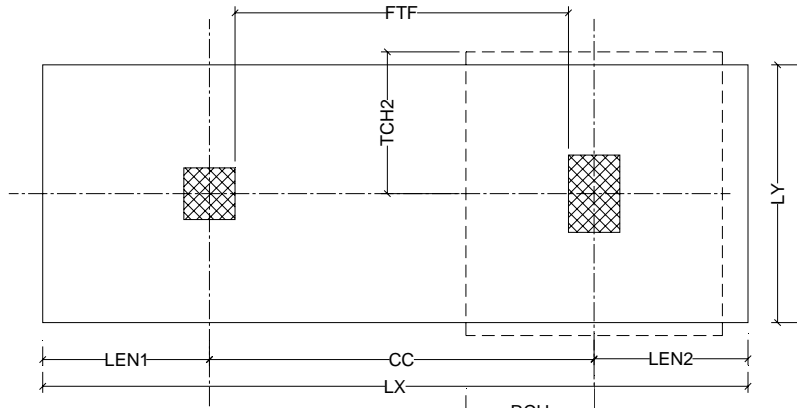


Figure 4. 12: critical areas for punching-column1- case3

Case: Critical section for right column outside the footing area at top and bottom & within the footing area on the left side.

$$RCH + TCH2 < LEN2 \text{..} \& \text{..} RCH + TCH2 \geq L_y / 2 \quad Eq.4.78$$

Perimeter: $PER2 = 2 * L_y$ Eq.4.79

Area: $ARE2 = 2 * RCH * L_y$ Eq.4.80

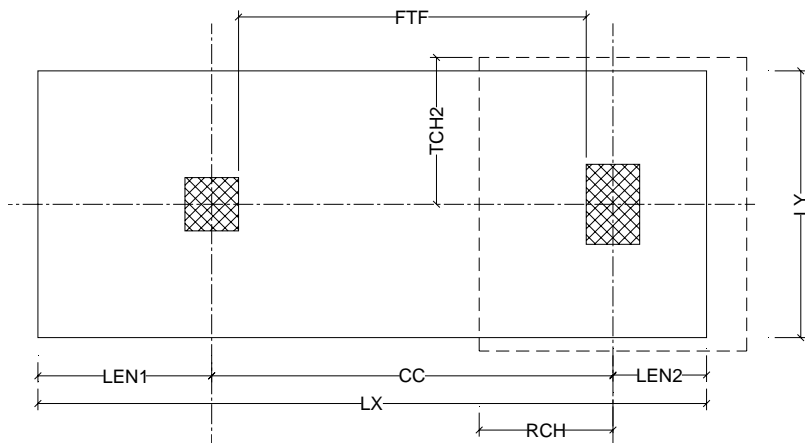


Figure 4. 13: critical areas for punching-column1- case4

Case: Critical section for right column outside the footing area on top, bottom and left side of the footing.

$$RCH + TCH2 \geq LEN2 \text{..} \& \text{..} RCH + TCH2 \geq L_y / 2 \quad Eq.4.81$$

Perimeter: $PER2 = L_y$ Eq.4.82

Area: $ARE2 = (LEN2 + RCH) * L_y$ Eq.4.83

4.7.1.2.1.4 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION FOR DOUBLE COLUMN

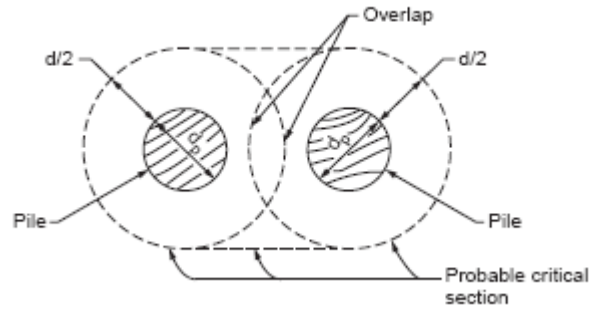


Figure 4. 14: Modified critical section for shear with overlapping critical perimeters

If the critical regions of the two columns intersect, as shown in figure 4.14, the two columns shall be considered as a single column.

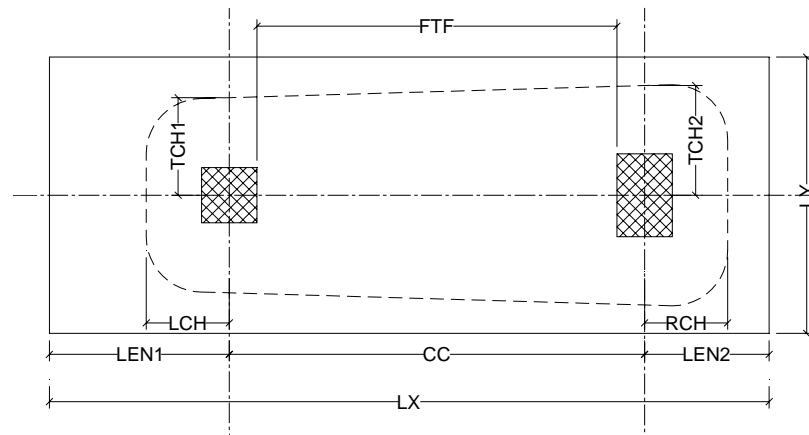


Figure 4. 15: critical areas for punching-double column- case1

Case: Critical section for double column within the premise of the footing.

$$LCH + TCH1 < LEN_1 \dots \& \dots RCH + TCH2 < LEN_2 \dots \& \dots TCH + \min(LCH, RCH) + CC / 2 < L_y / 2$$

Perimeter: $PER3 = 4 * PERC + 2 * FTF + CL_{y1} + CL_{y2}$ Eq.4.84

Area: $ARE3 = (FTF + 3 * DE) * (CYAV + 3 * DE) - 4 * RED$ Eq.4.85

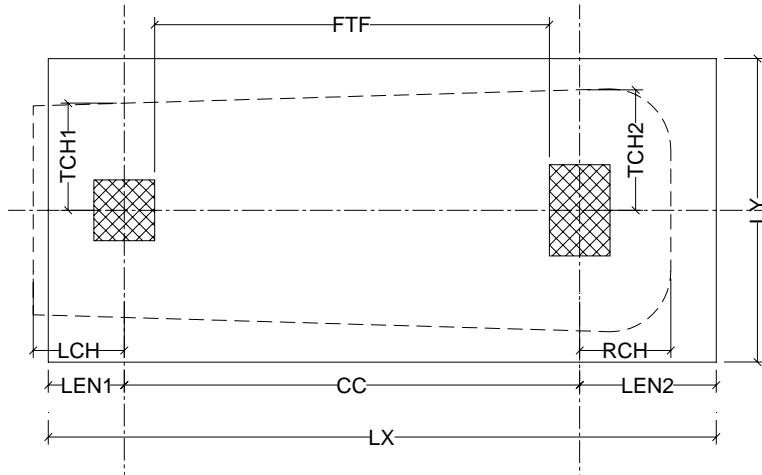


Figure 4. 16: critical areas for punching-double columns- case2

Case: Critical area for double column outside the footing area on the left side and inside the footing area on top, bottom and right side of the footing.

$$LCH + TCH1 \geq LEN_1 \dots \& \dots RCH + TCH2 < LEN_2 \dots \& \dots TCH + \min(LCH, RCH) + CC / 2 < L_y / 2$$

Perimeter: $PER3 = 2 * (FTF + LEN1 - CL_{x1} / 2) + 2 * PERC + CL_{y2}$ Eq.4.86

Area: $ARE3 = (FTF + LEN_1 - CL_{x1} / 2 + 1.5 * DE) * (TCH1 + TCH2) - 2 * RED$ Eq.4.87

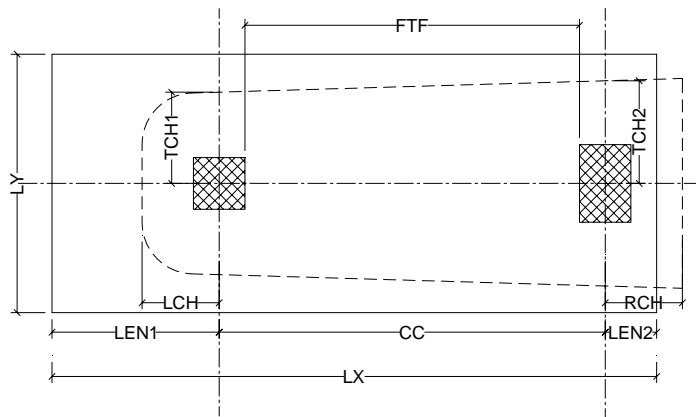


Figure 4. 17: critical areas for punching-double columns- case3

Case: Critical area for double column outside the footing area on the right side and inside the footing area on top, bottom and left side of the footing.

$$LCH + TCH1 < LEN_1 \dots \& \dots RCH + TCH2 \geq LEN_2 \dots \& \dots TCH + \min(LCH, RCH) + CC / 2 < L_y / 2$$

Perimeter: $PER3 = 2 * (FTF + LEN_2 - CL_{x2} / 2) + 2 * PERC + CL_{y1}$ Eq.4.88

Area: $ARE3 = (FTF + LEN_2 - CL_{x2} / 2 + 1.5 * DE) * (TCH1 + TCH2) - 2 * RED$ Eq.4.89

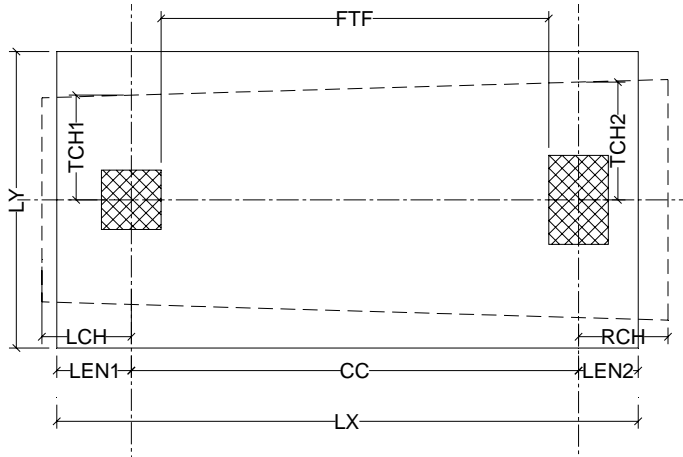


Figure 4. 18: critical areas for punching-double columns- case4

Case: Critical area for double column outside the footing area on the left and right side and inside the footing area on top and bottom side of the footing.

$$LCH + TCH1 \geq LEN_1 \dots \& \dots RCH + TCH2 \geq LEN2 \dots \& \dots TCH + \min(LCH, RCH) + CC / 2 < L_y / 2$$

Perimeter: $PER3 = 2 * L_x$ Eq.4.90

Area: $ARE3 = L_x * (TCH1 + TCH2)$ Eq.4.91

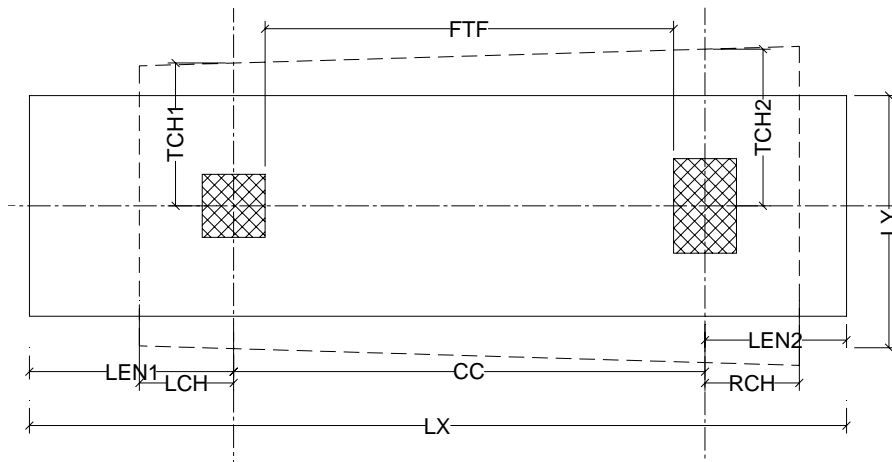


Figure 4. 19: critical areas for punching-double columns- case5

Case: Critical area for double column inside the footing area on the left and right side and outside the footing area on top and bottom side of the footing.

$$LCH + TCH1 < LEN_1 \dots \& \dots RCH + TCH2 < LEN2 \dots \& \dots TCH + \min(LCH, RCH) + CC / 2 \geq L_y / 2$$

Perimeter: $PER3 = 2 * L_y$ Eq.4.92

Area: $ARE3 = L_y * (CC + LCH + RCH)$ Eq.4.93

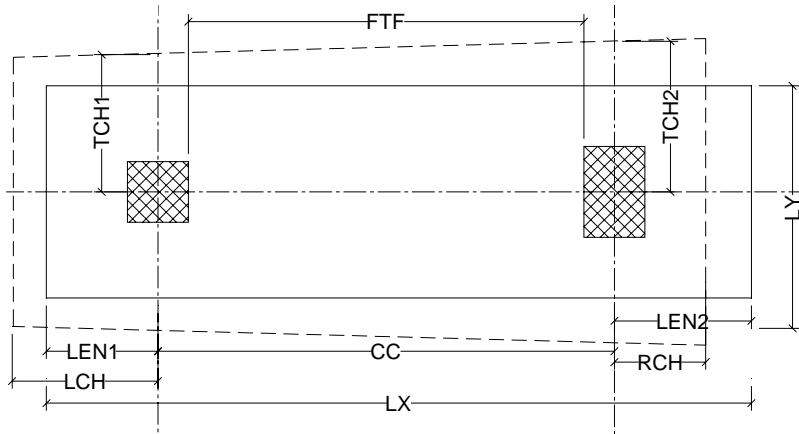


Figure 4. 20: critical areas for punching-double columns- case6

Case: Critical area for double column outside the footing area on top bottom and left side and inside the footing area on the right side of the footing.

$$LCH + TCH1 \geq LEN_1 \dots \& \dots RCH + TCH2 < LEN_2 \dots \& \dots TCH + \min(LCH, RCH) + CC / 2 \geq L_y / 2$$

Perimeter: $PER3 = L_y$ Eq.4.94

Area: $ARE3 = (FTF + 1.5 * DE + LEN_1 - CL_{x1} / 2) * L_y$ Eq.4.95

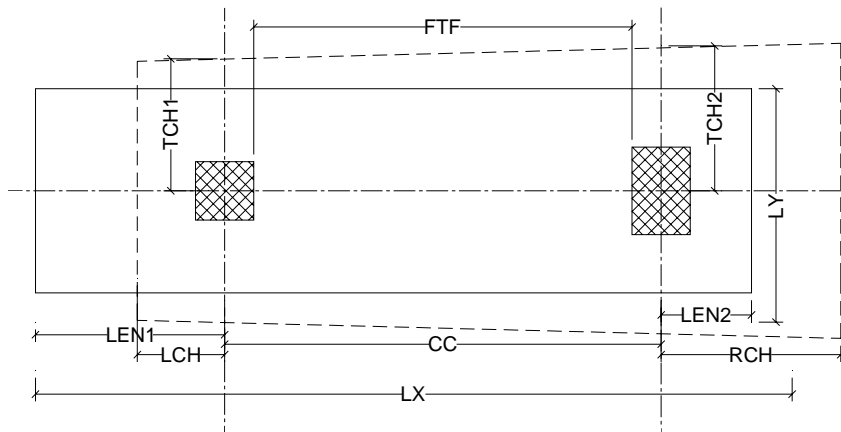


Figure 4. 21: critical areas for punching-double columns- case7

Case: Critical area for double column outside the footing area on top bottom and right side and inside the footing area on the left side of the footing.

$$LCH + TCH1 < LEN_1 \dots \& \dots RCH + TCH2 \geq LEN_2 \dots \& \dots TCH + \min(LCH, RCH) + CC / 2 \geq L_y / 2$$

Perimeter: $PER3 = L_y$ Eq.4.98

Area: $ARE3 = (FTF + LEN_2 + 1.5 * DE - CL_{x2} / 2) * L_y$ Eq.4.97

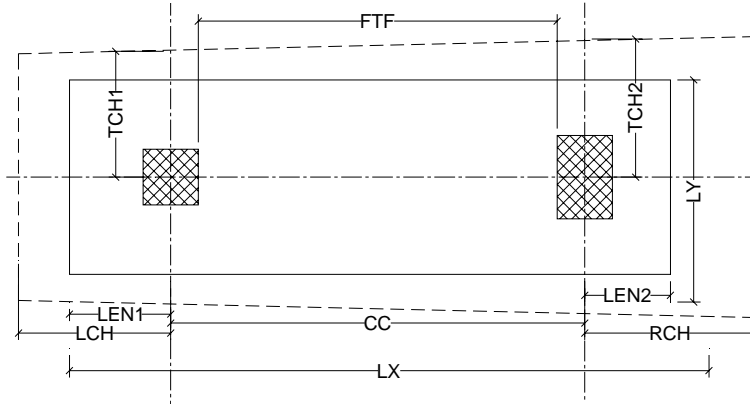


Figure 4. 22: critical areas for punching-double columns- case8

Case: Critical area for double column outside the premise of the footing area on all sides.

$$LCH + TCH1 \geq LEN1.. \& ..RCH + TCH2 \geq LEN2.. \& ..TCH + \min(LCH, RCH) + CC / 2 \geq L_y / 2$$

Perimeter: $PER3 = 0$ Eq.4.98

Area: $ARE3 = 0$ Eq.4.99

4.7.2 CHECKING FOOTING THICKNESS FOR WIDE BEAM SHEAR

Various investigators have suggested different locations for the idealized critical shear surfaces for wide beam shear. EBCS 2, 1995 specifies that they be located at d distance from the face of the column. Refer to figure 4.23.

The footing design is satisfactory for wide beam shear when it satisfies the condition, $P_{RESI} > W_{SF}$, on all critical surfaces, where, P_{RESI} is the wide beam shear capacity on the critical surface and W_{SF} is the factored shear stress on critical surface.

4.7.2.1 CALCULATION OF WIDE BEAM SHEAR RESISTANCE

The nominal one-way shear stress capacity on the critical section is:

$$P_{RES} = 0.25 * F_{ctd} * k_1 * k_2 \tag{Eq.4.100}$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_1 = \min(1 + 50\rho, 2)$$

$$\rho = \min(0.015, \sqrt{\rho_x, \rho_y})$$

$$K_2 = \max(1.6 - D_e, 1)$$

The design shear is the algebraic sum of all design ultimate vertical loads acting on one side or of outside the periphery of critical section.

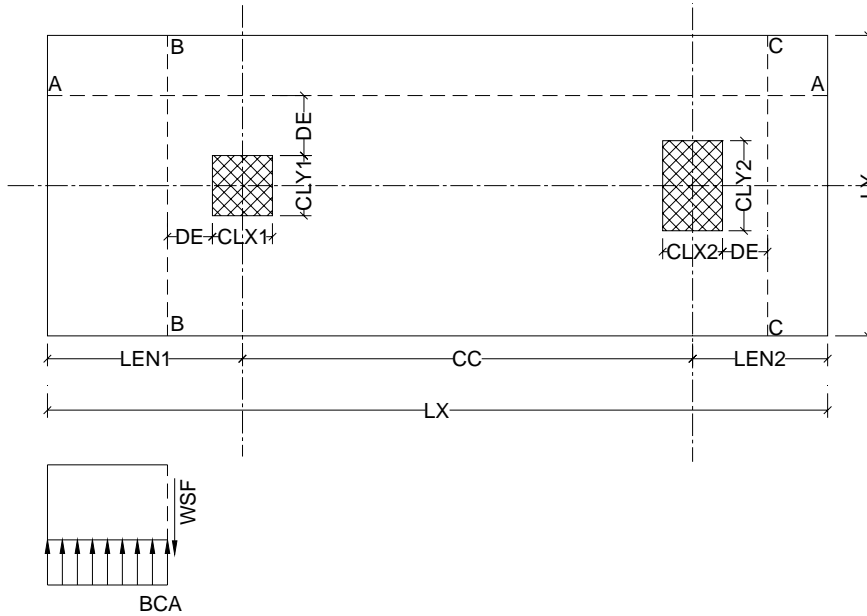


Figure 4. 23: figure 4.9 critical sections for wide beam shear

4.7.2.2 CALCULATION OF APPLIED WIDE BEAM SHEAR STRESS

1. Calculation of wide beam shear stress to left of colum1 (section B-B)

$$AREA = (LEN_1 - CL_{x1} / 2 - DE) * L_y$$

$$PERIMETER = L_y$$

$$WSF1 = \frac{1.4 * BCA * AREA}{PERIMETER * DE}$$

$$= \frac{1.4 * BCA * (LEN_1 - CL_{x1} / 2 - DE) * L_y}{L_y * DE} \geq 0$$

Eq.4.101

2. Calculation of wide beam shear stress to right of column 2 (section C-C)

$$AREA = (LEN_2 - CL_{x2} / 2 - DE) * L_y$$

$$PERIMETER = L_y$$

$$WSF2 = \frac{1.4 * BCA * AREA}{PERIMETER * DE}$$

$$= \frac{1.4 * BCA * (LEN_2 - CL_{x2} / 2 - DE) * L_y}{L_y * DE} \geq 0$$

Eq.4.102

3. Calculation of wide beam shear stress at top & bottom (section A-A)

$$AREA = (L_y / 2 - CYAV / 2 - DE) * L_x$$

$$PERIMETER = L_x$$

$$WSF3 = \frac{1.4 * BCA * AREA}{PERIMETER * DE}$$

$$= \frac{1.4 * BCA * (L_y / 2 - CYAV / 2 - DE) * L_x}{L_x * DE} \geq 0$$

Eq.4.103

4.8 REINFORCEMENT CALCULATIONS

The footing is designed as reinforced concrete beam and critical sections for bending are at the face of the columns. There will be both negative bending steel in the bottom of the footing near columns and positive bending steel in the top near or in the center portion between columns.

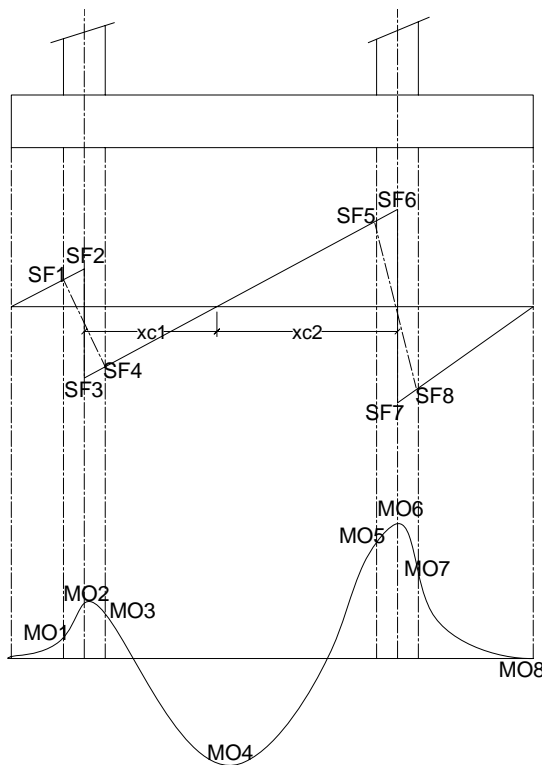


Figure 4. 24: shear force & bending moment diagram

1. Flexural reinforcement for Y direction top
Minimum reinforcement is provided here.

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$As = \rho_{\min} * 1000 * D_e$$

2. Flexural reinforcement for Y direction bottom

$$M_{oyb} = 1.4 * \frac{(L_y / 2 - \min(CL_{y1} / 2, CL_{y2} / 2))^2 * 10^6}{2 * BCA}$$

$$\rho = \frac{1 - \sqrt{1 - 2M_{oyb}}}{f_{cd} * 1000 * d_{ef}^2}$$

$$\rho = \frac{1 - \sqrt{1 - 2M_{oyb}}}{f_{cd} * f_{yd}}$$

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$As = \max(\rho, \rho_{\min}) * 1000 * d_{ef}$$

3. Flexural reinforcement for X direction top, refer to figure 4.24.

$$M_{oxt} = 1.4 * MO4 / L_y * 10^6$$

$$\rho = \frac{1 - \sqrt{1 - 2M_{oxt}}}{f_{cd} * 1000 * d_{ef}^2}$$

$$\rho = \frac{1 - \sqrt{1 - 2M_{oxt}}}{f_{cd} * f_{yd}}$$

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$As = \max(\rho, \rho_{\min}) * 1000 * d_{ef}$$

4. Flexural reinforcement for X direction bottom, refer to figure 4.24.

$$M_{oxb} = 1.4 * \max(MO1, MO3, MO5, MO7) / L_y * 10^6$$

$$\rho = \frac{1 - \sqrt{1 - 2M_{oxb}}}{f_{cd} * 1000 * d_{ef}^2}$$

$$\rho = \frac{1 - \sqrt{1 - 2M_{oxb}}}{f_{cd} * f_{yd}}$$

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$As = \max(\rho, \rho_{\min}) * 1000 * d_{ef}$$

4.9 DEVELOPMENT LENGTH CALCULATION

The design bond strength f_{bd}

$$f_{bd} = 1.4 * f_{ctd} \quad Eq.4.104$$

Where f_{ctd} is the tensile strength of concrete.

