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

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May, 2011
Addis Ababa, Ethiopia
Addis Ababa University
School of Graduate Studies
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Last but not least...my last word of thanks goes to God.
Contents

ACKNOWLEDGEMENT .......................................................................................................................... i

List of figures ...................................................................................................................................... vi

List of tables ....................................................................................................................................... viii

ABSTRACT ......................................................................................................................................... ix

LIST OF SYMBOLS ........................................................................................................................... x

1 INTRODUCTION ............................................................................................................................ 1

1.1 Background ................................................................................................................................ 1

1.2 Problem Statement ...................................................................................................................... 1

1.3 Aim and Objectives ...................................................................................................................... 2

1.4 Scope of Study ............................................................................................................................... 2

1.5 Thesis Outline ............................................................................................................................... 2

2 LITERATURE REVIEW .................................................................................................................. 4

2.1 INTRODUCTION ........................................................................................................................ 4

Foundations: Definition .................................................................................................................... 4

Foundations: Classification .............................................................................