The basic anchorage length l_b for a bar of diameter ϕ is:

$$l_b = \frac{\phi f_{yd}}{4 f_{bd}} \quad Eq.4.105$$

The required anchorage length l_{bnet} depends on the type of anchorage and on the stress in the reinforcement and can be calculated as:

$$l_{bnet} = a l_b \frac{A_{s,cal}}{A_{s,ef}} \geq l_{b,min} \quad Eq.4.106$$

where $A_{s,cal}$ is the theoretical area of reinforcement required by the design

$A_{s,ef}$ is the area of reinforcement actually provided

$a = 1.0$ for straight bar anchorage in tension or compression

$= 0.7$ for anchorage in tension with standard hooks

$l_{b,min}$ is the minimum anchorage length

$\frac{A_{s,cal}}{A_{s,ef}} \approx 1$ at the face of columns therefore,

$$l_{bnet} = a l_b = 0.7 l_b = 0.7 * \frac{\phi}{4} * \frac{f_{yd}}{1.4 * f_{ctd}} \geq l_{b,min} \quad Eq.4.107$$

$\frac{A_{s,cal}}{A_{s,ef}} \approx 0$ near the edges therefore $l_{bnet} = l_{b,min}$

$$l_{b,min} = 0.3 l_b > 10\phi > 200mm \quad Eq.4.108$$

4.10 THE SPREADSHEET PROGRAM

The general look of the spreadsheet program is shown in the figure below and when printed it can be a brief and adequate design report as shown in figure 4.25.

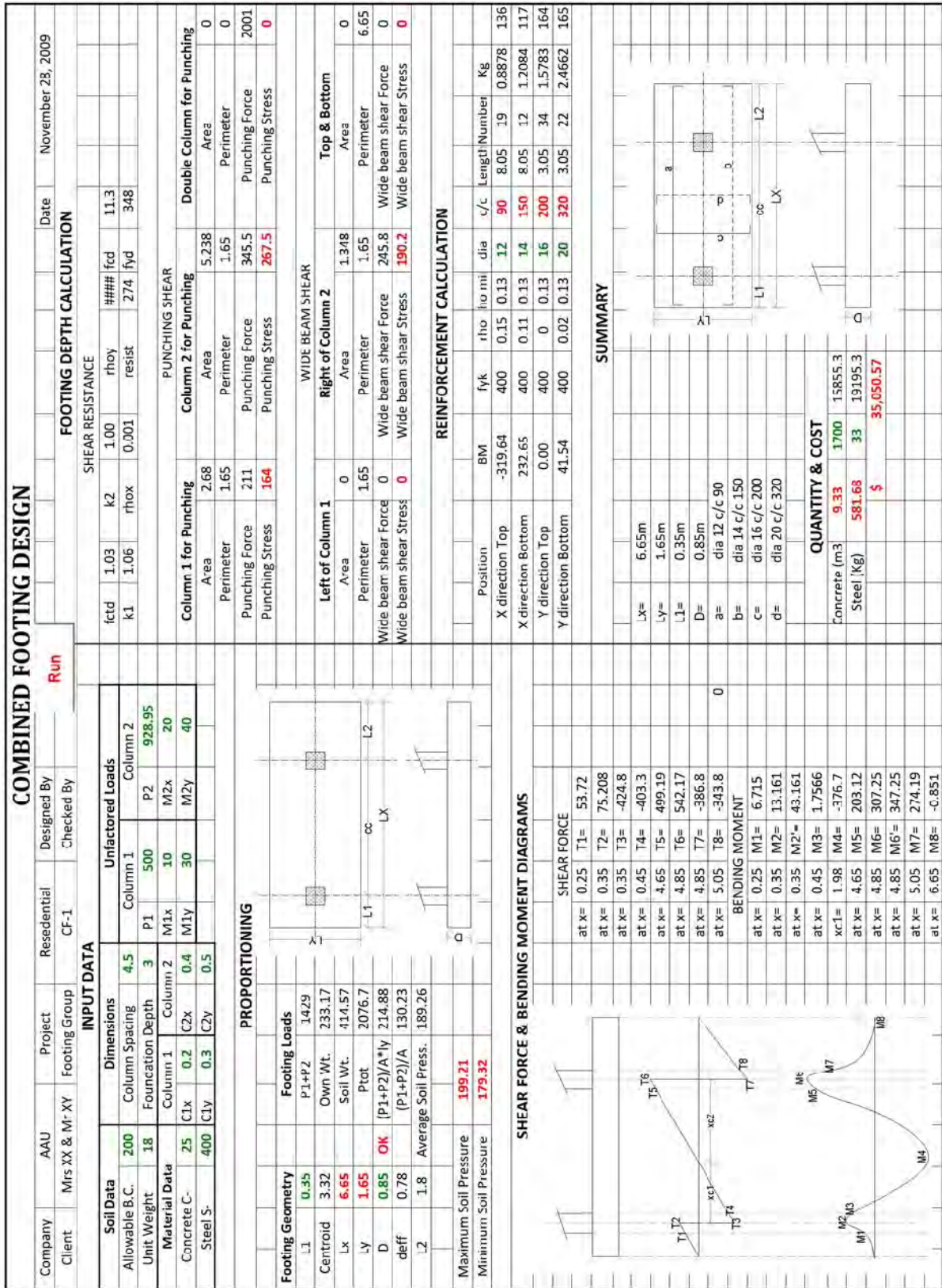


Figure 4. 25: the spreadsheet program for combined footings

The input data which have green font are listed below.

1. Allowable bearing capacity,
2. Unit weight of soil,
3. Column spacing,
4. Foundation depth,
5. Grade of concrete, Grade of steel,
6. Column dimensions,
7. Unfactored loads and moments,
8. Distance from left edge of footing to centerline of column1.
9. Diameters of each reinforcing bars.
10. Unit cost of concrete & steel

After entering all the input data then click the button “**Run**” to design the footing.

The output data which have red font are listed below.

1. Length of footing in the X direction
2. Length of footing in the Y direction
3. Total depth of footing
4. Material cost of footing

The checkpoints which also have red font are listed below.

1. Check maximum soil pressure
2. Check minimum soil pressure
3. Check punching for column1
4. Check punching for column2
5. Check punching for double column
6. Check wide beam shear at left of column1
7. Check wide beam shear at right of column2
8. Check wide beam shear at top and bottom

There are two cases of designing the footing

- a) When footing cannot project in left direction of column, perhaps because of the proximity of a property line, the distance L1 is predetermined. The user has to enter the value of L1.

- b) When footing can project in left direction of column, the distance L_1 can be of any value, the software can determine this distance so that minimum cost is attained by clicking the “**Optimize**” button.

The spreadsheet program produces takeoff in a separate sheet called “**Quantity**”.

To produce working drawing first run the macro named “**Combined.dvb**” on a new window of AutoCAD 2007, and then click the “**Draw**” button.

4.11 CONCLUSIONS ON SECTION 4

1. The fact that this spreadsheet program can design, draw and quantify combined footings considerably reduces the time needed for these processes and it also eliminates the error made during the information transfer from designer to drafts person and quantity surveyor.
2. Unlike many other spreadsheet programs available in this country, this spreadsheet program is developed according to the requirements of the recent version of Ethiopian Building Code Standards (EBCS). And little assumptions and approximations were made to the code during the spreadsheet development. This spreadsheet program considers every possible case during punching shear force calculation.
3. If the user has a freedom to choose the length L_1 , this spreadsheet can help the user determine L_1 with minimum cost of foundation.
4. The user can intervene and override any result during the whole process.

5 DESIGN OF STRAP (OR CANTILEVER) FOOTINGS

5.1 INTRODUCTION

Another expedient, which is used if a single footing cannot be centered under an exterior column, is to place the exterior column footing eccentrically and to connect it with the nearest interior column by a beam or strap. This strap, being counterweighted by the interior column load, resists the tilting tendency of the eccentric exterior footings and equalizes the pressure under it. Such foundations are known as strap, cantilever, or connected footings.

A strap footing is used when a column footing cannot project in one direction, perhaps because of the proximity of a property line, the footing may be helped out by an adjacent footing with more space. The strap is used to transmit the moment caused from eccentricity of the exterior column footing to the interior column footing so that a uniform soil pressure is computed beneath both footings.

The strap serves the same purpose as the interior portion of a combined footing but is much narrower to save materials. The strap footing may be used in lieu of a combined footing if the distance between columns is large and/or the allowable soil pressure is relatively large so that the additional footing area is not needed.

5.2 ASSUMPTIONS AND LIMITATIONS

The basic assumptions for the design of strap footings are:

- Footings must be rigid, so that the soil pressure distribution is linear.
- Strap must be rigid—perhaps $I(\text{strap})/I(\text{footing}) > 2$. This rigidity is necessary to control rotation of the exterior footing.
- Soil Pressures from the two connected footings should be approximately the same to avoid differential settlement.
- The strap should be securely attached to the column and footing by dowels so that the system acts as a unit.
- Horizontal loads and torsional moments transferred from columns must be very small.

5.3 LIST OF SYMBOLS SPECIFIC TO SECTION 5

BC	-	Allowable bearing capacity of underlying soil
GS	-	Unit weight of backfill soil
CC	-	center to center distance between columns
FD	-	foundation depth
CL_{x1}	-	dimension of column 1 in the x direction
CL_{y1}	-	dimension of column 1 in the y direction
CL_{x2}	-	dimension of column 2 in the x direction
CL_{y2}	-	dimension of column 2 in the y direction
PS_1	-	Unfactored Superstructure axial load from column 1
PS_2	-	Unfactored Superstructure axial load from column 2
M_{1x}	-	Unfactored superstructure moment from column 1 in the x direction
M_{1y}	-	Unfactored superstructure moment from column 1 in the y direction
M_{2x}	-	Unfactored superstructure moment from column 2 in the x direction
M_{2y}	-	Unfactored superstructure moment from column 2 in the y direction
CS	-	grade of concrete
SS	-	grade of steel
LEN_1	-	length of footing 1 in the x direction
LEN_2	-	length of footing 2 in the x direction
L_y	-	length of footing 1 & 2 in the y direction
D_{tot1}	-	total depth of footing 1
D_{tot2}	-	total depth of footing 2
D_{ef1}	-	effective depth of footing 1
D_{ef2}	-	effective depth of footing 2
H	-	total depth of strap
B	-	width of strap
OWT_1	-	own weight of footing 1
OWT_2	-	own weight of footing 2
SWT_1	-	weight of backfill above footing 1
SWT_2	-	weight of backfill above footing 2
$STRWT$	-	weight of strap

ρ_{x1}	-	steel ratio of footing 1 in the x direction
ρ_{y1}	-	steel ratio of footing 1 in the y direction
ρ_{x2}	-	steel ratio of footing 2 in the x direction
ρ_{y2}	-	steel ratio of footing 2 in the y direction
PSF_1	-	Punching Shear stress acting on footing1
$PRES_1$	-	Punching Shear resistance of footing1
PSF_2	-	Punching Shear stress acting on footing2
$PRES_2$	-	Punching Shear resistance of footing2

5.4 PROCEDURES

- Step 1:** Proportioning of footings
- Step 2:** Calculation of shear force & bending moment diagrams
- Step 3:** Determination of footing thickness
- Step 4:** Determination of strap dimensions
- Step 5:** Reinforcement calculation
- Step 6:** Calculation of development length of bars

5.5 PROPORTIONING OF FOOTINGS

The allowable soil pressure controls the plan ($B \times L$) dimensions of a footing. Soil Pressures from the two connected footings should be approximately the same to avoid differential settlement. Therefore the same width is used for the two footings. It should be noted that footing sizes are determined for unfactored service loads and soil pressures, in contrast to the strength design of reinforced concrete members, which utilizes factored loads and factored nominal strengths.

Loads acting on the foundation are:

1. Super structure loads, PS_1 & PS_2
2. Weight of backfill soil
 - a) On top of footing1, $SWT_1 = GS * (FD - D_{tot1}) * (LEN_1 * L_y - CL_{x1} * CL_{y1})$ Eq.5.1
 - b) On top of footing 2, $SWT_2 = GS * (FD - D_{tot2}) * (LEN_2 * L_y - CL_{x2} * CL_{y2})$ Eq.5.2
3. Own weight of footing
 - a) Weight footing1, $OWT_1 = 25 * D_{tot1} * LEN_1 * L_y$ Eq.5.3
 - b) Weight footing 2, $OWT_2 = 25 * D_{tot2} * LEN_2 * L_y$ Eq.5.4

$$4. \text{ Weight of strap, } STRWT = 25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2) \quad Eq.5.5$$

Where GS is unit weight of backfill soil, and FD is depth of foundation. For other notations see figure 5.1.

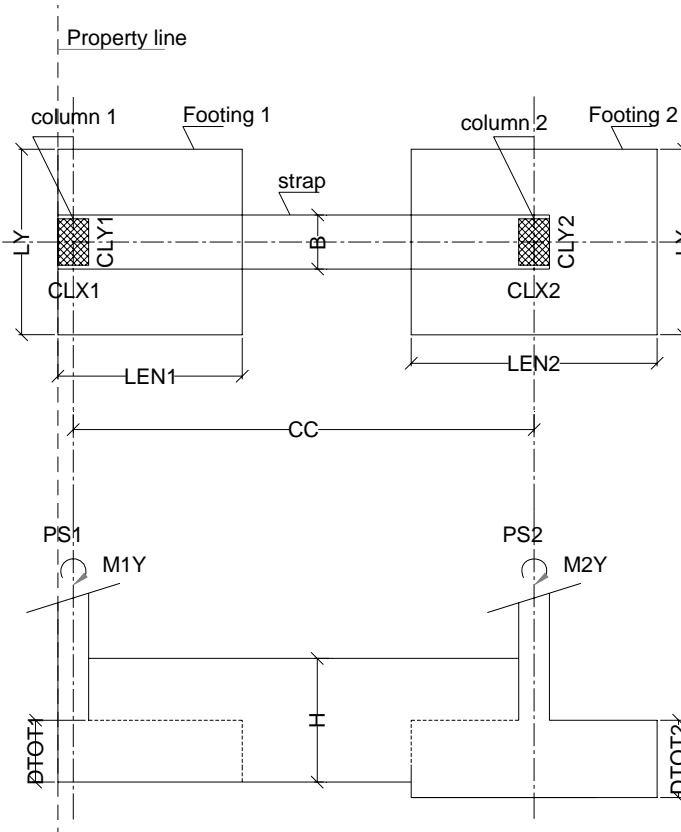


Figure 5. 1: Strap footing

The column transmits, at its juncture with the footing, not only a vertical load but also a bending moment. In either case, the load effects at the footing base can be represented by the vertical load P and a bending moment M . The resulting bearing pressures are again assumed to be linearly distributed. As long as the resulting eccentricity $e = M/P$ does not exceed the kern distance k of the footing area, the usual flexure formula permits the determination of the bearing pressures at the two extreme edges, as shown in figure 5.2.

$$Q_{\max,\min} = \frac{P}{A} \pm \frac{M_x * C_x}{I_x} \pm \frac{M_y * C_y}{I_y} \quad Eq.5.6$$

$$Q_{\max 1} = \frac{REA_1 + SWT_1 + OWT_1 + STRWT / 2}{LEN_1 * L_y} + \frac{6 * |M_{1x}|}{LEN_1 * L_y^2} \leq BC \quad Eq.5.7$$

$$Q_{\max 2} = \frac{REA_2 + SWT_2 + OWT_2 + STRWT / 2}{LEN_2 * L_y} + \frac{6 * |M_{2x}|}{LEN_2 * L_y^2} \leq BC \quad Eq.5.8$$

$$Q_{\min 1} = \frac{REA_1 + SWT_1 + OWT_1 + STRWT / 2}{LEN_1 * L_y} - \frac{6 * |M_{1x}|}{LEN_1 * L_y^2} \geq 0 \quad Eq.5.9$$

$$Q_{\min 2} = \frac{REA_2 + SWT_2 + OWT_2 + STRWT / 2}{LEN_2 * L_y} - \frac{6 * |M_{2x}|}{LEN_2 * L_y^2} \geq 0 \quad Eq.5.10$$

Where, REA_1 & REA_2 are soil reactions due to superstructure loads on footings 1 & 2.

BC is the allowable bearing capacity of the soil.

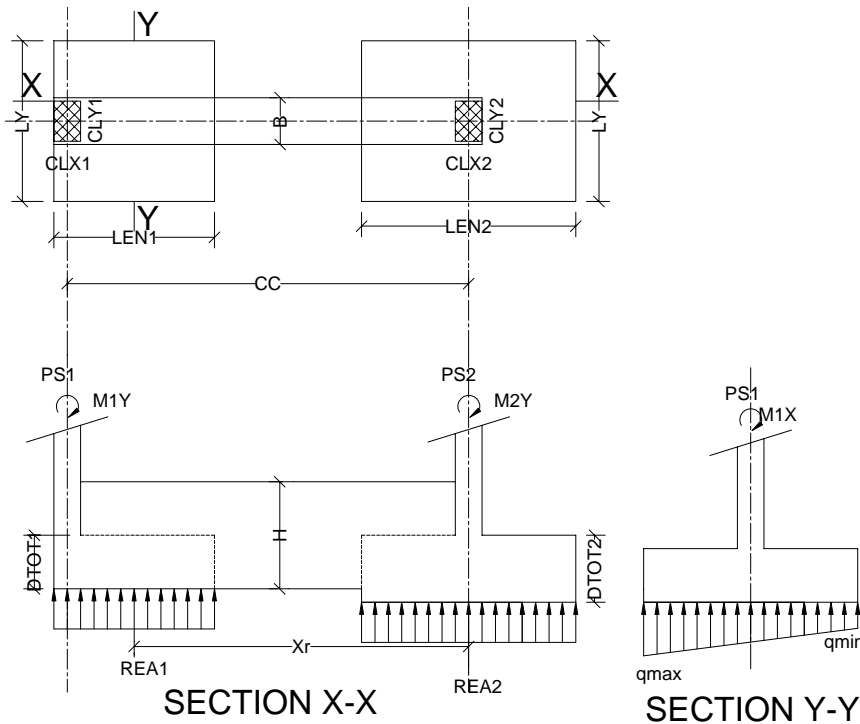


Figure 5. 2: Pressure distributions under strap footing

The basic steps in proportioning of strap footings are:

STEP1. Assume LEN_1

STEP2. Calculate X_r , $X_r = CC + CL_{x1} / 2 - LEN_1 / 2$

$$Eq.5.11$$

STEP3. Calculate REA_1 & REA_2

Taking $\sum M$ about $REA_2=0$,

$$REA_1 = \frac{PS_1 * CC + |M_{1y} + M_{2y}|}{X_r} \quad Eq.5.12$$

Taking $\sum F_z=0$

$$REA_2 = PS_1 + PS_2 - REA_1 \quad Eq.5.13$$

STEP4. Calculate L_y

$$\frac{REA_1 + SWT_1 + OWT_1 + STRWT / 2}{LEN_1 * L_y} + \frac{6 * |M_{1x}|}{LEN_1 * L_y^2} = BC \quad Eq.5.14$$

Where,

$$SWT_1 = GS * (FD - D_{tot1}) * (LEN_1 * L_y - CL_{x1} * CL_{y1})$$

$$OWT_1 = 25 * D_{tot1} * LEN_1 * L_y$$

$$STRWT = 25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2)$$

Equating...

$$\frac{REA_1 + GS * (FD - D_{tot1}) * (LEN_1 * L_y - CL_{y1} * CL_{x1}) + 25 * D_{tot1} * L_y * LEN_1}{LEN_1 * L_y} + \frac{25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2) / 2}{LEN_1 * L_y} + \frac{6 * |M_{1x}|}{LEN_1 * L_y^2} = BC \quad Eq.5.15$$

Rearranging..

$$A * L_y^2 + B * L_y = 0 \quad Eq.5.16$$

Where;

$$A = BC * LEN_1 - LEN_1 * GS * (FD - D_{tot1}) - 25 * LEN_1 * D_{tot1} \quad Eq.5.17$$

$$B = CL_{x1} * CL_{y1} * GS * (FD - D_{tot1}) - 12.5 * B * H * (CC - CL_{x1} / 2 - CL_{x2} / 2) - REA_1 \quad Eq.5.18$$

$$C = -6 * |M_{1x}| \quad Eq.5.19$$

Solving for L_y ..

$$L_y = \frac{-B + \sqrt{B^2 - 4 * A * C}}{2 * A} \quad Eq.5.20$$

STEP5. Calculate LEN_2

$$\frac{REA_2 + SWT_2 + OWT_2 + STRWT / 2}{LEN_2 * L_y} + \frac{6 * |M_{2x}|}{LEN_2 * L_y^2} = BC \quad Eq.5.21$$

Where:

$$SWT_2 = GS * (FD - D_{tot2}) * (LEN_2 * L_y - CL_{x2} * CL_{y2})$$

$$OWT_2 = 25 * D_{tot2} * LEN_2 * L_y$$

$$STRWT = 25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2)$$

Equating...

$$\frac{REA_2 + GS * (FD - D_{tot2}) * (LEN_2 * L_y - CL_{y2} * CL_{x2}) + 25 * D_{tot2} * L_y * LEN_2}{LEN_2 * L_y} + \frac{25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2) / 2}{LEN_2 * L_y} + \frac{6 * |M_{2x}|}{LEN_2 * L_y^2} = BC \quad Eq.5.22$$

Rearranging and solving for LEN_2 .

$$LEN_2 = \frac{6 * |M_{2x}| + L_y * REA_2 + 12.5 * L_y * B * H * (CC - CL_{x1} / 2 - CL_{x2} / 2) - L_y * CL_{x2} * CL_{y2} * GS * (FD - D_{tot2})}{BC * L_y^2 - (FD - D_{tot2}) * GS * L_y^2 - 25 * L_y^2 * D_{tot2}} \quad Eq.5.23$$

STEP6. Check if $Q_{min} > 0$

$$Q_{min1} = \frac{REA_1 + GS * (FD - D_{tot1}) * (LEN_1 * L_y - CL_{y1} * CL_{x1}) + 25 * D_{tot1} * L_y * LEN_1}{LEN_1 * L_y} + \frac{25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2) / 2}{LEN_1 * L_y} - \frac{6 * |M_{1x}|}{LEN_1 * L_y^2} \geq 0 \quad Eq.5.24$$

$$Q_{min2} = \frac{REA_2 + GS * (FD - D_{tot2}) * (LEN_2 * L_y - CL_{y2} * CL_{x2}) + 25 * D_{tot2} * L_y * LEN_2}{LEN_2 * L_y} + \frac{25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2) / 2}{LEN_2 * L_y} - \frac{6 * |M_{2x}|}{LEN_2 * L_y^2} \geq 0 \quad Eq.5.25$$

5.6 SHEAR FORCE AND BENDING MOMENT DIAGRAMS

The column loads are actually distributed over the column width but should always be taken as concentrated loads. This assumption greatly simplifies the shear and moment computations, and the values at the critical locations are the same if shear force & bending moment diagram is calculated by using distributed or concentrated load.

The shear and bending moments will be determined at different sections (critical locations) along the length of the footing as described in figure 5.3.

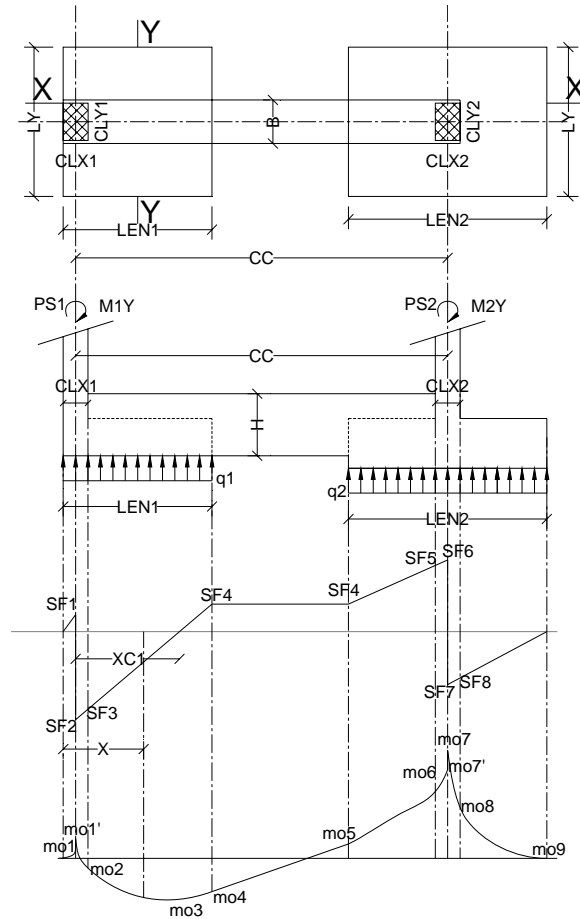


Figure 5. 3: shear force and bending moment diagram

- The distributed load from the constant pressure per unit length is:

$$Q_1 = \frac{REA_1}{L_y * LEN_1} * L_y = \frac{REA_1}{LEN_1} \quad Eq.5.26$$

$$Q_2 = \frac{REA_2}{L_y * LEN_2} * L_y = \frac{REA_2}{LEN_2} \quad Eq.5.27$$

- Shear force and bending moment at the center of column 1

$$X = CL_{x1} / 2 \quad Eq.5.28$$

$$SF1 = REA_1 / LEN_1 * CL_{x1} / 2 \quad Eq.5.29$$

$$SF2 = SF1 - PS_1 \quad Eq.5.30$$

$$MO1 = SF1 + CL_{x1} / 4 \quad Eq.5.31$$

$$MO1' = MO1 + M_{1y} \quad Eq.5.32$$

- Shear force and bending moment at the face of column 1

$$X = CL_{x1} \quad Eq.5.33$$

$$SF3 = SF2 + REA_1 / LEN_1 * CL_{x1} / 2 \quad Eq.5.34$$

$$MO2 = MO1' + (SF2 + SF3) / 2 * CL_{x1} / 2 \quad Eq.5.35$$

- Maximum Bending Moment

$$XC1 = \frac{-SF2}{SF4 - SF2} * (LEN_1 - CL_{x1} / 2) \quad Eq.5.36$$

$$MO3 = MO1' + SF2 * XC1 / 2 \quad Eq.5.37$$

- Shear force and bending moment at the end of footing 1

$$X = LEN_1 \quad Eq.5.38$$

$$SF4 = SF2 + REA_1 / LEN_1 * (LEN_1 - CL_{x1} / 2) \quad Eq.5.39$$

$$MO4 = MO3 + SF4 * (LEN_1 - CL_{x1} / 2 - XC1) / 2 \quad Eq.5.40$$

- Shear force and bending moment at the beginning of footing 2

$$X = CC + CL_{x1} / 2 - LEN_2 / 2 \quad Eq.5.41$$

$$SF4 = SF2 + REA_1 / LEN_1 * (LEN_1 - CL_{x1} / 2) \quad Eq.5.42$$

$$MO5 = MO4 + SF4 * (CC + CL_{x1} / 2 - LEN_1 - LEN_2 / 2) \quad Eq.5.43$$

- Shear force and bending moment at the left face of column 2

$$X = CC + CL_{x1} / 2 - CL_{x2} / 2 \quad Eq.5.44$$

$$SF5 = SF4 + REA_2 / LEN_2 * (LEN_2 / 2 - CL_{x2} / 2) \quad Eq.5.45$$

$$MO6 = MO5 + (SF4 + SF5) / 2 * (LEN_2 / 2 - CL_{x2} / 2) \quad Eq.5.46$$

- Shear force and bending moment at the center of column 2

$$X = CC + CL_{x1} / 2 \quad Eq.5.47$$

$$SF6 = SF4 + REA_2 / LEN_2 * LEN_2 / 2 \quad Eq.5.48$$

$$SF7 = SF6 - PS_2 \quad Eq.5.49$$

$$MO7 = MO5 + (SF4 + SF6) / 2 * LEN_2 / 2 \quad Eq.5.50$$

$$MO7' = MO7 + M_{2y} \quad Eq.5.51$$

- Shear force and bending moment at the right face of column 2

$$X = CC + CL_{x1} / 2 + CL_{x2} / 2 \quad Eq.5.52$$

$$SF8 = SF7 + REA_2 / LEN_2 * CL_{x2} / 2 \quad Eq.5.53$$

$$MO8 = MO7' + (SF7 + SF8) / 2 * CL_{x2} / 2 \quad Eq.5.54$$

- (Check) Shear force and bending moment at the right end of footing 2

$$X = CC + CL_{x1} / 2 + LEN_2 / 2 \quad Eq.5.55$$

$$SF = SF7 + REA_2 / LEN_2 * LEN_2 / 2 = 0 \quad Eq.5.56$$

$$MO9 = MO7' + SF7 * LEN_2 / 4 \quad Eq.5.57$$

5.7 DETERMINATION OF FOOTING THICKNESS

Shear stresses usually control the footing thickness D. And there are two modes of shear failure.

- One way shear also known as wide beam shear or diagonal compression shear
- Two way shear also known as punching shear or diagonal tension shear

Footing thicknesses are determined for factored service loads and soil pressures.

Calculation of effective depths

$$\text{For Footing 1, } D_{ef1}, D_{ef1} = D_{tot1} - 0.05 - \Phi_1 \quad Eq.5.58$$

$$\text{For Footing 2, } D_{ef2}, D_{ef2} = D_{tot2} - 0.05 - \Phi_2 \quad Eq.5.59$$

Where D_{tot1} & D_{tot2} are total depths of footings 1 & 2 respectively.

Φ_1 & Φ_2 are average diameters of reinforcement for footings 1 & 2 respectively.

5.7.1 CHECKING FOOTING THICKNESS FOR PUNCHING SHEAR

Various investigators have suggested different locations for the idealized critical shear surfaces for punching. EBCS 2, 1995 specifies that they be located at $1.5d$ distance from the face of the column. The footing design is satisfactory for punching shear when it satisfies the condition, $P_{RESI} > P_{SF}$, on all critical surfaces, where, P_{RESI} is the punching shear capacity on the critical surface and P_{SF} is the factored shear stress on critical surface.

5.7.1.1 CALCULATION OF PUNCHING SHEAR CAPACITY

- Calculation of punching shear resistance for footing1

$$P_{RES1} = 0.25 * F_{ctd} * k_{1L} * k_{2L} \quad Eq.5.60$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_{1L} = \min(1 + 50\rho, 2)$$

$$\rho = \min(0.015, \sqrt{\rho_{x1}, \rho_{y1}})$$

$$K_{2L} = \max(1.6 - D_{ef1}, 1)$$

- Calculation of punching shear resistance for footing2

$$P_{RES2} = 0.25 * F_{ctd} * k_{1R} * k_{2R} \quad Eq.5.61$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_{1R} = \min(1 + 50\rho, 2)$$

$$\rho = \min(0.015, \sqrt{\rho_{x2}, \rho_{y2}})$$

$$K_{2R} = \max(1.6 - D_{ef2}, 1)$$

5.7.1.2 CALCULATION OF PUNCHING SHEAR STRESS ON CRITICAL SURFACES

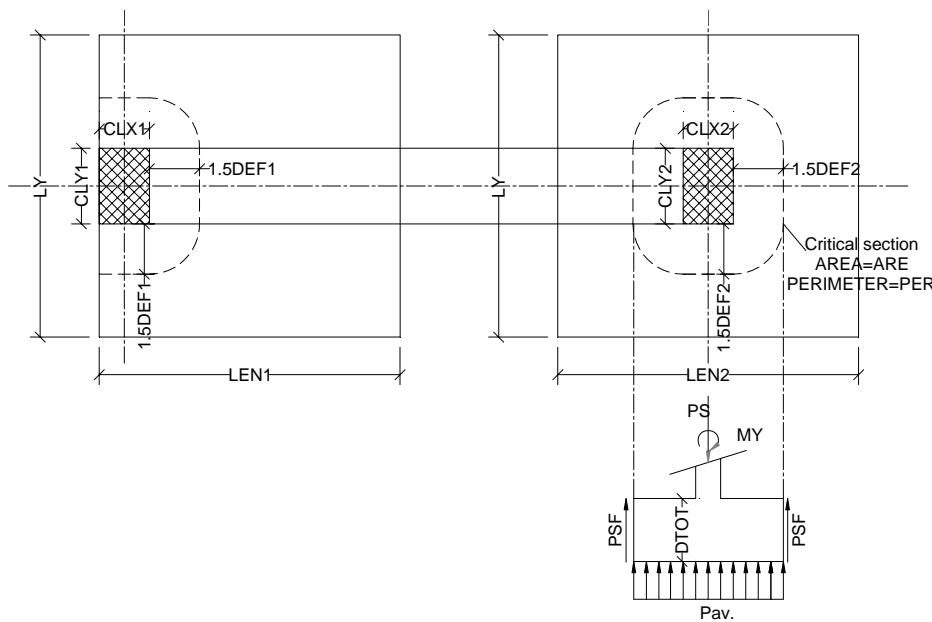


Figure 5. 4: Critical Section for Punching

The footing may be subject to applied normal force and bending moment i.e. P , M_x , M_y , all of which produce shear forces on the critical shear surfaces. The design shear is the algebraic sum of all design ultimate vertical loads acting on one side or outside the periphery of critical section.

Taking $\sum F_z=0$, refer to figure 5.4.

$$PSF = 1.4 * \frac{(PS - \frac{REA}{LEN * L_y} * ARE)}{PER * D_{ef}} \quad Eq.5.62$$

Calculation of punching shear stress for footing1

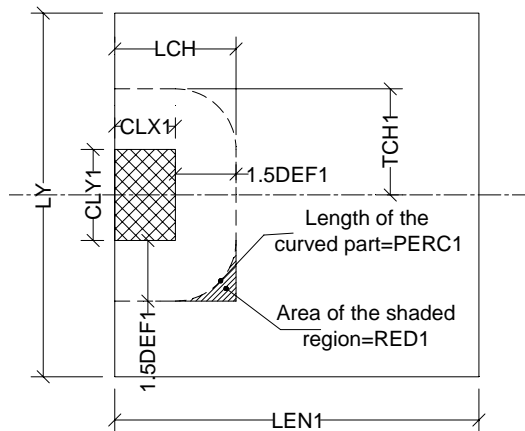
$$PSF1 = 1.4 * \frac{(PS_1 - \frac{REA1}{LEN_1 * L_y} * ARE1)}{PER1 * D_{ef1}} \quad Eq.5.63$$

Calculation of punching shear stress for footing2

$$PSF2 = 1.4 * \frac{(PS_2 - \frac{REA2}{LEN_2 * L_y} * ARE2)}{PER2 * D_{ef2}} \quad Eq.5.64$$

5.7.1.2.1 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION

5.7.1.2.1.1 DEFINITIONS



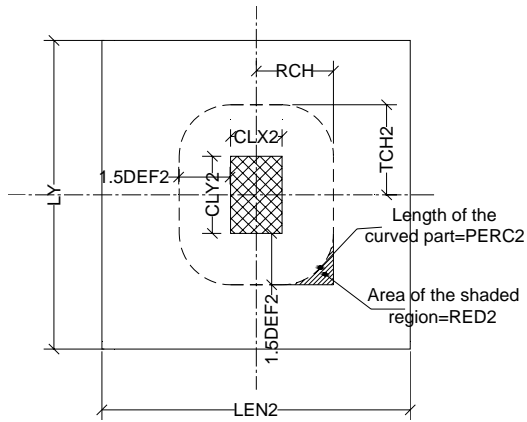
$$LCH = CL_{x1} + 1.5 * D_{ef1} \quad Eq.5.65$$

$$TCH1 = CL_{y1} / 2 + 1.5 * D_{ef1} \quad Eq.5.66$$

$$PERC1 = 0.75 * \pi * D_{ef1} \quad Eq.5.67$$

$$RED1 = (2.25 - 0.5625 * \pi) * D_{ef1}^2 \quad Eq.5.68$$

Figure 5. 5: Critical Section for punching – definitions – footing1



$$RCH = CL_{x2} / 2 + 1.5 * D_{ef2} \quad Eq.5.69$$

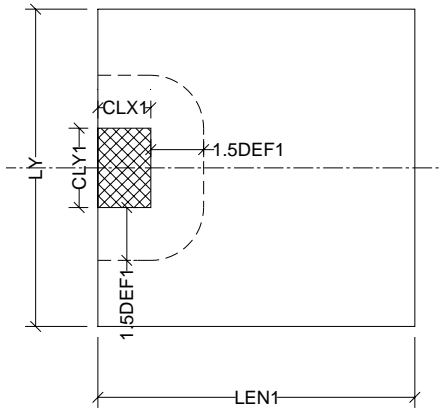
$$TCH2 = CL_{y2} / 2 + 1.5 * D_{ef2} \quad Eq.5.70$$

$$PERC2 = 0.75 * \pi * D_{ef2} \quad Eq.5.71$$

$$RED2 = (2.25 - 0.5625 * \pi) * D_{ef2}^2 \quad Eq.5.72$$

Figure 5. 6: Critical Section for punching – definitions – footing2

5.7.1.2.1.2 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION FOR COLUMN 1



CASE: Critical area outside of footing1 only on the left side of the footing.

$$LCH < LEN_1 \text{ \& } THC1 < L_y / 2 \quad Eq.5.73$$

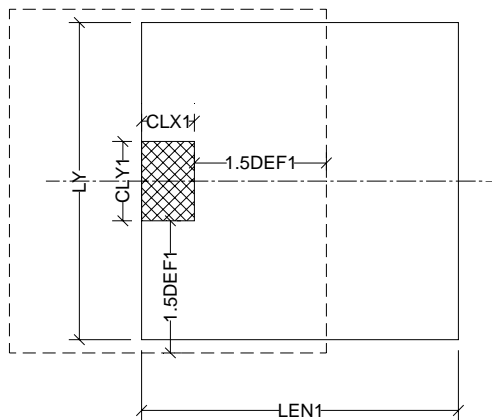
PERIMETER:

$$PER1 = 2 * CL_{x1} + CL_{y1} + 2 * PERC1 \quad Eq.5.74$$

AREA:

$$ARE1 = 2 * LCH * TCH1 - 2 * RED1 \quad Eq.5.75$$

Figure 5. 7: Critical Section for Punching around column1 case1



CASE: Critical area outside footing1 on the left, top and bottom sides of the footing.

$$LCH < LEN_1 \text{ \& } THC1 \geq L_y / 2 \quad Eq.5.76$$

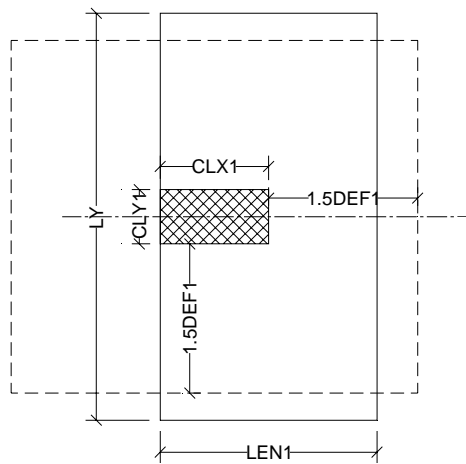
PERIMETER:

$$PER1 = L_y \quad Eq.5.77$$

AREA:

$$ARE1 = LCH * L_y \quad Eq.5.78$$

Figure 5. 8: Critical Section for Punching around column1 case2



CASE: Critical area outside footing1 on the left and right sides of the footing.

$$LCH \geq LEN_1 \text{ \& } THC1 < L_y / 2 \quad Eq.5.79$$

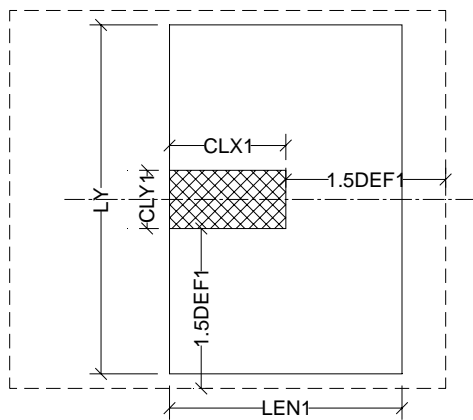
PERIMETER:

$$PER1 = 2 * LEN_1 \quad Eq.5.80$$

AREA:

$$ARE1 = 2 * TCH1 * LEN_1 \quad Eq.5.81$$

Figure 5. 9: Critical Section for Punching around column1 case3



CASE: Critical area outside footing1 on all sides of the footing.

$$LCH \geq LEN_1 \text{ \& } THC1 \geq L_y / 2 \quad Eq.5.82$$

PERIMETER:

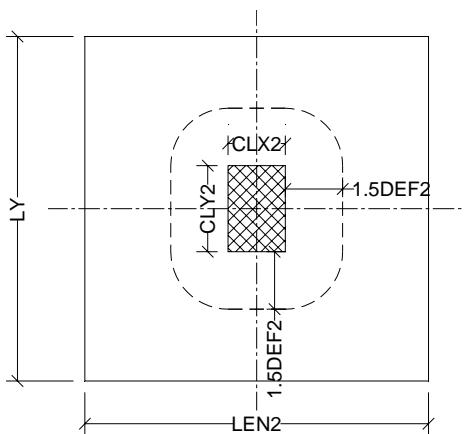
$$PER1 = 0 \quad Eq.5.83$$

AREA:

$$ARE1 = 0 \quad Eq.5.84$$

Figure 5. 10: Critical Section for Punching around column1 case4

5.7.1.2.1.3 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION FOR COLUMN 2



CASE: Critical area inside of footing2 on all sides of the footing.

$$RCH < LEN_2 / 2 \text{ \& } THC2 < L_y / 2 \quad Eq.5.85$$

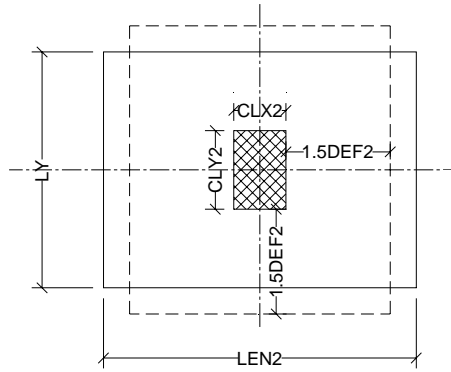
PERIMETER:

$$PER2 = 2 * CL_{x2} + 2 * CL_{y2} + 4 * PERC2 \quad Eq.5.86$$

AREA:

$$ARE2 = 4 * RCH * TCH2 - 4 * RED2 \quad Eq.5.87$$

Figure 5. 11: Critical Section for Punching around column2 case1



CASE: Critical area outside of footing2 on top and bottom sides of the footing.

$$RCH < LEN_2 / 2 \ \& \ THC2 \geq L_y / 2 \quad Eq.5.88$$

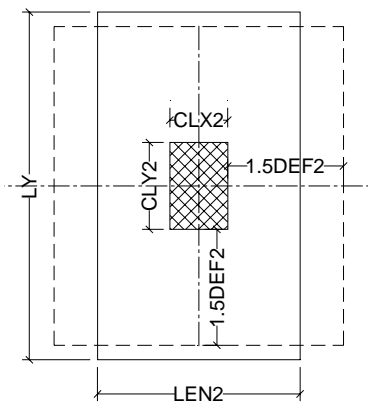
PERIMETER:

$$PER2 = 2 * L_y \quad Eq.5.89$$

AREA:

$$ARE2 = 2 * RCH * L_y \quad Eq.5.90$$

Figure 5. 12: Critical Section for Punching around column2 case2



CASE: Critical area outside of footing2 on left and right sides of the footing.

$$RCH \geq LEN_2 / 2 \ \& \ THC2 < L_y / 2 \quad Eq.5.91$$

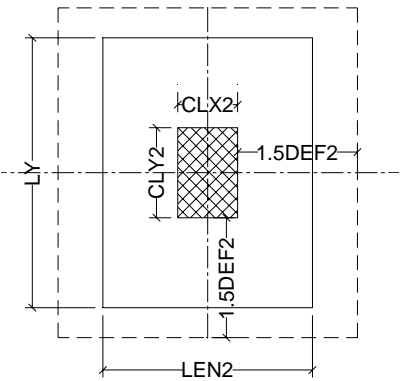
PERIMETER:

$$PER2 = 2 * LEN_2 \quad Eq.5.92$$

AREA:

$$ARE2 = 2 * TCH2 * LEN_2 \quad Eq.5.93$$

Figure 5. 13: Critical Section for Punching around column2 case3



CASE: Critical area outside of footing2 on all sides of the footing.

$$RCH \geq LEN_2 / 2 \ \& \ THC2 \geq L_y / 2 \quad Eq.5.94$$

PERIMETER:

$$PER2 = 0 \quad Eq.5.95$$

AREA:

$$ARE2 = 0 \quad Eq.5.96$$

Figure 5. 14: Critical Section for Punching around column2 case4

5.7.2 CHECKING FOOTING THICKNESS FOR WIDE BEAM SHEAR

Various investigators have suggested different locations for the idealized critical shear surfaces for wide beam shear. EBCS 2, 1995 specifies that they be located at d distance from the face of the column.

The footing design is satisfactory for wide beam shear when it satisfies the condition, $P_{RES1} > W_{SF}$, on all critical surfaces, where, P_{RES1} is the wide beam shear capacity on the critical surface and W_{SF} is the factored shear stress on critical surface.

5.7.2.1 CALCULATION OF WIDE BEAM SHEAR RESISTANCE

- Calculation of wide beam shear resistance for footing1

$$P_{RES1} = 0.25 * F_{ctd} * k_{1L} * k_{2L} \quad Eq.5.97$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_{1L} = \min(1 + 50\rho, 2)$$

$$\rho = \min(0.015, \sqrt{\rho_{x1}, \rho_{y1}})$$

$$K_{2L} = \max(1.6 - D_{ef1}, 1)$$

- Calculation of wide beam shear resistance for footing2

$$P_{RES2} = 0.25 * F_{ctd} * k_{1R} * k_{2R} \quad Eq.5.98$$

$$F_{ctd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}$$

$$K_{1R} = \min(1 + 50\rho, 2)$$

$$\rho = \min(0.015, \sqrt{\rho_{x2}, \rho_{y2}})$$

$$K_{2R} = \max(1.6 - D_{ef2}, 1)$$

5.7.2.2 CALCULATION OF APPLIED WIDE BEAM SHEAR STRESS

The design shear is the algebraic sum of all design ultimate vertical loads acting on one side of or outside the periphery of critical section.

- Calculation of wide beam shear stress for left of footing1

$$W_{SF1} = 1.4 * \frac{REA1}{L_y * LEN_1} * \frac{AREA}{PERIMETER * D_{ef1}}$$

$$AREA = L_y * (LEN_1 - CL_{x1} - D_{ef1})$$

$$PERIMETER = L_y$$

$$W_{SF1} = 1.4 * \frac{REA1}{L_y * LEN_1} * \frac{L_y * (LEN_1 - CL_{x1} - D_{ef1})}{L_y * D_{ef1}}$$

Eq.5.99

- Calculation of wide beam shear stress for top & bottom of footing1

$$W_{SF1} = 1.4 * \frac{REA1}{L_y * LEN_1} * \frac{AREA}{PERIMETER * D_{ef1}}$$

$$AREA = LEN_1 * (L_y / 2 - CL_{y1} / 2 - D_{ef1})$$

$$PERIMETER = LEN_1$$

$$W_{SF1} = 1.4 * \frac{REA1}{L_y * LEN_1} * \frac{LEN_1 * (L_y / 2 - CL_{y1} / 2 - D_{ef1})}{LEN_1 * D_{ef1}}$$

Eq.5.100

- Calculation of wide beam shear stress for right of footing2

$$W_{SF2} = 1.4 * \frac{REA2}{L_y * LEN_2} * \frac{AREA}{PERIMETER * D_{ef2}}$$

$$AREA = L_y * (LEN_2 / 2 - CL_{x2} / 2 - D_{ef2})$$

$$PERIMETER = L_y$$

$$W_{SF2} = 1.4 * \frac{REA2}{L_y * LEN_2} * \frac{L_y * (LEN_2 / 2 - CL_{x2} / 2 - D_{ef2})}{L_y * D_{ef2}}$$

Eq.5.101

- Calculation of wide beam shear stress for top & bottom of footing2

$$W_{SF2} = 1.4 * \frac{REA2}{L_y * LEN_2} * \frac{AREA}{PERIMETER * D_{ef2}}$$

$$AREA = LEN_2 * (L_y / 2 - CL_{y2} / 2 - D_{ef2})$$

$$PERIMETER = LEN_2$$

$$W_{SF2} = 1.4 * \frac{REA2}{L_y * LEN_2} * \frac{LEN_2 * (L_y / 2 - CL_{y2} / 2 - D_{ef2})}{LEN_2 * D_{ef2}}$$

Eq.5.102

5.8 DETERMINATION OF STRAP DIMENSIONS

By default Width of strap is determined from the maximum dimension in the y direction of the two columns i.e. $\max(CL_{y1}, CL_{y2})$. But the user has the freedom to change the width of the strap.

The adequacy of the provided depth of strap is checked at different sections for single reinforcement and diagonal compression shear failure.

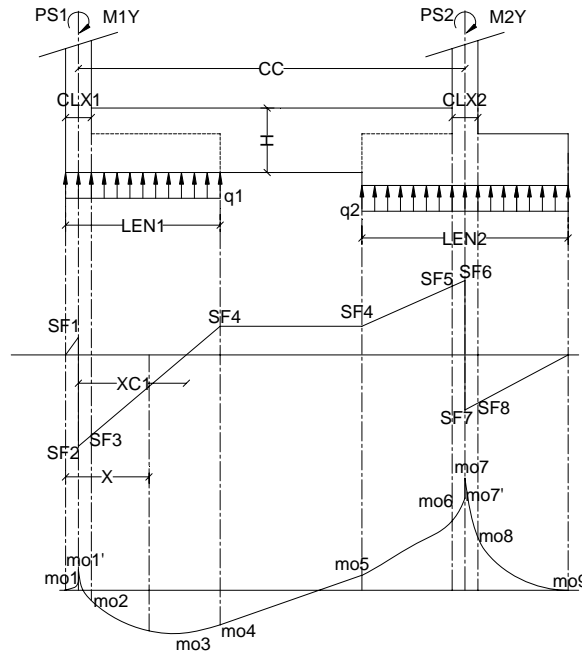


Figure 5. 15: Shear force and bending moment diagram

1. Checking if the strap is singly reinforced

- At **MO3**, refer to figure 5.15.

$$H_{ef} = \sqrt{\frac{1.4 * |MO3|}{0.2952 * B * f_{cd}}} + 70mm \geq H + \max(D_{tot1} - D_{tot2}, 0) \quad Eq.5.103$$

- At **MO6**, refer to figure 5.15.

$$H_{ef} = \sqrt{\frac{1.4 * |MO6|}{0.2952 * B * f_{cd}}} + 70mm \geq H + \max(D_{tot2} - D_{tot1}, 0) \quad Eq.5.104$$

- **At MO4 or MO5**, refer to figure 5.15.

$$H_{ef} = \sqrt{\frac{1.4 * \max(|MO4|, |MO5|)}{0.2952 * B * f_{cd}}} + 70mm \geq H$$

Eq.5.105

2. In order to prevent diagonal compression failure in the concrete, the shear resistance V_{Rd} of a section given by the equation below shall not be less than the applied shear force V_{sd} .

$$V_{Rd} = 0.25 * f_{cd} * B * H_{eff}$$

Eq.5.106

- **At SF3**, refer to figure 5.15.

$$H_{ef} = H + \max(0, D_{tot1} - D_{tot2}) - 70mm$$

Eq.5.107

$$V_{Rd} = 0.25 * f_{cd} * B * H_{eff} \geq 1.4 * SF3$$

Eq.5.108

- **At SF6**

$$H_{eff} = H + \max(0, D_{tot2} - D_{tot1}) - 70mm$$

Eq.5.109

$$V_{RD} = 0.25 * f_{cd} * B * H_{ef} \geq 1.4 * SF6 \quad \text{Eq.5.110}$$

- **At SF4**, refer to figure 5.15.

$$H_{eff} = H - 70mm \quad \text{Eq.5.111}$$

$$V_{Rd} = 0.25 * f_{cd} * B * H_{eff} \geq 1.4 * |SF4|$$

Eq.5.112

5.9 REINFORCEMENT CALCULATIONS

The footings and the strap are designed as reinforced concrete beam and there will be both negative bending steel at the bottom of the footing near columns and positive bending steel at the top of the strap near or in the center portion between columns. Critical sections for bending are at the face of the columns. Figure 5.16 shows shear force and bending moment diagrams at the critical sections.

1. Flexural reinforcement for strap top

$$M_{oST} = 1.4 * MO3 * 10^6 \tag{Eq.5.113}$$

$$\rho = \frac{1 - \sqrt{1 - 2M_{oST}}}{\sqrt{f_{cd} * B * H_{ef}^2}} \cdot \frac{1}{f_{cd} * f_{yd}}$$

$$\rho_{min} = \frac{0.6}{f_{yk}}$$

$$As = \max(\rho, \rho_{min}) * B * H_{ef}$$

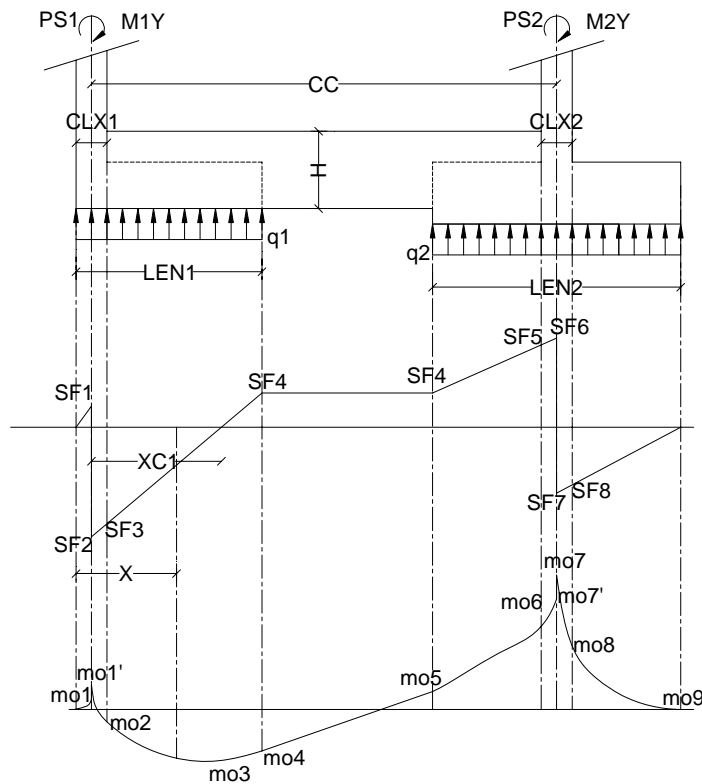


Figure 5. 16: shear force and bending moment diagrams

2. Flexural reinforcement for strap bottom, see figure 5.16.

$$M_{oSB} = 1.4 * \max(MO2, MO5, 0) * 10^6$$

$$\tag{Eq.5.114}$$

$$\rho = \frac{1 - \sqrt{\frac{1 - 2M_{oSB}}{f_{cd} * B * H_{ef}^2}}}{f_{cd} * f_{yd}}$$

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$As = \max(\rho, \rho_{\min}) * B * H_{ef}$$

3. Flexural reinforcement for footing1,X direction bottom

Minimum reinforcement is provided here

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$As = \rho_{\min} * 1000 * D_{ef1}$$

4. Flexural reinforcement for footing1,Y direction bottom

$$M_{o1YB} = 1.4 * \left(\frac{REA_1}{L_y * LEN_1} + \frac{12 * |M1_x| * (L_y / 4 + CL_{y1} / 4)}{LEN_1 * L_y^3} \right) * \frac{LEN_1 * (L_y / 2 - CL_{y1} / 2)^2}{2}$$

Eq.5.115

$$\rho = \frac{1 - \sqrt{\frac{1 - 2M_{o1YB}}{f_{cd} * LEN_1 * D_{ef1}^2}}}{f_{cd} * f_{yd}}$$

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$As = \max(\rho, \rho_{\min}) * LEN_1 * D_{ef1}$$

5. Flexural reinforcement for footing2,X direction bottom, see figure 5.16.

$$M_{o2XB} = 1.4 * \max(MO8, MO6) * 10^6$$

Eq.5.116

$$\rho = \frac{1 - \sqrt{\frac{1 - 2M_{o2XB}}{f_{cd} * L_y * D_{ef2}^2}}}{f_{cd} * f_{yd}}$$

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$A_s = \max(\rho, \rho_{\min}) * L_y * D_{ef2}$$

6. Flexural reinforcement for footing2,Y direction bottom

$$M_{o2YB} = 1.4 * \left(\frac{REA_2}{L_y * LEN_2} + \frac{12 * |M_{2,x}| * (L_y / 4 + CL_{y2} / 4)}{LEN_2 * L_y^3} \right) * \frac{LEN_2 * (L_y / 2 - CL_{y2} / 2)^2}{2}$$

Eq.5.117

$$\rho = \frac{1 - \sqrt{\frac{1 - 2M_{o2YB}}{f_{cd} * LEN_2 * D_{ef2}^2}}}{f_{cd} * f_{yd}}$$

$$\rho_{\min} = \frac{0.6}{f_{yk}}$$

$$A_s = \max(\rho, \rho_{\min}) * LEN_2 * D_{ef2}$$

7. Shear reinforcement for strap

The design shear force of the strap is calculated at d distance from the face of the column.

Shear force at HEF distance from face of column 1

$$SF10 = SF2 + \frac{(CL_{x1} / 2 + H_{ef}) * REA_1}{LEN_1} \quad Eq.5.118$$

Shear force at HEF distance from face of column 2

$$SF11 = SF4 + \frac{(LEN_2 / 2 - CL_{x2} / 2 - H_{ef}) * REA_2}{LEN_2} \quad Eq.5.119$$

Design shear force

$$V_{sd} = 1.4 * \max(SF10, SF11)$$

Eq.5.120

Concrete carrying capacity

$$V_c = 0.25 * f_{ctd} * K_1 * K_2 * B * H_{ef} \quad Eq.5.121$$

$$K_1 = \min(2, 1 + 50\rho)$$

Eq.5.122

$$K_2 = \max(1, 1.6 - H_{ef})$$

Eq.5.123

Shear carried by steel

$$V_s = V_{sd} - V_c$$

Eq.5.124

Shear area

$$A_v = \pi * \phi^2 / 2$$

Eq.5.124

Stirrup spacing

$$S = \frac{A_v * H_{ef} * f_{yd}}{V_s}$$

Eq.5.125

Minimum reinforcement

$$\rho_{\min} = 0.4 / f_{yk}$$

Eq.5.126

$$S_{\max} = \frac{A_v * f_{yk}}{0.4 * H_{ef}}$$

Eq.5.127

5.10 DEVELOPMENT LENGTH CALCULATION

The design bond strength f_{bd}

$$f_{bd} = 1.4 * f_{ctd}$$

Eq.5.128

Where f_{ctd} is the tensile strength of concrete.

The basic anchorage length l_b for a bar of diameter ϕ is:

$$l_b = \frac{\Phi f_{yd}}{4 f_{bd}}$$

Eq.5.130

The required anchorage length l_{bnet} depends on the type of anchorage and on the stress in the reinforcement and can be calculated as:

$$l_{bnet} = a l_b \frac{A_{s,cal}}{A_{s,ef}} \geq l_{b,min} \quad \text{Eq.5.131}$$

where $A_{s,cal}$ is the theoretical area of reinforcement required by the design

$A_{s,ef}$ is the area of reinforcement actually provided

$a = 1.0$ for straight bar anchorage in tension or compression

$= 0.7$ for anchorage in tension with standard hooks

$l_{b,min}$ is the minimum anchorage length

$\frac{A_{s,cal}}{A_{s,ef}} \approx 1$ at the face of columns therefore,

$$l_{bnet} = a l_b = 0.7 l_b = 0.7 * \frac{\Phi}{4} * \frac{f_{yd}}{1.4 * f_{ctd}} \geq l_{b,min}$$

Eq.5.132

$\frac{A_{s,cal}}{A_{s,ef}} \approx 0$ near the edges therefore $l_{bnet} = l_{b,min}$

$$l_{b,min} = 0.3 l_b > 10\phi > 200mm$$

Eq.5.133

5.11 THE SPREADSHEET PROGRAM

The general look of the spreadsheet program is shown in the figure below and when printed it can be a brief and adequate design report as shown in figure 5.17.

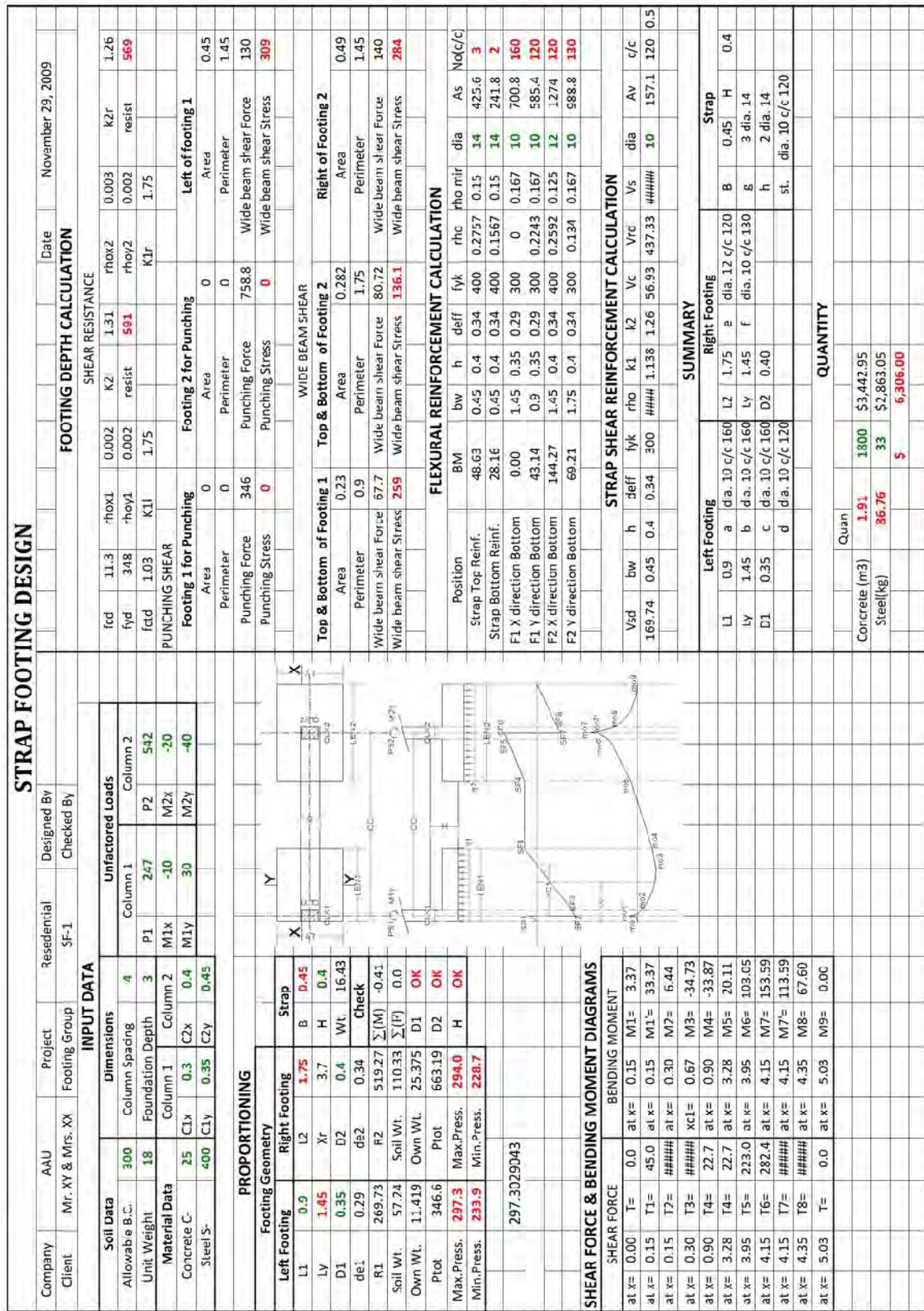


Figure 5. 17: the spreadsheet program for strap footings

The input data which have green font are listed below.

1. Allowable bearing capacity,
2. Unit weight of soil,
3. Column spacing,
4. Foundation depth,
5. Grade of concrete, Grade of steel,
6. Column dimensions,
7. Unfactored loads and moments,
8. Length of footing1 in the x direction
9. Diameters of each reinforcing bars.
10. Unit cost of concrete & steel
11. Width of strap

After entering all the input data then click the button “**Run**” to design the footing.

The output data which have red font are listed below.

1. Length of footing in the X direction
2. Length of footing in the Y direction
3. Total depth of each footing
4. Total depth of strap
5. Material cost of footing

The checkpoints which also have red font are listed below.

1. Check maximum soil pressure
2. Check minimum soil pressure
3. Check adequacy of depth of strap
4. Check punching for column1
5. Check punching for column2
6. Check punching for double column
7. Check wide beam shear at left of column1
8. Check wide beam shear at right of column2
9. Check wide beam shear at top and bottom

The user has the freedom to choose Length of footing1 in the x direction; the software can determine this distance so that minimum cost is attained by clicking the “**Optimize**” button.

The spreadsheet program produces takeoff in a separate sheet called “**Quantity**”.

To produce working drawing first run the macro named “Isolated.dvb” on a new window of AutoCAD 2007, and then click the “**Draw**” button.

5.12 CONCLUSIONS ON SECTION 5

1. This spreadsheet program considers every possible case during punching shear force calculation.
2. The user has a freedom to choose the length LI ; this spreadsheet can help the user determine LI so that minimum cost of foundation is attained.
3. The user can intervene and override any result of the spreadsheet during the whole process.
4. The spreadsheet programs calculate development length of each reinforcing bars.

6 GENERAL CONCLUSIONS

The fact that the spreadsheet programs can design, draw and quantify foundations considerably reduces the time needed for these processes and it also eliminates the error made during the information transfer from designer to drafts person and quantity surveyor.

Most engineers, quantity surveyors, and draftspersons are familiar with the software Microsoft Excel and AutoCAD. These computer programs are also user friendly. The software developed during this study use interfaces of Excel and AutoCAD. This makes the spreadsheet programs and the AutoCAD macros developed in this study as user friendly as the more advanced software Excel & AutoCAD. Copying, printing, and saving are very easy.

Foundation design consists of iterations. In the usual spreadsheet programs, iteration is made by hand whereas; the spreadsheet programs developed in this study allow iterations to be made by clicking a button. Iterations also help the user arrange of foundations so that minimum cost of materials is acquired.

The notations used in this report are similar to the symbols in the spreadsheet programs also the formulas in the report are identical to the formulas in the spreadsheet programs. This enables the user to have detailed information on the theories behind each formula.

Unlike many other spreadsheet programs available in this country, this spreadsheet program is developed according to the requirements of the recent version of Ethiopian Building Code Standards (EBCS). And little assumptions and approximations were made to the code during the spreadsheet development.

Finally, structural design has been described as: using materials not fully understood, to make frames which cannot be accurately analyzed, to resist forces which can only be estimated. Foundation design is, at best no better. ‘Accuracy’ is a chimera and the designer must exercise judgment.

7 BIBLIOGRAPHY

1. *Designers Manual*. Osney Mead, Oxford: Blackwell Science.
2. Draycott, T. (1990). *Structural Elements Design manual*. Oxford: Butterworth Heinemany.
3. *Ethiopian Building Code Standard BASIS OF DESIGN AND ACTIONS ON STRUCTURES*. (1995). Addis Ababa: 1995.
4. *Ethiopian Building Code Standard FOUNDATIONS*. (1995). Addis Ababa: Ministry of Works & Urban Development.
5. *Ethiopian Building Code Standard STRUCTURAL USE OF CONCRETE*. (1995). Addis Ababa: Wnistry of Works & Urban Development.
6. Hodgkinson, A. (1986). *Foundation Design*. Architectural Press Ltd.
7. Joseph E. Bowles, P. (1997). *Foundation Analysis and Design*. Peoria, Illions: The McGraw-Hill Companies, Inc.
8. Teferra, A. (1992). *Foundation Engineering*. Addis Ababa: Addis Ababa University Press.
9. W., F. C., & J., Y. R. (2003). *The Civil Engineering Handbook Second Edition*. Boca Raton London New York Washington, D.C.: CRC Press.
10. W., G. C., G., S., G., I. P., & J., M. G. (1994). *Structural Foundation Designers Manual*. Osney Mead, Oxford: Blackwell Science.

APPENDIX 1- SOLVED EXAMPLE FOR ISOLATED FOOTINGS

Appendix 1 solves an actual problem of isolated footings by using the programs developed by this thesis. A typical problem of isolated footings includes grouping, analysis and design, report writing, quantifying, and producing detailed drawings.

A.1.1 INPUT DATA

A B+G+7 building is analyzed using the software ETABS. Foundation reactions of the structure can be printed in “.txt” format which in turn can be opened by using EXCEL. The three dimensional look of the model is shown in figure A.1.1.

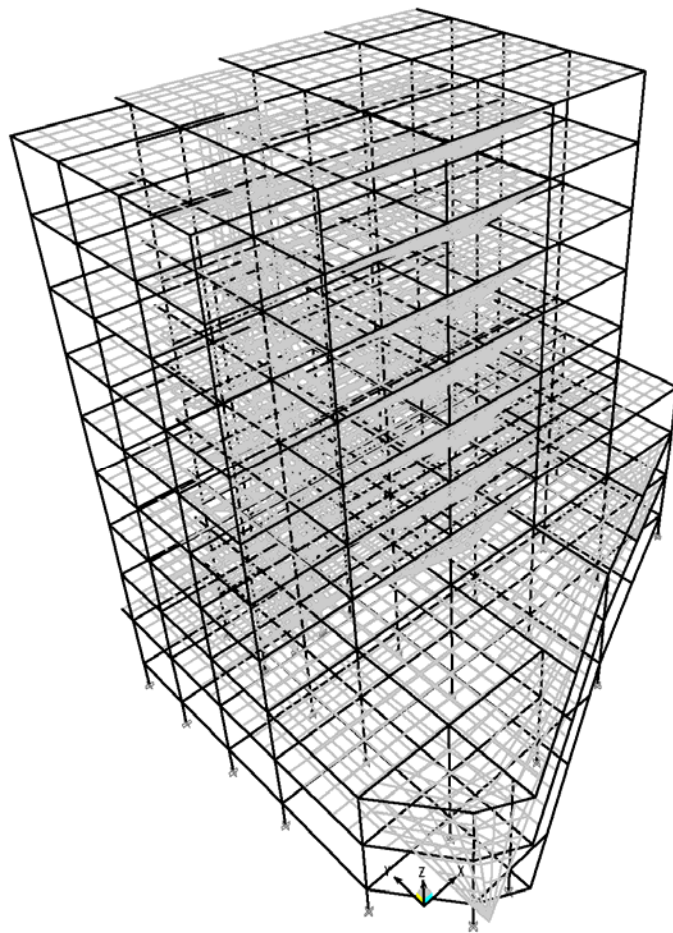


Figure A.1.18: three dimensional look of the building to be solved.

In ETABS each point is assigned with a specific number as shown in figure A.1.2. Foundation reactions are given using these labels.

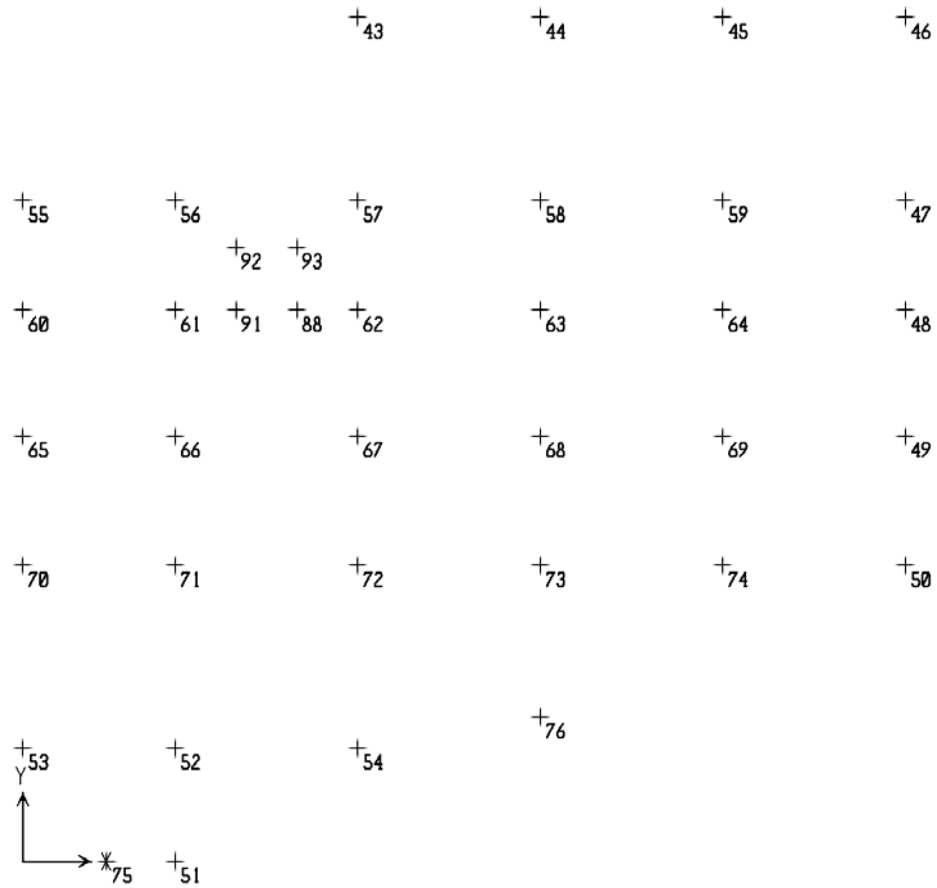


Figure A.1.2: Foundation layout vs. point labels used to identify foundation reactions.

Unfactored foundation reactions for each label can be printed from ETABS in a “.txt” format as shown in figure A.1.3.

ETABS v9.5.0 File: Units:KN-m March 8, 2010 16:27 PAGE 1

LOADING COMBINATIONS

COMBO	COMBO TYPE	CASE	CASE TYPE	SCALE FACTOR
COMB10	ADD	DEAD LIVE	Static Static	1.0000 1.0000

ETABS v9.5.0 File: Units:KN-m March 8, 2010 16:27 PAGE 2

SUPPORT REACTIONS

STORY	POINT	LOAD	FX	FY	FZ	MX	MY	MZ
BASE	43	COMB10	8.69	-11.68	648.98	3.271	0.449	-0.100
BASE	44	COMB10	-3.49	-10.02	1312.15	7.616	-4.069	-0.089
BASE	45	COMB10	-1.67	-5.22	924.39	3.493	-1.914	0.046
BASE	46	COMB10	-8.65	-8.42	363.88	3.876	-4.571	0.014
BASE	47	COMB10	-7.35	4.57	739.79	-2.400	-4.144	-0.008
BASE	48	COMB10	-8.02	-0.16	576.20	-0.202	-4.432	0.011
BASE	49	COMB10	-8.14	1.68	647.08	-1.125	-4.316	0.013
BASE	50	COMB10	-22.65	-3.60	526.55	1.310	-11.041	0.001
BASE	51	COMB10	14.21	-6.98	556.56	2.683	6.188	-0.017
BASE	52	COMB10	-0.42	6.25	835.36	-3.499	-0.802	-0.004
BASE	53	COMB10	5.68	5.88	416.68	-3.383	2.173	-0.023
BASE	54	COMB10	4.08	-24.08	1010.57	10.536	1.111	0.006
BASE	55	COMB10	8.11	-3.99	1096.51	-1.835	4.725	0.331
BASE	56	COMB10	6.24	-2.55	1509.71	-5.748	2.637	-0.471
BASE	57	COMB10	1.89	19.74	2130.19	-8.968	-2.574	-0.032
BASE	58	COMB10	-3.26	-2.43	3646.60	-0.479	-4.157	0.017
BASE	59	COMB10	-7.09	-0.96	2865.73	-1.809	-5.940	0.001
BASE	60	COMB10	10.21	1.11	1643.59	-3.807	7.636	0.112
BASE	61	COMB10	0.45	4.81	1508.92	-6.737	2.449	-0.179
BASE	62	COMB10	0.64	6.47	1905.92	-7.251	-3.825	-1.177
BASE	63	COMB10	-3.93	2.08	3200.25	-2.586	-5.032	0.089
BASE	64	COMB10	-7.06	3.34	2459.58	-3.761	-6.198	0.039
BASE	65	COMB10	9.82	3.12	1795.66	-4.711	6.489	-0.025
BASE	66	COMB10	8.70	1.28	2918.82	-4.174	4.591	-0.036
BASE	67	COMB10	0.89	1.23	3196.55	-4.219	0.336	0.174
BASE	68	COMB10	-0.29	0.86	3319.85	-2.817	-1.227	0.041
BASE	69	COMB10	-3.50	5.60	2554.82	-5.595	-3.261	0.039
BASE	70	COMB10	10.54	-0.17	1413.07	-3.277	7.644	-0.111
BASE	71	COMB10	8.79	1.75	2607.23	-3.424	5.163	-0.084
BASE	72	COMB10	2.10	11.58	3028.13	-7.965	0.484	-0.115
BASE	73	COMB10	-1.03	8.34	2692.64	-6.193	-1.948	-0.028
BASE	74	COMB10	4.86	-43.73	2184.12	14.148	-0.170	-0.087
BASE	75	COMB10	-1.69	2.52	261.30	-1.919	-1.283	-0.019
BASE	76	COMB10	4.46	-1.96	632.42	0.253	1.429	-0.060
BASE	88	COMB10	-57.01	83.73	804.31	-5.242	-3.244	-0.177
BASE	91	COMB10	75.63	42.92	669.97	-1.960	4.016	-0.120
BASE	92	COMB10	35.77	-61.82	567.22	3.551	1.519	-0.087
BASE	93	COMB10	-74.20	-41.38	650.98	1.182	-4.549	-0.114
Summation	0, 0, Base	COMB10	2.33	-10.30	59822.26	940562.744	-790462.065	-290.008

Figure A.1.3: Foundation reactions printed in “.txt” format.

The foundation reactions in “.txt” format can be opened by using Microsoft EXCEL and can easily be changed to the form as shown in figure A.1.4.

POINT	FZ	MX	MY
43	648.98	3.271	0.449
44	1312.15	7.616	-4.069
45	924.39	3.493	-1.914
46	363.88	3.876	-4.571
47	739.79	-2.4	-4.144
48	576.2	-0.202	-4.432
49	647.08	-1.125	-4.316
50	526.55	1.31	-11.041
51	556.56	2.683	6.188
52	835.36	-3.499	-0.802
53	416.68	-3.383	2.173
54	1010.57	10.536	1.111
55	1096.51	-1.835	4.725
56	1509.71	-5.748	2.637
57	2130.19	-8.968	-2.574
58	3646.6	-0.479	-4.157
59	2865.73	-1.809	-5.94
60	1643.59	-3.807	7.636
61	1508.92	-6.737	2.449
62	1905.92	-7.251	-3.825
63	3200.25	-2.586	-5.032
64	2459.58	-3.761	-6.198
65	1795.66	-4.711	6.489
66	2918.82	-4.174	4.591
67	3196.55	-4.219	0.336
68	3319.85	-2.817	-1.227
69	2554.82	-5.595	-3.261
70	1413.07	-3.277	7.644
71	2607.23	-3.424	5.163
72	3028.13	-7.965	0.484
73	2692.64	-6.193	-1.948
74	2184.12	14.148	-0.17
75	261.3	-1.919	-1.283
76	632.42	0.253	1.429
88	804.31	-5.242	-3.244
91	669.97	-1.96	4.016
92	567.22	3.551	1.519
93	650.98	1.182	-4.549

Figure A.1.4: Foundation reactions rearranged by using Excel.

A.1.2 GROUPING OF FOOTINGS

The rearranged foundation reactions can then be copied and pasted into the spreadsheet program *isolated.xls* where grouping, analysis and design, quantifying and report writing for isolated footings are performed.

At this stage in addition to foundation reactions allowable bearing capacity and number of footing groups have to be entered.

	A	B	C	D	E	F	H	I	J	M	N	O	P	Q	R	S
1	B.C.	300	Round	0.1				nfoot	3			Total Area				
2	Maximum	3.5	Minimum	1	New	Sort				Forward		265.58	Backward	Calculate	Ok	
3	POINT	FZ	MX	MY	Length	group	Length	Number	group	group length		Pes	total area	P	Mx	M _y
4	43	648.98	3.271	0.449	1.5	3	3.5	1	1	1	3.5	11	134.75	3647	-0.479	-4.157
5	44	1312.15	7.616	-4.069	2.1	2	3.4	1	1	2	2.7	12	87.48	2184	14.148	-0.17
6	45	924.39	3.493	-1.914	1.8	2	3.3	2	1	3	1.7	15	43.35	835.4	-3.499	-0.802
7	46	363.88	3.876	-4.571	1.2	3	3.2	2	1							
8	47	739.79	-2.4	-4.144	1.6	3	3.1	1	1							
9	48	576.2	-0.202	-4.432	1.4	3	3	3	1							
10	49	647.08	-1.125	-4.316	1.5	3	2.9	1	1							
11	50	526.55	1.31	-11.041	1.4	3	2.8	0	1							
12	51	556.56	2.683	6.188	1.4	3	2.7	2	2							
13	52	835.36	-3.499	-0.802	1.7	3	2.6	1	2							
14	53	416.68	-3.383	2.173	1.2	3	2.5	1	2							
15	54	1010.57	10.536	1.111	1.9	2	2.4	1	2							
16	55	1096.51	-1.835	4.725	2	2	2.3	2	2							
17	56	1509.71	-5.748	2.637	2.3	2	2.2	1	2							
18	57	2130.19	-8.968	-2.574	2.7	2	2.1	1	2							
19	58	3646.6	-0.479	-4.157	3.5	1	2	1	2							
20	59	2865.73	-1.809	-5.94	3.1	1	1.9	1	2							
21	60	1643.59	-3.807	7.636	2.4	2	1.8	1	2							
22	61	1508.92	-6.737	2.449	2.3	2	1.7	2	3							
23	62	1905.92	-7.251	-3.825	2.6	2	1.6	1	3							
24	63	3200.25	-2.586	-5.032	3.3	1	1.5	5	3							
25	64	2459.58	-3.761	-6.198	2.9	1	1.4	4	3							
26	65	1795.66	-4.711	6.489	2.5	2	1.3	0	3							
27	66	2918.82	-4.174	4.591	3.2	1	1.2	2	3							
28	67	3196.55	-4.219	0.336	3.3	1	1.1	0	3							
29	68	3319.85	-2.817	-1.227	3.4	1	1	1	3							
30	69	2554.82	-5.595	-3.261	3	1										
31	70	1413.07	-3.277	7.644	2.2	2										
32	71	2607.23	-3.424	5.163	3	1										
33	72	3028.13	-7.965	0.484	3.2	1										
34	73	2692.64	-6.193	-1.948	3	1										
35	74	2184.12	14.148	-0.17	2.7	2										
36	75	261.3	-1.919	-1.283	1	3										
37	76	632.42	0.253	1.429	1.5	3										
38	88	804.31	-5.242	-3.244	1.7	3										
39	91	669.97	-1.96	4.016	1.5	3										
40	92	567.22	3.551	1.519	1.4	3										
41	93	650.98	1.182	-4.549	1.5	3										
42																

Figure A.1.5: Grouping of footings

As an output of the grouping process, name of groups is written in front of each foundation reaction as shown in figure A.1.5. In addition, a summary of group names, number of pieces and design loads is written in a separate sheet as shown in figure A.1.6.

A.1.3 ANALYSIS AND DESIGN

After grouping is completed and summary is written, analysis and design of each group can be performed in the “summary” worksheet. Additional information like foundation depth, unit weight of soil, concrete strength, column dimensions, and diameters of reinforcement must be entered. Clicking “**Run**” will do the analysis and design for each footing group. Sizes of footings and spacing of reinforcements is automatically displayed in the summary as shown in figure A.1.7.

SUMMARY OF FOOTING DESIGN														
		Bearing Capacity=	300											
		Foundation Depth=	1.5											
		Unit weight of Soil=	18											
		Concrete C=	25											
		Number of Groups=	3											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Group	P	Mx	My	Pcs	Cx	Cy	Lx	Ly	D	d_{iax}	c/cx	d_{ia}y	c/cy	
F-1	3646.6	-0.479	-4.157	11	0.4	0.4				12	140	12	150	
F-2	2184.12	14.148	-0.17	12	0.4	0.4				12	150	12	160	
F-3	835.36	-3.499	-0.802	15	0.4	0.4				12	180	12	190	

Figure A.1. 6: Summary of footing design before analysis and design

SUMMARY OF FOOTING DESIGN													
		Bearing Capacity=	300										
		Foundation Depth=	1.5										
		Unit weight of Soil=	18										
		Concrete C=	25										
		Number of Groups=	3										
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Group	P	Mx	My	Pcs	Cx	Cy	Lx	Ly	D	d_{iax}	c/cx	d_{ia}y	c/cy
F-1	3646.6	-0.479	-4.157	11	0.4	0.4	3.7	3.7	1.2	14	110	14	110
F-2	2184.12	14.148	-0.17	12	0.4	0.4	2.9	2.9	0.8	12	130	12	130
F-3	835.36	-3.499	-0.802	15	0.4	0.4	1.8	1.8	0.45	10	130	10	130

Figure A.1.7: Summary of footing design after analysis and design

A.1.4 DESIGN REPORT

Brief design report for each footing group is found in a separate sheet called “**Report**”. The user has to select the footing group name in the dropdown button. Figures A.1.8, to A.1.10 show brief design report for F-1, F-2 & F-3.

Footing Design						
Footing Group	F-1	C= 25				
Super-structure load, P_s (Kn)	835.36	$fcd=11.333$				
M_x (Kn-m)	-3.499					
M_y (Kn-m)	-0.802					
Column width, a * b (m)	0.40	0.4				
Foundation depth, f_d (m)	1.50					
Ultimate bearing capacity, s (Kpa)	300					
Footing Dimension, (L_x, L_y) m	1.80	1.80				
Depth, D (m)	0.45	OK				
Footing Area, A_f (m ²)	3.24					
Effective depth, d (m)	$= D - 0.05 \cdot \text{bar dia.}$	0.390				
Own Weight of Footing W_c (Kn)	$= A_f \cdot D \cdot g$	36				
Unit weight of soil g_s (Kn/m ³)	18.00					
Soil Weight, W_s (Kn)	$= (A_f - A_c) \cdot (f_d - D) \cdot g_s$	58		Area	2.17	
Total load on footing P_t (Kn)	$= P_s + W_c + W_s$	930		Perimeter	5.28	
Checking Bearing pressure (Kpa)	$= P_t / A_f$	287.0				
Max. soil pressure, Q_{max} (Kpa)	$(P/A) \cdot (1 + 6 \cdot e_y / L_x + 6 \cdot e_x / L_y) < Q_{ult}$	291.5				
Min. Soil pressure, Q_{min} (Kpa)	$(P/A) \cdot (1 - 6 \cdot e_y / L_x - 6 \cdot e_x / L_y) > 0.0$	282.6				
Tensile strength of conc. f_{ctd} (Mpa)	$0.21 \cdot (f_t)^{0.5/1.5}$	1.03				
Allowable punching resistance of concrete, V_{up} (Kn/m ²)	$0.25 \cdot f_{ctd} \cdot K_1 \cdot K_2 \cdot 10^3$	338.0				
Allowable wide beam shear resistance of concrete V_{wd} (Kn/m ²)	$0.25 \cdot f_{ctd} \cdot K_1 \cdot K_2 \cdot 10^3$	338.0				
Punching Shear, V_p (kn)	$P_s \cdot (7.07 \cdot d^2 + 3 \cdot d \cdot (a+b) + ab) \cdot Q_{act}$	546.3				
Punching Shear Stress V_{up} (Kpa)	$V_p / ((9.42 \cdot d^2 + 2 \cdot (a+b) \cdot d)$	265.5				
Wide beam Shear, V_{wv} (Kn/m)	$(P_s / A_f) \cdot (L_x / 2 - d - a / 2)$	144.2	145.5			
Wide beam Shear stress (Kn/m ²)	$V_{wv} / (b \cdot d)$	205.5	207.3			
Max Design Moment, M_d (Kn-m)	$0.25 \cdot (Q_{min} + 3 \cdot Q_{max}) \cdot ((L_x - a) / 2)^2 \cdot 0.5$	63.3	63.7			
Design yield strength (Mpa)	f_{yd}	261	261			
ρ (%)	$(1 - \sqrt{1 - (2 \cdot M_d / (1000 \cdot d^2 \cdot f_{ctd}))}) \cdot f_{ctd} / f_{yd}$	0.163	0.164			
Diameter of Steel (mm)		10	10			
Single Area, a_s (mm ²)	$\pi \cdot \text{dia.}^2 / 4$	78.54	78.54			
Area of Steel required, $A_{s,r}$ (mm ²)	$\rho \cdot b \cdot d$	634.0	638.2			
Minimum Reinforcement, $A_{s,min}$ (mm ²)	$(0.5 / f_{yk}) \cdot b \cdot d = 0.0012 \cdot b \cdot d$	650.0	650.0			
Provided Area of steel A_s (mm ²)	$\text{MAX}(\text{required}, \text{designed})$	650.0	650.0			
Spacing, S (mm)	$a_s \cdot 100 / (\rho \cdot d)$	121	121			
Allowable bond stress, f_{ctd}	$2 \cdot f_{ctd}$	2.06	2.06			
Number of bars / meter length		9.3	9.3			
Actual bond stress, $f_{act,s}$	$V / (\text{perimeter} \cdot J \cdot d)$	1.78	1.78			
Bond checking		Fbact.<Fbd, OK	Fbact.<Fbd, OK			
Adjusted spacing (mm)		140	150			
Number of bars / meter length		9	9			
Actual bond stress, $f_{act,s}$		1.78	1.78			
Bond re-checking		Fbact.<Fbd, OK	Fbact.<Fbd, OK			
k2		1.210				
k1		1.08				
rho provided		0.001666667	0.001666667			

Figure A.1.8: Brief design report of footing 1.

Footing Design					
Footing Group	F-2	C= 25			
Super-structure load, P_s (Kn)	2184.12	fcd=11.333			
M_x (Kn-m)	14.148				
M_y (Kn-m)	-0.17				
Column width, a (m) * b(m)	0.40	0.4			
Foundation depth, f_g (m)	1.50				
Ultimate bearing capacity, s (Kpa)	300				
Footing Dimension, ($L_x * L_y$) m	2.90	2.90			
Depth, D (m)	0.80	OK			
Footing Area, A_f (m ²)	8.41				
Effective depth, d (m)	= D - 0.05-bar dia.	0.738			
Own Weight of Footing, Wc (Kn)	= $A_f * D * g_c$	168			
Unit weight of soil, g_s (Kn/m ³)	18.00				
Soil Weight, Ws(Kn)	= $(A_f - A_c) * (f_g - D) * g_s$	104	Area	5.78	
Total load on footing, P_r (Kn)	= $P_s + W_c + W_s$	2456	Perimeter	8.56	
Checking Bearing pressure (Kpa)	= P_r / A	292.1			
Max. soil pressure, Qmax. (Kpa)	$(P/A) * (1 + 6 * e_x / L_x + 6 * e_y / L_y) < Q_{ult}$	295.6			
Min. Soil pressure, Qmin. (Kpa)	$(P/A) * (1 - 6 * e_x / L_x - 6 * e_y / L_y) > 0.0$	288.5			
Tensile strength of conc., f_{ctd} (Mpa)	$0.21 * (f_c) ^{0.5} / 1.5$	1.03			
Allowable punching resistance of concrete, V_{up} (Kn/m ²)	$0.25 * f_{ctd} * K_1 * K_2 * 10^3$	274.0			
Allowable wide beam shear resistance of concrete, v_{wd} (Kn/m ²)	$0.25 * f_{ctd} * K_1 * K_2 * 10^3$	274.0			
Punching Shear, V_p (kn)	$P_r * (7.07 * d^2 + 3 * d * (a + b) + ab) * Q_{act}$	1369.3			
Punching Shear Stress, V_{up} (Kpa)	$V_p / ((9.42 * d^2 + 2 * (a + b)) * d)$	216.9			
Wide beam Shear, V_w (Kn/m)	$(P_s / A_f) * (L / 2 - d - a / 2)$	385.7	389.9		
Wide beam Shear stress (Kn/m ²)	$V_{wp} / (b * d)$	180.2	182.2		
Max Design Moment, Md (Kn-m)	$0.25 * (Q_{min} + 3 * Q_{max}) * ((L - a) / 2) * 0.5$	202.9	204.4		
Design yield strength (Mpa)	f_{yd}	348	348		
ρ (%)	$(1 - \sqrt{1 - (2 * M) / (1000 * d^2 * f_{cd})}) * f_{cd} / f_{yd}$	0.109	0.110		
Diameter of Steel, (mm)		12	12		
Single Area, a_s (mm ²)	$pi * dia.^2 / 4$	113.10	113.10		
Area of Steel required, $A_{s,d}$ (mm ²)	$\rho * b * d$	809.9	810.1		
Minimum Reinforcement, $A_{s,min}$ (mm ²)	$(0.5 / f_{yk}) * b * d = 0.0012 * b * d$	922.5	922.5		
Provided Area of steel, A_s (mm ²)	MAX(required,designed)	922.5	922.5		
Spacing, S (mm)	$a_s * 100 / (\rho * d)$	123	123		
Allowable bond stress, F_{bd}	$2 * F_{ctd}$	2.06	2.06		
Number of bars / meter length		9.2	9.2		
Actual bond stress, $F_{s,act}$	$V / (\text{perimeter} * d)$	1.42	1.42		
Bond checking		Fbact.<Fbd, OK	Fbact.<Fbd, OK		
Adjusted spacing (mm)		130	130		
Number of bars / meter length		9	9		
Actual bond stress, $F_{s,act}$		1.42	1.42		
Bond re-checking		Fbact.<Fbd, OK	Fbact.<Fbd, OK		
k2		1.000			
k1		1.06			
rho provided		0.00125	0.00125		

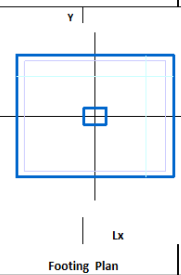


Figure A.1.9: Brief design report of footing 2.

Footing Design					
Footing Group	F-3	C=25			
Super-structure load, P _r (Kn)	835.36	fcd=11.333			
M _x (Kn-m)	-3.499				
M _y (Kn-m)	-0.802				
Column width, a (m) * b(m)	0.40	0.4			
Foundation depth, f _d (m)	1.50				
Ultimate bearing capacity, s (Kpa)	300				
Footing Dimension, {L _x * L _y } m	1.80	1.80			
Depth, D (m)	0.45	OK			
Footing Area, A _f (m ²)	3.24				
Effective depth, d (m)	= D - 0.05-bar dia.	0.390			
Own Weight of Footing, W _c (Kn)	= A _f * D * γ _c	36			
Unit weight of soil, γ _s (Kn/m ³)	18.00				
Soil Weight, W _s (Kn)	= (A _f - A _c) * (γ _s - D) * γ _s	58	Area	2.17	
Total load on footing, P _r (Kn)	= P _s + W _c + W _s	930	Perimeter	5.28	
Checking Bearing pressure, q (Kpa)	= P _r / A	287.0			
Max. soil pressure, Q _{max} (Kpa)	(P/A) * (1 + 6 * e _y / L _y + 6 * e _x / L _x) < Q _{ult}	291.5			
Min. Soil pressure, Q _{min} (Kpa)	(P/A) * (1 - 6 * e _y / L _y - 6 * e _x / L _x) > 0.0	282.6			
Tensile strength of conc., f _{ctd} (Mpa)	0.21 * (f _{ck}) ^{0.5} / 1.5	1.03			
Allowable punching resistance of concrete, V _{up} (Kn/m ²)	0.25 * f _{ctd} * K ₁ * K ₂ * 10 ³	338.0			
Allowable wide beam shear resistance of concrete, V _{wd} (Kn/m ²)	0.25 * f _{ctd} * K ₁ * K ₂ * 10 ³	338.0			
Punching Shear, V _p (kn)	P _r * (7.07 * d ² + 3 * d * (a + b) + a * b) * Q _{act}	546.3			
Punching Shear Stress, V _{up} (Kpa)	V _p / ((9.42 * d ² + 2 * (a + b) * d)	265.5			
Wide beam Shear, V _{wb} (Kn/m)	(P _s / A _f) * (L _y / 2 - d - a / 2)	144.2	145.5		
Wide beam Shear stress, v (Kn/m ²)	V _{wb} / (b * d)	205.5	207.3		
Max Design Moment, M _d (Kn-m)	0.25 * (Q _{min} + 3 * Q _{max}) * ((L _x - a) / 2) ² * 0.5	63.3	63.7		
Design yield strength, f _{yd} (Mpa)	f _{yk}	261	261		
rho (%)	((1 - SQRT(1 - (2 * M _d / (1000 * d ² * 2 * f _{ctd})))) * f _{ctd} / f _{yd}	0.163	0.164		
Diameter of Steel, φ (mm)		10	10		
Single Area, a _s (mm ²)	π * dia. ² / 4	78.54	78.54		
Area of Steel required, A _{s,d} (mm ²)	ρ * b * d	634.0	638.2		
Minimum Reinforcement, A _{s,min} (mm ²)	(0.5 / f _{yk}) * b * d = 0.0012 * b * d	650.0	650.0		
Provided Area of steel, A _s (mm ²)	MAX(required, designed)	650.0	650.0		
Spacing, S (mm)	a _s * 100 / (ρ * d)	121	121		
Allowable bond stress, E _{sb}	2 * F _{ctd}	2.06	2.06		
Number of bars / meter length		9.3	9.3		
Actual bond stress, E _{sct,s}	V / (perimeter * j * d)	1.78	1.78		
Bond checking		F _{bact} < F _{b,d} , OK	F _{bact} < F _{b,d} , OK		
Adjusted spacing (mm)		130	130		
Number of bars / meter length		9	9		
Actual bond stress, E _{sct,s}		1.78	1.78		
Bond re-checking		F _{bact} < F _{b,d} , OK	F _{bact} < F _{b,d} , OK		
k ₂		1.210			
k ₁		1.08			
rho provided		0.001666667	0.001666667		

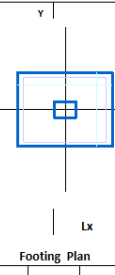


Figure A.1.10: Brief design report of footing 3.

A.1.5 BILL OF QUANTITIES

Bill of quantities for each footing group is found in a separate sheet called “*Quantity*”. The user has to select the footing group name in the dropdown button. Figure A.1.11, to A.1.13 show bill of quantities for F-1, F-2 & F-3.

Footing	F-1		Working Space		0.25								
Concrete		Steel				Lean Concrete		Formwork		Pit Excavation		Backfill	
Grade	C-25	Pos.	Xdir	Pos.	Ydir	Grade	C-5	Pcs.	11	Pcs.	11	Pcs.	11
Pcs.	11	Pcs.	11	Pcs.	11	Pcs.	11	L	3.7	L	4.2	L	4.2
L	3.7	No	35	No	35	L	4.2	B	3.7	B	4.2	B	4.2
B	3.7	L	5.8	L	5.8	B	4.2	D	0.7	D	1.5	D	1.5
D	0.7	Dia	14	Dia	14	m ²	194.04	m ²	113.96	m ³	291.06	m ³	185.65
m ³	105.41	Kg	2698.39	Kg	2698.39								
						5396.78							

Figure A.1.11: Bill of quantities for footing 1.

Footing	F-2		Working Space		0.25								
Concrete		Steel				Lean Concrete		Formwork		Pit Excavation		Backfill	
Grade	C-25	Pos.	Xdir	Pos.	Ydir	Grade	C-5	Pcs.	12	Pcs.	12	Pcs.	12
Pcs.	12	Pcs.	12	Pcs.	12	Pcs.	12	L	2.9	L	3.4	L	3.4
L	2.9	No	23	No	23	L	3.4	B	2.9	B	3.4	B	3.4
B	2.9	L	4.2	L	4.2	B	3.4	D	0.7	D	1.5	D	1.5
D	0.7	Dia	12	Dia	12	m ²	138.72	m ²	97.44	m ³	208.08	m ³	137.44
m ³	70.64	Kg	1029.15	Kg	1029.15								
						2058.31							

Figure A.1.12: Bill of quantities for footing 2.

Footing	F-3		Working Space		0.25								
Concrete		Steel				Lean Concrete		Formwork		Pit Excavation		Backfill	
Grade	C-25	Pos.	Xdir	Pos.	Ydir	Grade	C-5	Pcs.	15	Pcs.	15	Pcs.	15
Pcs.	15	Pcs.	15	Pcs.	15	Pcs.	15	L	1.8	L	2.3	L	2.3
L	1.8	No	15	No	15	L	2.3	B	1.8	B	2.3	B	2.3
B	1.8	L	2.4	L	2.4	B	2.3	D	0.7	D	1.5	D	1.5
D	0.7	Dia	10	Dia	10	m ²	79.35	m ²	75.60	m ³	119.03	m ³	85.01
m ³	34.02	Kg	332.93	Kg	332.93								
						665.86							

Figure A.1.13: Bill of quantities for footing 3.

A.1.6 DETAILED DRAWINGS

The input data for drawing isolated footings is copied from the worksheet “*Report*”. Figure A.1.14 shows input data for the drawing process.

F-1	Depth of Footing			1.20
Footing Width		Column Width		
X-Dir	Y-Dir	X-Dir	Y-Dir	
3.70	3.70	0.40	0.4	
Reinforcement X-Dir		Reinforcement Y-Dir		
Diam	Spacing	Diam	Spacing	
14	110	14	110	

F-2	Depth of Footing			0.30
Footing Width		Column Width		
X-Dir	Y-Dir	X-Dir	Y-Dir	
2.90	2.90	0.40	0.4	
Reinforcement X-Dir		Reinforcement Y-Dir		
Diam	Spacing	Diam	Spacing	
12	130	12	130	

F-3	Depth of Footing			0.45
Footing Width		Column Width		
X-Dir	Y-Dir	X-Dir	Y-Dir	
1.30	1.30	0.40	0.4	
Reinforcement X-Dir		Reinforcement Y-Dir		
Diam	Spacing	Diam	Spacing	
10	130	10	130	

Figure A.1.14: Input data for drawings.

To produce working drawings first run the macro “*Isolated.dvb*” in AutoCAD 2007. Then the input data is pasted. Clicking “Run” automatically produces detailed drawings as shown in figure A.1.15.

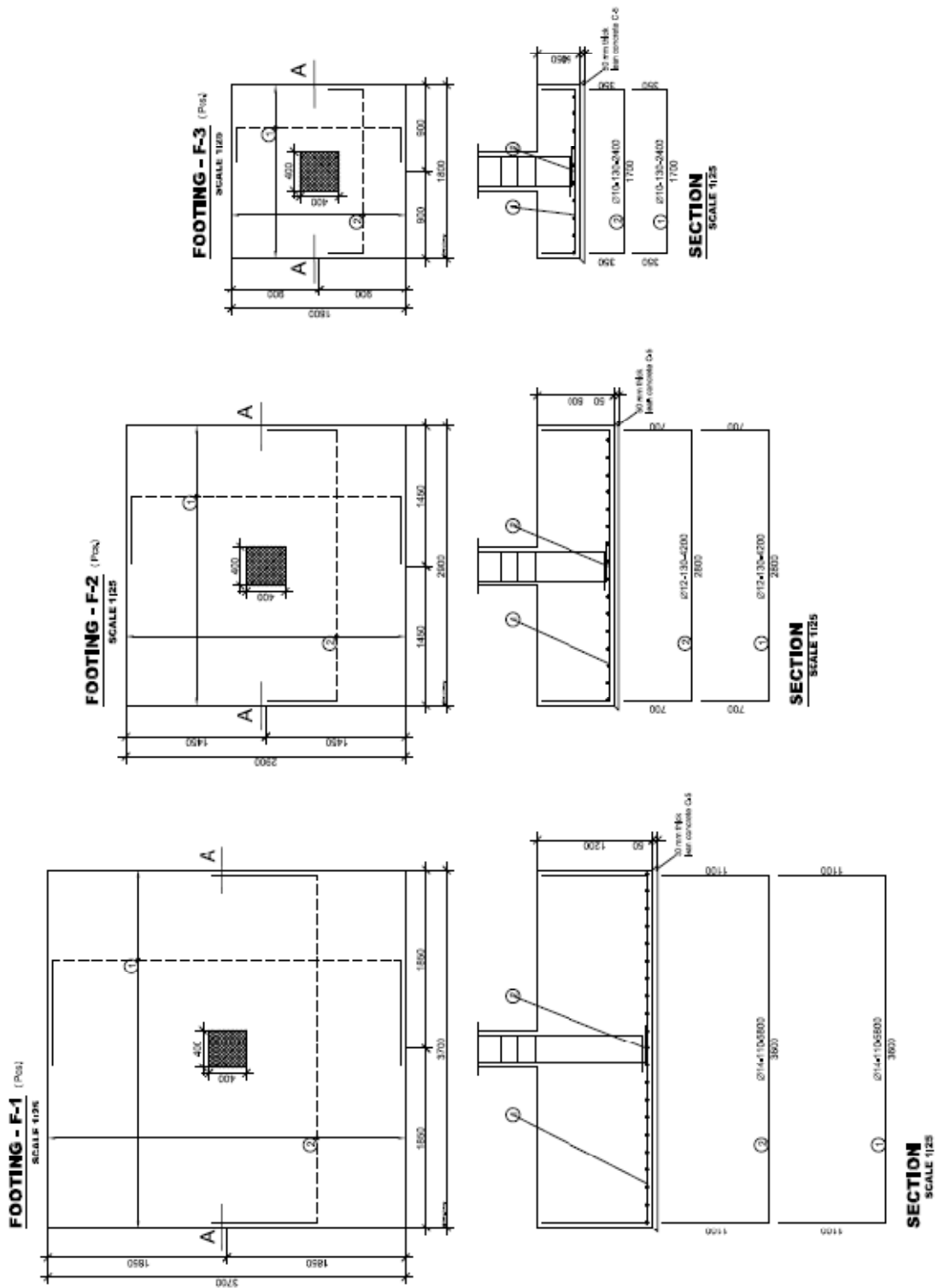


Figure A.1.15: Detailed drawings produced by the software.

APPENDIX 2- SOLVED EXAMPLE FOR COMBINED FOOTINGS

Appendix 2 solves an actual problem of combined footing by using the programs developed by this thesis. A typical problem of combined footing includes analysis and design, report writing, quantifying, and producing detailed drawings.

A.2.1 INPUT DATA

The basic input data for design of combined footings are.

1. Unfactored foundation Reactions.

$$P1=1795.66 \quad Mx=4.711 \quad My=6.489$$

$$P2=2918.82 \quad Mx=4.174 \quad My=4.591$$

2. Center to center between columns =5m
3. Allowable bearing capacity of supporting soil = 300kpa.
4. Column dimensions 0.4m x 0.4m.
5. Foundation depth =1.5m
6. Unit weight of backfill material =18kN/m³
7. L_1 , in our case the boundary is not close to column 1. Therefore the software should determine optimum value for L_1 .
8. Use C-25 concrete and S-300 steel if diameter of reinforcement is less than 12mm otherwise take S-400.

A.2.2 ANALYSIS AND DESIGN

After all input data is entered; clicking the “**Run**” button designs the footing for a given L_f . The “*optimize*” button is used to determine L_f if the user has the freedom to choose L_f .

A.2.3 DESIGN REPORT

Figure A.2.1 shows a brief design report of combined footings.

A.2.4 BILL OF QUANTITIES

Figure A.2.2 shows bill of quantities for combined footings.

Combined Footing				CF-1	Working Space	0.5	Pcs.	1		
Concrete		Lean Concrete		Formwork		Pit Excavation		Backfill		
C-	25	Grade	C-5	Pcs.	1	Pcs.	1	Pcs.	1	
Pcs.	1	Pcs.	1	L	7.8	L	8.8	L	8.8	
L	7.8	L	8.8	B	2.3	B	3.3	B	3.3	
B	2.3	B	3.3	D	1.25	D	1.5	D	1.5	
D	1.25	m ²	29.04	m ²	25.25	m ³	43.56	m ³	21.14	
m ³	22.43									

Steel				
Pos.	Xdir top	X dir bott	y dir top	y dir bott
Pcs.	1	1	1	1
No	24	19	61	61
L	10	10	4.5	4.5
Dia	16	16	16	16
Kg	378.80	299.88	433.25	433.25
	1545.19			

Figure A.2.2: Bill of Quantities

A.2.5 WORKING DRAWING

The input data for drawing combined footings is copied from the worksheet “*Design*”. Figure A.2.3 shows input data for the drawing process.

To produce working drawings first the macro “Combined.dvb” must be run in AutoCAD 2007. Then the input data is pasted. Clicking “*Run*” automatically produces detailed drawings as shown in figure A.2.4.

CF-1	Depth of Footing		1.25	
Footing Dimension				
X-Dir	Y-Dir	CC	L1	
7.80	2.30	5.00	0.80	
Column 2 Width		Column 1 Width		
X-Dir	Y-Dir	X-Dir	Y-Dir	
0.40	0.4	0.40	0.4	
Reinf. X-Dir-top		Reinf. Y-Dir top		
Diam	Spacing	Diam	Spacing	
16	100	16	130	
Reinf. X-Dir-bottom		Reinf. Y-Dir bottom		
Diam	Spacing	Diam	Spacing	
16	130	16	130	

Figure A.2.3: Input data for producing working drawing

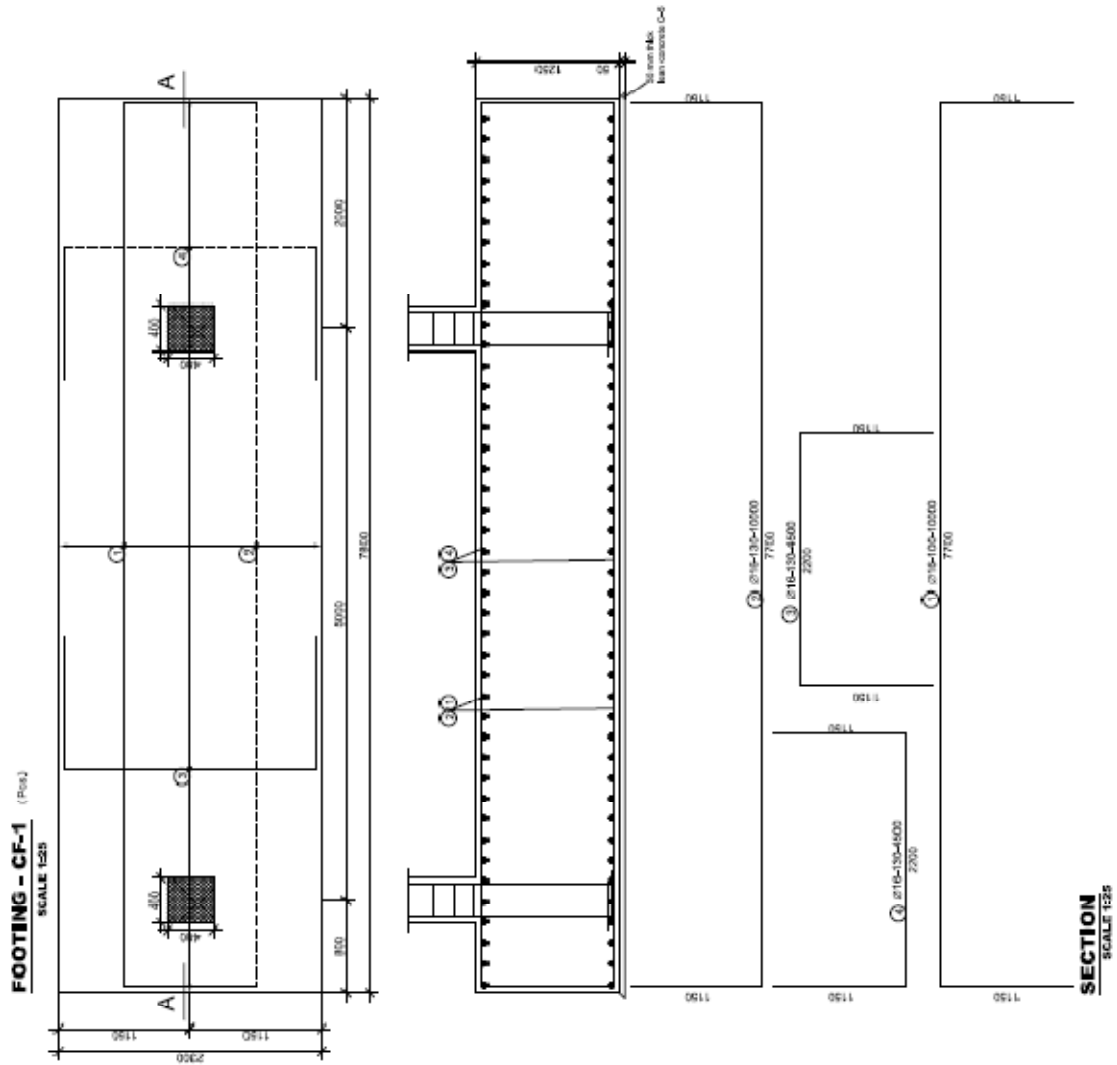


Figure A.2.4: Working drawing produced by software.

APPENDIX 3- SOLVED EXAMPLE FOR STRAP FOOTINGS

Appendix 3 solves an actual problem of a strap footing by using the programs developed by this thesis. A typical problem of strap footing includes analysis and design, report writing, quantifying, and producing detailed drawings.

A.3.1 INPUT DATA

The basic input data for design of strap footings are.

1. Unfactored foundation Reactions

$$P1=503.9 \quad Mx=1.25 \quad My=0.896$$

$$P2=805.25 \quad Mx=1.35 \quad My=0.28$$

2. Center to center between columns =4.7m
3. Allowable bearing capacity of supporting soil = 400kpa.
4. Column dimensions 0.25m x 0.4m.
5. Foundation depth =2m
6. Unit weight of backfill material =18kN/m³
7. Use C-25 concrete and S-300 steel if diameter of reinforcement is less than 12mm otherwise take S-400.

A.3.2 ANALYSIS AND DESIGN

After all input data is entered; clicking the “**Run**” button designs the footing for a given L_f . The “**optimize**” button is used to determine L_f so that minimum cost of material is acquired.

A.3.3 DESIGN REPORT

Figure A.3.1 shows a brief design report of strap footings.

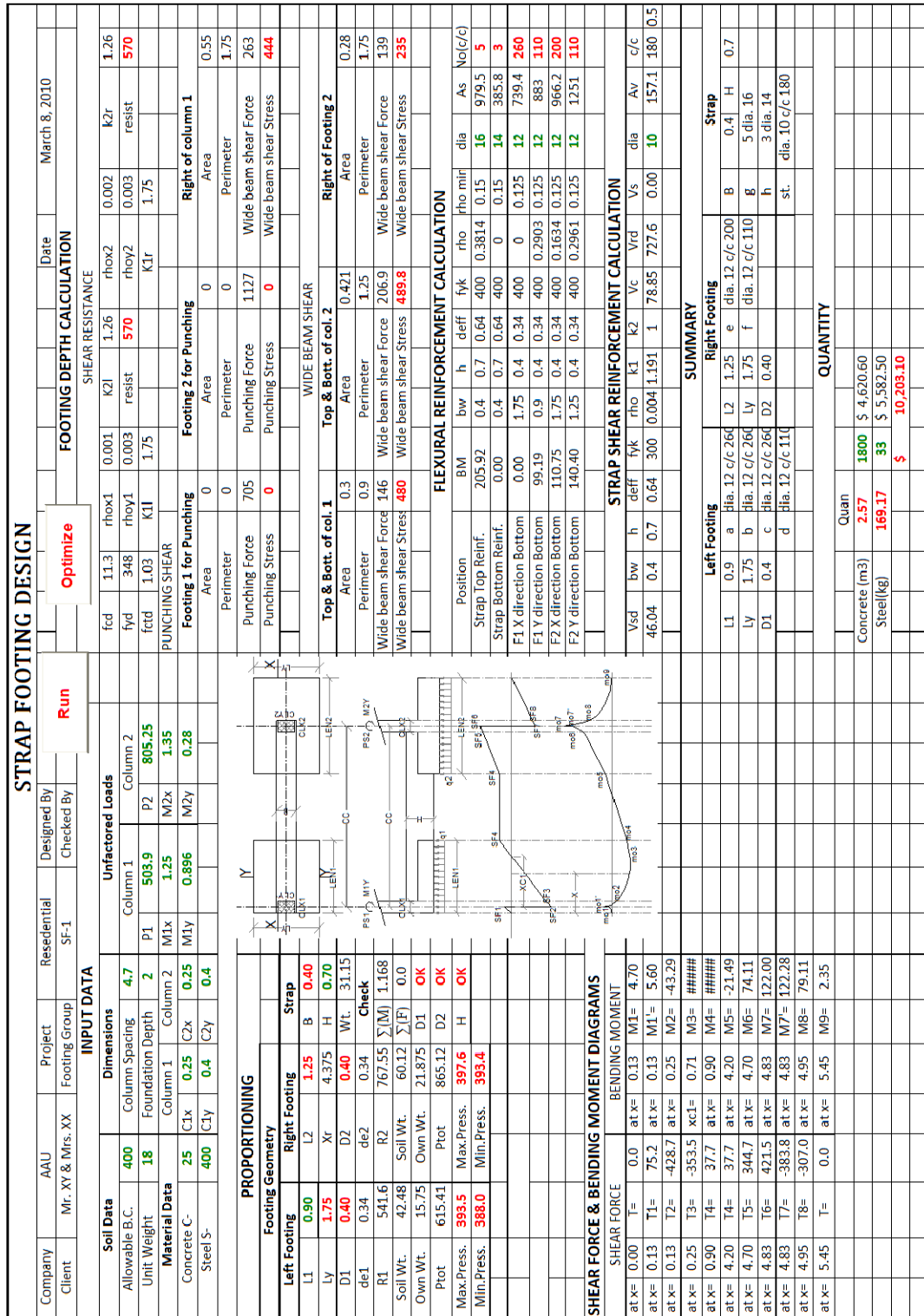


Figure A.3.1: Brief design report.

A.3.4 BILL OF QUANTITIES

Figure A.3.2 shows bill of quantities for strap footings.

concrete							
Foting 1		Foting 2		Strap			
Pcs.	1	Pcs.	1	Pcs.	1		
L	0.9	L	1.25	L	4.45		
B	1.75	B	1.75	B	0.4		
D	0.4	D	0.4	D	0.7		
m ³	0.63	m ³	0.88	m ³	1.06	2.57	

Formwork							
Footing 1		Footing 2		Strap			
Pcs.	1	Pcs.	1	Pcs.	1		
L	0.9	L	1.25	L	4.45		
B	1.75	B	1.75	B	0.4		
D	0.4	D	0.4	D	0.7		
m ²	2.12	m ²	2.40	m ²	5.31	9.83	

C-5 lean concrete							
Footing 1		Footing 2		Strap			
Pcs.	1	Pcs.	1	Pcs.	1		
L	0.9	L	1.25	L	3.3		
B	1.75	B	1.75	B	0.4		
m ²	1.58	m ²	2.19	m ²	1.32	5.08	

Pit excavation							
Footing 1		Footing 2		Strap			
Pcs.	1	Pcs.	1	Pcs.	1		
L	1.4	L	1.75	L	3.3		
B	2.25	B	2.25	B	0.9		
D	2	D	2	D	2		
m ³	6.30	m ³	7.88	m ³	5.94	20.12	

Backfill							
Footing 1		Footing 2		Strap			
pit	6.30	Pcs.	7.88	Pcs.	5.94		
concrete	0.63	L	0.88	L	1.06		
m ³	5.67	m ³	7.00	m ³	4.88	17.55	

Steel								
Pos.	F1 Xdir	F1 Y dir	F2 Xdir	F2 Y dir	Top Strap	bott strap	stirrup	
Pcs.	1	1	1	1	1	1	1	
No	8	9	10	12	5	3	26	
L	1.4	2.25	1.75	2.25	6.05	6.05	2	
Dia	12	12	12	12	16	14	10	
Kg	9.94	17.98	15.54	23.97	47.74	21.93	32.06	169.17

Figure A.3.2: Bill of Quantities

A.3.5 WORKING DRAWING

The input data for drawing strap footings is copied from the worksheet “*Design*”. Figure A.3.3 shows input data for the drawing process.

To produce working drawings first the macro “strap.dvb” must be run in AutoCAD 2007. Then the input data is pasted. Clicking “*Run*” automatically produces detailed drawings as shown in figure A.3.4.

SF-1	Depth 1	0.40	Depth 2	0.40	Spacing bn columns	4.70	
Footing 1 Width		Column1 Width		Footing2 Width		Column2 Width	
X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir
0.90	1.75	0.25	0.4	1.25	1.75	0.25	0.4
Reinf. X-Dir F1		Reinf. Y-Dir F1		Reinf. X-Dir F2		Reinf. Y-Dir F2	
Diam	Spacing	Diam	Spacing	Diam	Spacing	Diam	Spacing
12	260	12	110	12	200	12	110
Strap Dimensions		Strap top Reinf.		Strap Bottom Reinf.		Strap Stirrup.	
Width	Depth	No.	Diam	No.	Diam	Diam	Spacing
0.40	0.70	5	16	3	14	10	180

Figure A.3.3: Input data for producing working drawing

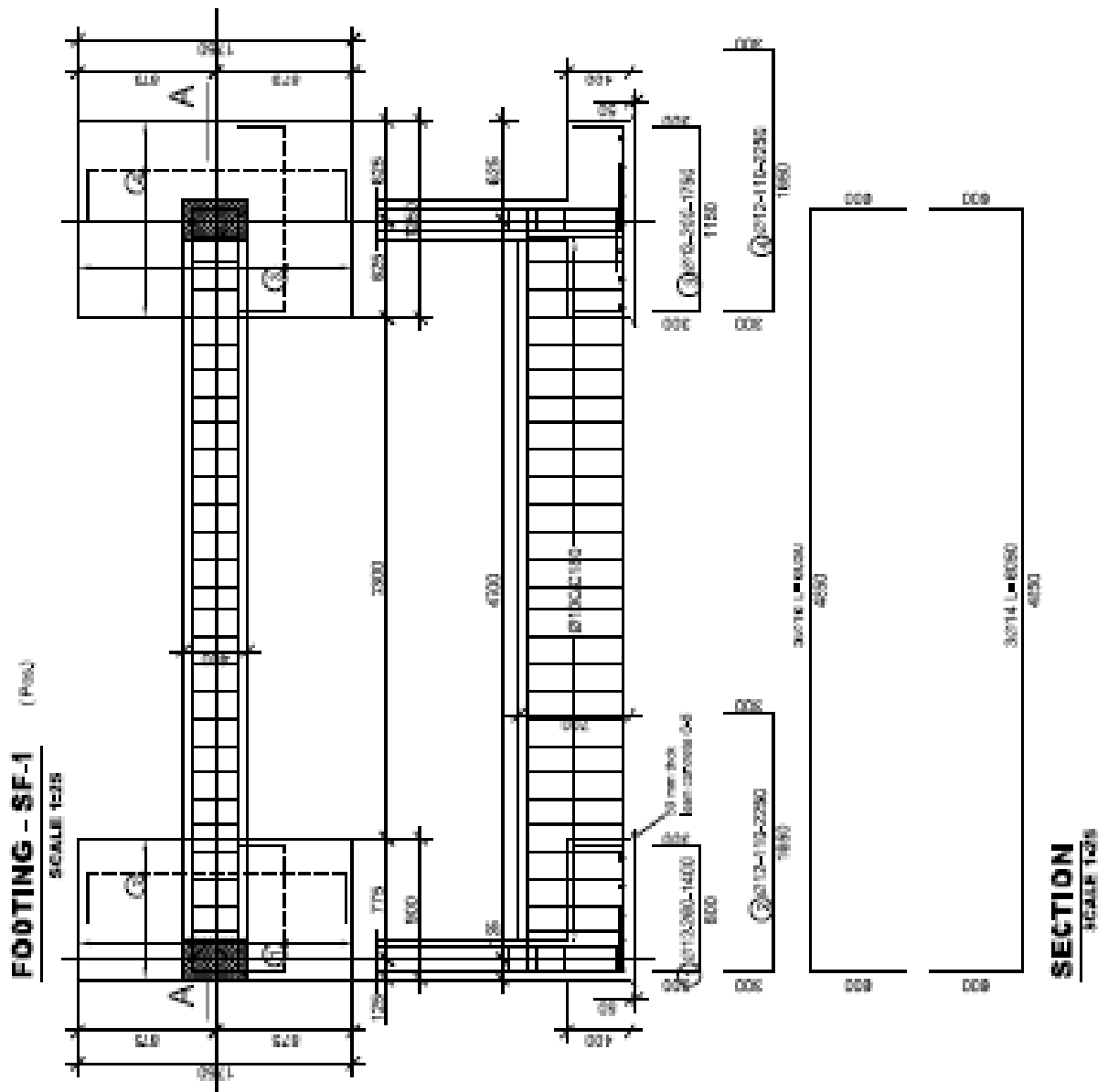


Figure A.3.4: Working drawing produced by software.

APPENDIX 4- SAMPLE VISUAL BASIC CODE FOR COMBINED FOOTINGS

A.4.1 MACRO FOR EXCEL

```
Private Sub CommandButton1_Click()
    quan = 10000000000#
    For i = 1 To 30
        Worksheets(1).Cells(15, 3).Value = Worksheets(1).Cells(9, 6).Value / 2 + 0.05 * (i - 1)
    For j = 1 To 100
        Worksheets(1).Cells(19, 3).Value = 0.1 + 0.05 * (j - 1)
    If Worksheets("Design").Cells(19, 4).Value = "OK" Then GoTo Here
    Next j
    Here:
    If quan > Worksheets(1).Cells(44, 20).Value Then quan = Worksheets(1).Cells(44, 20).Value: 11
    = Worksheets(1).Cells(9, 6).Value / 2 + 0.05 * (i - 1)
    Next i
    Worksheets(1).Cells(15, 3).Value = 11
    For j = 1 To 100
        Worksheets(1).Cells(19, 3).Value = 0.1 + 0.05 * (j - 1)
    If Worksheets("Design").Cells(19, 4).Value = "OK" Then GoTo here2
    Next j
    here2:
    End Sub

Private Sub CommandButton2_Click()
    For j = 1 To 100
        Worksheets(1).Cells(19, 3).Value = 0.1 + 0.05 * (j - 1)
    If Worksheets("Design").Cells(19, 4).Value = "OK" Then GoTo Here
    Next j
    Here:
    End Sub
```

A.4.2 MACRO FOR AUTOCAD 2007

Private Sub CommandButton1_Click()

'On Error GoTo err

Dim wfx, wfy, df, wcx, wcy, sc As Double

If mm.Value = True Then sc = 1000

If cm.Value = True Then sc = 100

If m.Value = True Then sc = 10

'Width of footing in the x direction

wfx = Sp1.Cells(4, 1) * sc

'Width of footing in the y direction

wfy = Sp1.Cells(4, 2) * sc

'depth of footing

df = Sp1.Cells(1, 4) * sc

'Width of footing in the x direction

xcol = Sp1.Cells(4, 3) * sc

'Width of footing in the y direction

ycol = Sp1.Cells(4, 4) * sc

Dim lineObj As AcadLine

Dim startPoint(0 To 2) As Double: Dim st(0 To 2) As Double

Dim endPoint(0 To 2) As Double

Dim center(0 To 2) As Double

Dim points(0 To 9) As Double: Dim pt(0 To 3) As Double: Dim point(0 To 7) As Double

Dim mtextObj As AcadMText

Dim insertionPoint(0 To 2) As Double

Dim height As Double

Dim newTextStyle As AcadTextStyle

Bold = False

Dim Bold2 As Boolean

SavetypeFace = typeFace

```
typeFace = "Arial"  
ThisDrawing.ActiveTextStyle.SetFont typeFace, _  
    Bold, Italic, Charset, PitchandFamily
```

```
Dim scaleFactor As Double
```

```
Set newTextStyle = ThisDrawing.TextStyles.Add("TITLE")
```

```
Set newTextStyle = ThisDrawing.TextStyles.Add("bartext")
```

```
ThisDrawing.ActiveTextStyle.SetFont typeFace, Bold, Italic, Charset, PitchandFamily
```

```
ThisDrawing.ActiveTextStyle = newTextStyle
```

```
'Layer assigning
```

```
Dim layerObj2 As AcadLayer
```

```
Set layerObj2 = ThisDrawing.Layers.Add("BAR-OUT")
```

```
'color for the layer
```

```
Dim color2 As New AcadAcCmColor
```

```
Call color2.SetRGB(255, 0, 255)
```

```
layerObj2.TrueColor = color2
```

```
'line type for the layer
```

```
Dim entry As AcadLineType
```

```
Dim found As Boolean
```

```
found = False
```

```
For Each entry In ThisDrawing.Linetypes
```

```
    If StrComp(entry.Name, "HIDDEN", 1) = 0 Then
```

```
        found = True
```

```
        Exit For
```

```
    End If
```

```
Next
```

```
If Not (found) Then ThisDrawing.Linetypes.Load "HIDDEN", "acad.lin"
```

```
layerObj2.Linetype = "HIDDEN"
```

```
layerObj2.Lineweight = acLnWt053
```

```
Set layerObj2 = ThisDrawing.Layers.Add("FOUND")
Call color2.SetRGB(0, 255, 255)
layerObj2.TrueColor = color2
layerObj2.Linetype = "Continuous"
layerObj2.Lineweight = acLnWt040
```

```
Set layerObj2 = ThisDrawing.Layers.Add("Footing3")
Call color2.SetRGB(0, 255, 0)
layerObj2.TrueColor = color2
layerObj2.Linetype = "Continuous"
layerObj2.Lineweight = acLnWt040
```

```
Set layerObj2 = ThisDrawing.Layers.Add("DIM")
Call color2.SetRGB(255, 0, 0)
layerObj2.TrueColor = color2
layerObj2.Linetype = "Continuous"
layerObj2.Lineweight = acLnWt005
```

```
Set layerObj2 = ThisDrawing.Layers.Add("Section")
Call color2.SetRGB(255, 255, 0)
layerObj2.TrueColor = color2
layerObj2.Linetype = "Continuous"
layerObj2.Lineweight = acLnWt025
```

```
Set layerObj2 = ThisDrawing.Layers.Add("Hatch")
Call color2.SetRGB(128, 128, 128)
layerObj2.TrueColor = color2
layerObj2.Linetype = "Continuous"
layerObj2.Lineweight = acLnWt000
```

```
Set layerObj2 = ThisDrawing.Layers.Add("BAR-IN")
Call color2.SetRGB(192, 192, 192)
layerObj2.TrueColor = color2
```

```
layerObj2.Linetype = "Continuous"  
layerObj2.Lineweight = acLnWt020
```

```
Set layerObj2 = ThisDrawing.Layers.Add("Rebar")  
Call color2.SetRGB(255, 255, 255)  
layerObj2.TrueColor = color2  
layerObj2.Linetype = "Continuous"  
layerObj2.Lineweight = acLnWt050
```

```
Set layerObj2 = ThisDrawing.Layers.Add("Rebar")  
Call color2.SetRGB(255, 255, 255)  
layerObj2.TrueColor = color2  
layerObj2.Linetype = "Continuous"  
layerObj2.Lineweight = acLnWt050
```

```
Set layerObj2 = ThisDrawing.Layers.Add("TEXT")  
Call color2.SetRGB(0, 255, 0)  
layerObj2.TrueColor = color2  
layerObj2.Linetype = "Continuous"  
layerObj2.Lineweight = acLnWt025
```

```
Set layerObj2 = ThisDrawing.Layers.Add("Lead")  
Call color2.SetRGB(128, 128, 128)  
layerObj2.TrueColor = color2  
layerObj2.Linetype = "Continuous"  
layerObj2.Lineweight = acLnWt020
```

```
Set layerObj2 = ThisDrawing.Layers.Add("TEX")  
Call color2.SetRGB(255, 255, 0)  
layerObj2.TrueColor = color2  
layerObj2.Linetype = "Continuous"  
layerObj2.Lineweight = acLnWt000
```

```
Dim dimObj As AcadDimAligned
```

Set newDimStyle = ThisDrawing.DimStyles.Add("SPACING")

ThisDrawing.ActiveDimStyle = newDimStyle

startPoint(0) = 0: startPoint(1) = 0: startPoint(2) = 0

endPoint(0) = wfx: endPoint(1) = 0: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = 0: startPoint(1) = 0: startPoint(2) = 0

endPoint(0) = 0: endPoint(1) = wfy: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = 0: startPoint(1) = wfy: startPoint(2) = 0

endPoint(0) = wfx: endPoint(1) = wfy: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx: startPoint(1) = 0: startPoint(2) = 0

endPoint(0) = wfx: endPoint(1) = wfy: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx * 3 / 4: startPoint(1) = 0.05 * sc: startPoint(2) = 0

endPoint(0) = wfx * 3 / 4: endPoint(1) = wfy - 0.05 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0.15

startPoint(0) = wfx * 3 / 4: startPoint(1) = wfy - 0.05 * sc: startPoint(2) = 0

endPoint(0) = wfx * 3 / 4 - df + 0.1 * sc: endPoint(1) = wfy - 0.05 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0

startPoint(0) = wfx * 3 / 4: startPoint(1) = 0.05 * sc: startPoint(2) = 0

endPoint(0) = wfx * 3 / 4 - df + 0.1 * sc: endPoint(1) = 0.05 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0

startPoint(0) = 0.05 * sc: startPoint(1) = wfy / 4: startPoint(2) = 0

endPoint(0) = wfx - 0.05 * sc: endPoint(1) = wfy / 4: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0.15

startPoint(0) = wfx - 0.05 * sc: startPoint(1) = wfy / 4: startPoint(2) = 0

endPoint(0) = wfx - 0.05 * sc: endPoint(1) = wfy / 4 + df - 0.1 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0

startPoint(0) = 0.05 * sc: startPoint(1) = wfy / 4: startPoint(2) = 0

endPoint(0) = 0.05 * sc: endPoint(1) = wfy / 4 + df - 0.1 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0

pt(0) = -0.25 * sc: pt(1) = wfy / 2 + 0.05 * sc:

pt(2) = 0.25 * sc: pt(3) = wfy / 2 + 0.05 * sc:

Set pline = ThisDrawing.ModelSpace.AddLightWeightPolyline(pt): pline.Layer = "TEX":

pline.ConstantWidth = 0.0085 * sc

pt(0) = wfx - 0.25 * sc: pt(1) = wfy / 2 + 0.05 * sc

pt(2) = wfx + 0.25 * sc: pt(3) = wfy / 2 + 0.05 * sc

Set pline = ThisDrawing.ModelSpace.AddLightWeightPolyline(pt): pline.Layer = "TEX":

pline.ConstantWidth = 0.0085 * sc

startPoint(0) = 0: startPoint(1) = wfy * 3 / 4: startPoint(2) = 0

endPoint(0) = wfx: endPoint(1) = wfy * 3 / 4: endPoint(2) = 0

Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, startPoint)

dimObj.DimensionLineColor = acByLayer: dimObj.Arrowhead1Type = acArrowDefault:

dimObj.Arrowhead2Type = acArrowDefault: dimObj.Layer = "DIM":

```
dimObj.ArrowheadSize = 0.07 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.01: dimObj.TextHeight = 0.03
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
dimObj.TextHeight = 0.001: dimObj.TextStyle = "bartext"
dimObj.ArrowheadSize = 0.075 * sc
dimObj.VerticalTextPosition = acOutside

startPoint(0) = wfx / 4: startPoint(1) = 0: startPoint(2) = 0
endPoint(0) = wfx / 4: endPoint(1) = wfy: endPoint(2) = 0
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, startPoint)
dimObj.DimensionLineColor = acByLayer: dimObj.Arrowhead1Type = acArrowDefault:
dimObj.Arrowhead2Type = acArrowDefault: dimObj.Layer = "DIM":
dimObj.ArrowheadSize = 0.07 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.01: dimObj.TextHeight = 0.03
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
dimObj.TextHeight = 0.001
dimObj.ArrowheadSize = 0.075 * sc
dimObj.VerticalTextPosition = acOutside
```

.....

'THE HATCHED CIRCLES

.....

```
TextString = "00"
typeFace = "Arial"
Dim hatchObj As AcadHatch
Dim patternName As String
Dim PatternType As Long
Dim bAssociativity As Boolean
patternName = "SOLID"
PatternType = 0
bAssociativity = True

Dim radius As Double
```

Dim circleObj As AcadCircle

radius = 0.016 * sc

Dim outerLoop(0 To 0) As AcadEntity

startPoint(0) = wfx / 4: startPoint(1) = wfy / 4: startPoint(2) = 0

Set hatchObj = ThisDrawing.ModelSpace.AddHatch(PatternType, patternName, bAssociativity)

Set outerLoop(0) = ThisDrawing.ModelSpace.AddCircle(startPoint, radius)

hatchObj.Layer = "DIM"

outerLoop(0).Layer = "DIM"

hatchObj.AppendOuterLoop (outerLoop)

hatchObj.Evaluate

ThisDrawing.Regen True

startPoint(0) = wfx / 4 * 3: startPoint(1) = wfy / 4 * 3: startPoint(2) = 0

Set hatchObj = ThisDrawing.ModelSpace.AddHatch(PatternType, patternName, bAssociativity)

Set outerLoop(0) = ThisDrawing.ModelSpace.AddCircle(startPoint, radius)

hatchObj.Layer = "DIM"

outerLoop(0).Layer = "DIM"

hatchObj.AppendOuterLoop (outerLoop)

hatchObj.Evaluate

ThisDrawing.Regen True

radius2 = 0.07 * sc

startPoint(0) = wfx / 4 * 1 - radius2: startPoint(1) = wfy / 4 * 1 + radius2: startPoint(2) = 0

Set circleObj = ThisDrawing.ModelSpace.AddCircle(startPoint, radius2): circleObj.Layer = "DIM"

TextString = "2"

startPoint(0) = wfx / 4 * 1 - radius2 - 0.016 * sc: startPoint(1) = wfy / 4 * 1 + radius2 + 0.032 * sc: startPoint(2) = 0

Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)

scalefactor = 0.075 / 0.2 * sc

mtextObj.ScaleEntity startPoint, scalefactor

```
mtextObj.Layer = "TEX"
.
radius2 = 0.07 * sc
startPoint(0) = wfx / 4 * 3 - radius2: startPoint(1) = wfy / 4 * 3 + radius2: startPoint(2) = 0
Set circleObj = ThisDrawing.ModelSpace.AddCircle(startPoint, radius2): circleObj.Layer =
"DIM"

TextString = "1"
startPoint(0) = wfx / 4 * 3 - radius2 - 0.01 * sc: startPoint(1) = wfy / 4 * 3 + radius2 + 0.03 * sc:
startPoint(2) = 0
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
scalefactor = 0.075 / 0.2 * sc
mtextObj.ScaleEntity startPoint, scalefactor
mtextObj.Layer = "TEX"

center(0) = wfx / 2
center(1) = wfy / 2
center(2) = 0

'Layer assigning
Dim layerObj6 As AcadLayer
Set layerObj6 = ThisDrawing.Layers.Add("HATCH")

'color for the layer
Dim color3 As New AcadAcCmColor
Call color3.SetRGB(128, 128, 128)
layerObj6.TrueColor = color3

'line type for the layer
Dim entry2 As AcadLineType
Dim found2 As Boolean
found2 = False
For Each entry2 In ThisDrawing.Linetypes
    If StrComp(entry2.Name, "ACAD_ISO02W100", 1) = 0 Then
```

```
        found2 = True
    Exit For
End If
Next
If Not (found2) Then ThisDrawing.Linetypes.Load "ACAD_ISO02W100", "acad.lin"
layerObj6.Linetype = "Continuous"

Dim layerObj7 As AcadLayer
Set layerObj7 = ThisDrawing.Layers.Add("CON")
Call color3.SetRGB(0, 255, 0)

layerObj7.TrueColor = color3

points(0) = center(0) - xcol / 2: points(1) = center(1) + ycol / 2
points(2) = center(0) + xcol / 2: points(3) = center(1) + ycol / 2
points(4) = center(0) + xcol / 2: points(5) = center(1) - ycol / 2
points(6) = center(0) - xcol / 2: points(7) = center(1) - ycol / 2
points(8) = center(0) - xcol / 2: points(9) = center(1) + ycol / 2
' Define the hatch
patternName = "ANSI37"
PatternType = 0
bAssociativity = True

' Create the associative Hatch object
Set hatchObj = ThisDrawing.ModelSpace.AddHatch(PatternType, patternName, bAssociativity)
Set outerLoop(0) = ThisDrawing.ModelSpace.AddLightWeightPolyline(points)
hatchObj.ISOPenWidth = acPenWidthUnk
hatchObj.PatternScale = 250 / 1000 * sc
hatchObj.Layer = "HATCH"
outerLoop(0).Layer = "CON"
hatchObj.AppendOuterLoop (outerLoop)
hatchObj.Evaluate
ThisDrawing.Regen True
```

.....
'section
.....

startPoint(0) = 0: startPoint(1) = -1.35 * sc - df: startPoint(2) = 0

endPoint(0) = wfx: endPoint(1) = -1.35 * sc - df: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =
"FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = 0: startPoint(1) = -1.35 * sc - df: startPoint(2) = 0

endPoint(0) = 0: endPoint(1) = -1.35 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =
"FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx: startPoint(1) = -1.35 * sc - df: startPoint(2) = 0

endPoint(0) = wfx: endPoint(1) = -1.35 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =
"FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = 0: startPoint(1) = -1.35 * sc: startPoint(2) = 0

endPoint(0) = wfx / 2 - xcol / 2: endPoint(1) = -1.35 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =
"FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx: startPoint(1) = -1.35 * sc: startPoint(2) = 0

endPoint(0) = wfx / 2 + xcol / 2: endPoint(1) = -1.35 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =
"FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx / 2 + xcol / 2: startPoint(1) = -1.35 * sc: startPoint(2) = 0

endPoint(0) = wfx / 2 + xcol / 2: endPoint(1) = -1.35 * sc + 0.6 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =
"FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx / 2 - xcol / 2: startPoint(1) = -1.35 * sc: startPoint(2) = 0

```
endPoint(0) = wfx / 2 - xcol / 2: endPoint(1) = -1.35 * sc + 0.6 * sc: endPoint(2) = 0
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =
"FOUND": lineObj.LinetypeScale = 0.1
.
startPoint(0) = wfx / 2 - xcol / 2 + 0.05 * sc: startPoint(1) = -1.35 * sc + 0.075 * sc - df:
startPoint(2) = 0
endPoint(0) = wfx / 2 - xcol / 2 + 0.05 * sc: endPoint(1) = -1.35 * sc + 0.6 * sc: endPoint(2) = 0
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-
OUT": lineObj.LinetypeScale = 0.001
.
startPoint(0) = wfx / 2 + xcol / 2 - 0.05 * sc: startPoint(1) = -1.35 * sc + 0.1 * sc - df:
startPoint(2) = 0
endPoint(0) = wfx / 2 + xcol / 2 - 0.05 * sc: endPoint(1) = -1.35 * sc + 0.6 * sc: endPoint(2) = 0
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-
OUT": lineObj.LinetypeScale = 0.001
.
startPoint(0) = wfx / 2 - xcol / 2 + 0.05 * sc: startPoint(1) = -1.35 * sc + 0.075 * sc - df:
startPoint(2) = 0
endPoint(0) = wfx / 2 - xcol / 2 + xcol + 0.05 * sc: endPoint(1) = -1.35 * sc + 0.075 * sc - df:
endPoint(2) = 0
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-
OUT": lineObj.LinetypeScale = 0.001
.
startPoint(0) = wfx / 2 + xcol / 2 - 0.05 * sc: startPoint(1) = -1.35 * sc + 0.1 * sc - df:
startPoint(2) = 0
endPoint(0) = wfx / 2 + xcol / 2 - xcol - 0.05 * sc: endPoint(1) = -1.35 * sc + 0.1 * sc - df:
endPoint(2) = 0
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-
OUT": lineObj.LinetypeScale = 0.001
.
startPoint(0) = wfx / 2 - xcol / 2 + 0.05 * sc: startPoint(1) = -1.35 * sc + 0.025 * sc: startPoint(2)
= 0
```

endPoint(0) = wfx / 2 + xcol / 2 - 0.05 * sc: endPoint(1) = -1.35 * sc + 0.025 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-IN": lineObj.LinetypeScale = 0.001

startPoint(0) = wfx / 2 - xcol / 2 + 0.05 * sc: startPoint(1) = -1.35 * sc + 0.025 * sc + 0.17 * sc * 1: startPoint(2) = 0

endPoint(0) = wfx / 2 + xcol / 2 - 0.05 * sc: endPoint(1) = -1.35 * sc + 0.025 * sc + 0.17 * sc * 1: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-IN": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx / 2 - xcol / 2 + 0.05 * sc: startPoint(1) = -1.35 * sc + 0.025 * sc + 0.17 * sc * 2: startPoint(2) = 0

endPoint(0) = wfx / 2 + xcol / 2 - 0.05 * sc: endPoint(1) = -1.35 * sc + 0.025 * sc + 0.17 * sc * 2: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-IN": lineObj.LinetypeScale = 0.1

startPoint(0) = wfx / 2 - xcol / 2 - 0.075 * sc: startPoint(1) = -1.35 * sc + 0.6 * sc: startPoint(2) = 0

endPoint(0) = wfx / 2 + xcol / 2 + 0.075 * sc: endPoint(1) = -1.35 * sc + 0.6 * sc: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "Hatch": lineObj.LinetypeScale = 0.1

startPoint(0) = -0.05 * sc: startPoint(1) = -1.4 * sc - df: startPoint(2) = 0

endPoint(0) = wfx + 0.05 * sc: endPoint(1) = -1.4 * sc - df: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "FOUND": lineObj.LinetypeScale = 0.1

startPoint(0) = -0.05 * sc: startPoint(1) = -1.4 * sc - df: startPoint(2) = 0

endPoint(0) = 0: endPoint(1) = -1.35 * sc - df: endPoint(2) = 0

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =  
"FOUND": lineObj.LinetypeScale = 0.1
```

```
startPoint(0) = wfx: startPoint(1) = -1.35 * sc - df: startPoint(2) = 0
```

```
endPoint(0) = wfx + 0.05 * sc: endPoint(1) = -1.4 * sc - df: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer =  
"FOUND": lineObj.LinetypeScale = 0.1
```

```
startPoint(0) = 0.05 * sc: startPoint(1) = -1.3 * sc - df: startPoint(2) = 0
```

```
endPoint(0) = wfx - 0.05 * sc: endPoint(1) = -1.3 * sc - df: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-  
OUT": lineObj.LinetypeScale = 0
```

```
startPoint(0) = 0.05 * sc: startPoint(1) = -1.3 * sc - df: startPoint(2) = 0
```

```
endPoint(0) = 0.05 * sc: endPoint(1) = -1.3 * sc + df - 0.1 * sc - df: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-  
OUT": lineObj.LinetypeScale = 0
```

```
startPoint(0) = wfx - 0.05 * sc: startPoint(1) = -1.3 * sc - df: startPoint(2) = 0
```

```
endPoint(0) = wfx - 0.05 * sc: endPoint(1) = -1.3 * sc + df - 0.1 * sc - df: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-  
OUT": lineObj.LinetypeScale = 0
```

```
radius = 0.008 * sc
```

```
For i = 0 To (wfx - 0.1 * sc) / (0.18 * sc)
```

```
startPoint(0) = 0.05 * sc + radius + 0.18 * sc * i: startPoint(1) = -1.3 * sc + radius - df:
```

```
startPoint(2) = 0
```

```
Set hatchObj = ThisDrawing.ModelSpace.AddHatch(PatternType, patternName, bAssociativity)
```

```
Set outerLoop(0) = ThisDrawing.ModelSpace.AddCircle(startPoint, radius)
```

```
hatchObj.Layer = "BAR-OUT"
```

```
outerLoop(0).Layer = "BAR-OUT"
```

```
hatchObj.AppendOuterLoop (outerLoop)
```

```
hatchObj.Evaluate
```

ThisDrawing.Regen True

Next i

.....

Text

.....

TextString = "A"

startPoint(0) = -0.17 * sc: startPoint(1) = wfy / 2 + 0.29 * sc: startPoint(2) = 0

Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)

scalefactor = 0.15 / 0.2 * sc

mtextObj.ScaleEntity startPoint, scalefactor

mtextObj.Layer = "TEXT"

startPoint(0) = wfx + 0.08 * sc: startPoint(1) = wfy / 2 + 0.29 * sc: startPoint(2) = 0

Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)

scalefactor = 0.15 / 0.2 * sc

mtextObj.ScaleEntity startPoint, scalefactor

mtextObj.Layer = "TEXT"

radius2 = 0.07 * sc

startPoint(0) = wfx / 3 * 2 - radius2: startPoint(1) = -1.1 * sc: startPoint(2) = 0

Set circleObj = ThisDrawing.ModelSpace.AddCircle(startPoint, radius2): circleObj.Layer = "DIM"

.

TextString = "2"

startPoint(0) = wfx / 3 * 2 - radius2 - 0.016 * sc: startPoint(1) = -1.1 * sc + 0.032 * sc:

startPoint(2) = 0

Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)

scalefactor = 0.075 / 0.2 * sc

mtextObj.ScaleEntity startPoint, scalefactor

mtextObj.Layer = "TEX"

.

radius2 = 0.07 * sc

startPoint(0) = wfx / 3 - radius2: startPoint(1) = -1.1 * sc: startPoint(2) = 0

```
Set circleObj = ThisDrawing.ModelSpace.AddCircle(startPoint, radius2): circleObj.Layer = "DIM"
```

```
TextString = "1"
```

```
startPoint(0) = wfx / 3 - radius2 - 0.01 * sc: startPoint(1) = -1.1 * sc + 0.03 * sc: startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.075 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
startPoint(0) = wfx / 3 - radius2: startPoint(1) = -1.1 * sc: startPoint(2) = 0
```

```
endPoint(0) = 0.18 * sc * 2.5: endPoint(1) = -1.3 * sc - df: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "Lead":
```

```
lineObj.LinetypeScale = 0.1
```

```
startPoint(0) = wfx / 3 * 2 - radius2: startPoint(1) = -1.1 * sc: startPoint(2) = 0
```

```
endPoint(0) = 0.18 * sc * wfx / 1000 / 0.18 / 2: endPoint(1) = -1.3 * sc + 0.008 * sc - df:
```

```
endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "Lead":
```

```
lineObj.LinetypeScale = 0.1
```

```
.....  
"DIMENSION  
.....
```

```
endPoint(0) = 0: endPoint(1) = 0: endPoint(2) = 0
```

```
startPoint(0) = 0: startPoint(1) = wfy: startPoint(2) = 0
```

```
st(0) = 0 - 0.52 * sc: st(1) = wfy: st(2) = 0
```

```
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
```

```
'dimObj.VerticalTextPosition = acVertCentered
```

```
dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:
```

```
dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
' dimObj.TextRotation = 3.14 / 2

If mm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
End If

If cm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
End If

If m.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
End If

endPoint(0) = 0: endPoint(1) = 0: endPoint(2) = 0
startPoint(0) = 0: startPoint(1) = wfy / 2: startPoint(2) = 0
st(0) = 0 - 0.32 * sc: st(1) = wfy: st(2) = 0
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:
dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
If mm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
End If

If cm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
End If

If m.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
```

End If

endPoint(0) = 0: endPoint(1) = wfy: endPoint(2) = 0

startPoint(0) = 0: startPoint(1) = wfy / 2: startPoint(2) = 0

st(0) = 0 - 0.32 * sc: st(1) = wfy: st(2) = 0

Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)

dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:

dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":

dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:

dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc

dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc

If mm.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionZero

End If

If cm.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionOne

End If

If m.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionThree

End If

endPoint(0) = 0: endPoint(1) = -0# * sc: endPoint(2) = 0

startPoint(0) = wfx: startPoint(1) = -0# * sc: startPoint(2) = 0

st(0) = wfx: st(1) = -0.42 * sc: st(2) = 0

Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)

dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:

dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":

dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:

dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc

dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc

If mm.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionZero

```
End If
If cm.Value = True Then
    dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
End If
If m.Value = True Then
    dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
End If
endPoint(0) = 0: endPoint(1) = -0# * sc: endPoint(2) = 0
startPoint(0) = wfx / 2: startPoint(1) = -0# * sc: startPoint(2) = 0
st(0) = wfx: st(1) = -0.21 * sc: st(2) = 0
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
    dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:
dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":
    dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
    dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
If mm.Value = True Then
    dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
End If
If cm.Value = True Then
    dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
End If
If m.Value = True Then
    dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
End If
endPoint(0) = wfx: endPoint(1) = -0# * sc: endPoint(2) = 0
startPoint(0) = wfx / 2: startPoint(1) = -0# * sc: startPoint(2) = 0
st(0) = wfx: st(1) = -0.21 * sc: st(2) = 0
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
    dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:
dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
If mm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
End If
If cm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
End If
If m.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
End If

endPoint(0) = wfx / 2 - xcol / 2: endPoint(1) = wfy / 2 + ycol / 2: endPoint(2) = 0
startPoint(0) = wfx / 2 + xcol / 2: startPoint(1) = wfy / 2 + ycol / 2: startPoint(2) = 0
st(0) = wfx / 2 + xcol / 2: st(1) = wfy / 2 + ycol / 2 + 0.06 * sc: st(2) = 0
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:
dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
If mm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
End If
If cm.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
End If
If m.Value = True Then
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
End If
```

```
endPoint(0) = wfx / 2 - xcol / 2: endPoint(1) = wfy / 2 - ycol / 2: endPoint(2) = 0
startPoint(0) = wfx / 2 - xcol / 2: startPoint(1) = wfy / 2 + ycol / 2: startPoint(2) = 0
st(0) = wfx / 2 - xcol / 2 - 0.06 * sc: st(1) = wfy / 2 + ycol / 2: st(2) = 0
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:
dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":
    dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
    dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
    If mm.Value = True Then
        dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
    End If
    If cm.Value = True Then
        dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
    End If
    If m.Value = True Then
        dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
    End If
.
```

```
endPoint(0) = wfx: endPoint(1) = -1.35 * sc - df: endPoint(2) = 0
startPoint(0) = wfx: startPoint(1) = -1.35 * sc: startPoint(2) = 0
st(0) = wfx + 0.32 * sc: st(1) = -1.35 * sc: st(2) = 0
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:
dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":
    dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
    dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
    If mm.Value = True Then
        dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
    End If
```

If cm.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionOne

End If

If m.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionThree

End If

endPoint(0) = wfx: endPoint(1) = -1.35 * sc - df: endPoint(2) = 0

startPoint(0) = wfx: startPoint(1) = -1.4 * sc - df: startPoint(2) = 0

st(0) = wfx + 0.32 * sc: st(1) = -1.4 * sc - df: st(2) = 0

Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)

dimObj.DimensionLineColor = acRed: dimObj.Arrowhead1Type = acArrowOblique:

dimObj.Arrowhead2Type = acArrowOblique: dimObj.Layer = "TEX":

dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:

dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc

dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc

If mm.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionZero

End If

If cm.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionOne

End If

If m.Value = True Then

dimObj.PrimaryUnitsPrecision = acDimPrecisionThree

End If

.....
'dimension
.....

startPoint(0) = 0.05 * sc: startPoint(1) = -1.35 * sc - df * 2: startPoint(2) = 0

endPoint(0) = wfx - 0.05 * sc: endPoint(1) = -1.35 * sc - df * 2: endPoint(2) = 0

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0
```

```
st(0) = 0.05 * sc: st(1) = -1.35 * sc - df * 2 - 0.12 * sc: st(2) = 0
```

```
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
```

```
dimObj.DimLine1Suppress = True: dimObj.DimLine2Suppress = True:
```

```
dimObj.ExtLine1Suppress = True: dimObj.ExtLine2Suppress = True: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
```

```
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
```

```
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
```

```
dimObj.TextRotation = 3.14
```

```
If mm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
```

```
End If
```

```
If cm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
```

```
End If
```

```
If m.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
```

```
End If
```

```
startPoint(0) = wfx - 0.05 * sc: startPoint(1) = -1.35 * sc - df * 2: startPoint(2) = 0
```

```
endPoint(0) = wfx - 0.05 * sc: endPoint(1) = -1.35 * sc - df * 2 + df - 0.1 * sc: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-OUT": lineObj.LinetypeScale = 0
```

```
st(0) = wfx + 0.05 * sc: st(1) = -1.35 * sc - df * 2: st(2) = 0
```

```
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
```

```
dimObj.DimLine1Suppress = True: dimObj.DimLine2Suppress = True:
```

```
dimObj.ExtLine1Suppress = True: dimObj.ExtLine2Suppress = True: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
```

```
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
```

```
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
```

```
If mm.Value = True Then  
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
```

```
End If
```

```
If cm.Value = True Then  
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
```

```
End If
```

```
If m.Value = True Then  
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
```

```
End If
```

```
startPoint(0) = 0.05 * sc: startPoint(1) = -1.35 * sc - df * 2: startPoint(2) = 0
```

```
endPoint(0) = 0.05 * sc: endPoint(1) = -1.35 * sc - df * 2 + df - 0.1 * sc: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-  
OUT": lineObj.LinetypeScale = 0
```

```
st(0) = 0.02 * sc: st(1) = -1.35 * sc - df * 2: st(2) = 0
```

```
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
```

```
dimObj.DimLine1Suppress = True: dimObj.DimLine2Suppress = True:
```

```
dimObj.ExtLine1Suppress = True: dimObj.ExtLine2Suppress = True: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
```

```
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
```

```
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
```

```
If mm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
```

```
End If
```

```
If cm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
```

```
End If
```

```
If m.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
```

```
End If
```

```
TextString = "%C" & Sp1.Cells(7, 1) & "-" & Sp1.Cells(7, 2) & "-" & wfx / 1 + 2 * df / 1 - 0.3  
* sc / 1
```

```
startPoint(0) = wfx / 2 - 0.333 * sc: startPoint(1) = -1.35 * sc - df * 2 + radius2 + 0.05 * sc:
```

```
startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.075 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
startPoint(0) = 0.05 * sc: startPoint(1) = -1.35 * sc - df * 3: startPoint(2) = 0
```

```
endPoint(0) = wfy - 0.05 * sc: endPoint(1) = -1.35 * sc - df * 3: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-  
OUT": lineObj.LinetypeScale = 0
```

```
st(0) = 0.05 * sc: st(1) = -1.35 * sc - df * 3 - 0.12 * sc: st(2) = 0
```

```
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
```

```
dimObj.DimLine1Suppress = True: dimObj.DimLine2Suppress = True:
```

```
dimObj.ExtLine1Suppress = True: dimObj.ExtLine2Suppress = True: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
```

```
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
```

```
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
```

```
If mm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
```

```
End If
```

```
If cm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
```

```
End If
```

```
If m.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
```

```
End If
```

```
startPoint(0) = wfy - 0.05 * sc: startPoint(1) = -1.35 * sc - df * 3: startPoint(2) = 0
```

```
endPoint(0) = wfy - 0.05 * sc: endPoint(1) = -1.35 * sc - df * 3 + df - 0.1 * sc: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-  
OUT": lineObj.LinetypeScale = 0
```

```
st(0) = wfy + 0.05 * sc: st(1) = -1.35 * sc - df * 3: st(2) = 0
```

```
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
```

```
dimObj.DimLine1Suppress = True: dimObj.DimLine2Suppress = True:
```

```
dimObj.ExtLine1Suppress = True: dimObj.ExtLine2Suppress = True: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
```

```
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
```

```
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
```

```
If mm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
```

```
End If
```

```
If cm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
```

```
End If
```

```
If m.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
```

```
End If
```

```
startPoint(0) = 0.05 * sc: startPoint(1) = -1.35 * sc - df * 3: startPoint(2) = 0
```

```
endPoint(0) = 0.05 * sc: endPoint(1) = -1.35 * sc - df * 3 + df - 0.1 * sc: endPoint(2) = 0
```

```
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "BAR-  
OUT": lineObj.LinetypeScale = 0
```

```
st(0) = 0.02 * sc: st(1) = -1.35 * sc - df * 3: st(2) = 0
```

```
Set dimObj = ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)
```

```
dimObj.DimLine1Suppress = True: dimObj.DimLine2Suppress = True:
```

```
dimObj.ExtLine1Suppress = True: dimObj.ExtLine2Suppress = True: dimObj.Layer = "TEX":
```

```
dimObj.ArrowheadSize = 0.075 * sc: dimObj.ExtensionLineColor = acRed:
```

```
dimObj.ExtensionLineExtend = 0.07 * sc: dimObj.TextHeight = 0.075 * sc
```

```
dimObj.VerticalTextPosition = acAbove: dimObj.DimensionLineExtend = 0.075 * sc
```

```
If mm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionZero
```

```
End If
```

```
If cm.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
```

```
End If
```

```
If m.Value = True Then
```

```
dimObj.PrimaryUnitsPrecision = acDimPrecisionThree
```

```
End If
```

```
TextString = "%C" & Sp1.Cells(7, 3) & "-" & Sp1.Cells(7, 4) & "-" & (wfy + 2 * df - 0.3 * sc) / 1
```

```
startPoint(0) = wfy / 2 - 0.333 * sc: startPoint(1) = -1.35 * sc - df * 3 + radius2 + 0.05 * sc:
```

```
startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.075 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
radius2 = 0.07 * sc
```

```
startPoint(0) = wfx / 4 - radius2: startPoint(1) = -1.35 * sc - df * 3 + radius2: startPoint(2) = 0
```

```
Set circleObj = ThisDrawing.ModelSpace.AddCircle(startPoint, radius2): circleObj.Layer = "DIM"
```

```
TextString = "1"
```

```
startPoint(0) = wfx / 4 - radius2 - 0.01 * sc: startPoint(1) = -1.35 * sc - df * 3 + radius2 + 0.03 * sc: startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.075 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
startPoint(0) = wfx / 4 - radius2: startPoint(1) = -1.35 * sc - df * 2 + radius2: startPoint(2) = 0
```

```
Set circleObj = ThisDrawing.ModelSpace.AddCircle(startPoint, radius2): circleObj.Layer = "DIM"
```

```
TextString = "2"
```

```
startPoint(0) = wfx / 4 - radius2 - 0.01 * sc: startPoint(1) = -1.35 * sc - df * 2 + radius2 + 0.03 * sc: startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.075 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
TextString = t1 & t2 & t3 & t4 & t5 & t6 & t7 & t8
```

```
startPoint(0) = 0: startPoint(1) = -0.35 * sc: startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.02 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
TextString = wfx * wfy * df / sc / sc / sc & "m3 of Concrete"
```

```
startPoint(0) = 0: startPoint(1) = -0.38 * sc: startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.02 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
TextString = wfx * 2 / sc * df / sc + wfy * df / sc / sc * 2 & "m2 of formwork"
```

```
startPoint(0) = 0: startPoint(1) = -0.41 * sc: startPoint(2) = 0
```

```
Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)
```

```
scalefactor = 0.02 / 0.2 * sc
```

```
mtextObj.ScaleEntity startPoint, scalefactor
```

```
mtextObj.Layer = "TEX"
```

```
TextString = "50 mm thick"
```

startPoint(0) = wfx + 0.145 * sc: startPoint(1) = -1.4 * sc - 0.18 * sc - df: startPoint(2) = 0

Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)

scalefactor = 0.06 / 0.2 * sc

mtextObj.ScaleEntity startPoint, scalefactor

mtextObj.Layer = "TEX"

TextString = "lean concrete C-5"

startPoint(0) = wfx + 0.145 * sc: startPoint(1) = -1.4 * sc - 0.18 * sc - 0.1 * sc - df: startPoint(2)

= 0

Set mtextObj = ThisDrawing.ModelSpace.AddMText(startPoint, height, TextString)

scalefactor = 0.06 / 0.2 * sc

mtextObj.ScaleEntity startPoint, scalefactor

mtextObj.Layer = "TEX"

startPoint(0) = wfx + 0.145 * sc: startPoint(1) = -1.4 * sc - 0.18 * sc - df: startPoint(2) = 0

endPoint(0) = wfx: endPoint(1) = -1.38 * sc - df: endPoint(2) = 0

Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, endPoint): lineObj.Layer = "Lead":

lineObj.LinetypeScale = 0.1

|
height = 0.2

TextString = "(Pcs.)"

startPoint(0) = 1.4 * sc: startPoint(1) = wfy + 0.285 * sc: startPoint(2) = 0

Set textObj = ThisDrawing.ModelSpace.AddText(TextString, startPoint, height)

scalefactor = 0.075 / 0.2 * sc

textObj.ScaleEntity startPoint, scalefactor

textObj.Layer = "TEX"

|
Set newTextStyle = ThisDrawing.TextStyles.Add("TITLE")

ThisDrawing.ActiveTextStyle = newTextStyle

typeFace = "Arial Black"

ThisDrawing.ActiveTextStyle.SetFont typeFace, Bold, Italic, Charset, PitchandFamily

|
TextString = "%%UFOOTING - " & Sp1.Cells(1, 1)

```
startPoint(0) = 0: startPoint(1) = wfy + 0.285 * sc: startPoint(2) = 0
Set textObj = ThisDrawing.ModelSpace.AddText(TextString, startPoint, height)
scalefactor = 0.125 / 0.2 * sc
textObj.ScaleEntity startPoint, scalefactor
textObj.Layer = "TEXT"
TextString = "SCALE 1:25"
startPoint(0) = 0.65 * sc: startPoint(1) = wfy + 0.1 * sc: startPoint(2) = 0
Set textObj = ThisDrawing.ModelSpace.AddText(TextString, startPoint, height)
scalefactor = 0.075 / 0.2 * sc
textObj.ScaleEntity startPoint, scalefactor
textObj.Layer = "TEXT"
TextString = "%USECTION"
startPoint(0) = 0: startPoint(1) = -1.7 * sc - df * 3: startPoint(2) = 0
Set textObj = ThisDrawing.ModelSpace.AddText(TextString, startPoint, height)
scalefactor = 0.125 / 0.2 * sc
textObj.ScaleEntity startPoint, scalefactor
textObj.Layer = "TEXT"
TextString = "SCALE 1:25"
startPoint(0) = 0.3 * sc: startPoint(1) = -1.85 * sc - df * 3: startPoint(2) = 0
Set textObj = ThisDrawing.ModelSpace.AddText(TextString, startPoint, height)
scalefactor = 0.075 / 0.2 * sc
textObj.ScaleEntity startPoint, scalefactor
textObj.Layer = "TEXT"
ZoomAll
End
Exit Sub
err:
MsgBox ("Error")
End
Resume Next
End Sub
```

|

Bibliography

1. *Designers Manual*. Osney Mead, Oxford: Blackwell Science.
2. Draycott, T. (1990). *Structural Elements Design manual*. Oxford: Butterworth Heinemany.
3. *Ethiopian Building Code Standard BASIS OF DESIGN AND ACTIONS ON STRUCTURES*. (1995). Addis Ababa: 1995.
4. *Ethiopian Building Code Standard FOUNDATIONS*. (1995). Addis Ababa: Ministry of Works & Urban Development.
5. *Ethiopian Building Code Standard STRUCTURAL USE OF CONCRETE*. (1995). Addis Ababa: Wnistry of Works & Urban Development.
6. Hodgkinson, A. (1986). *Foundation Design*. Architectural Press Ltd.
7. Joseph E. Bowles, P. (1997). *Foundation Analysis and Design*. Peoria, Illions: The McGraw-Hill Companies, Inc.
8. Teferra, A. (1992). *Foundation Engineering*. Addis Ababa: Addis Ababa University Press.
9. W., F. C., & J., Y. R. (2003). *The Civil Engineering Handbook Second Edition*. Boca Raton London New York Washington, D.C.: CRC Press.
10. W., G. C., G., S., G., I. P., & J., M. G. (1994). *Structural Foundation Designers Manual*. Osney Mead, Oxford: Blackwell Science.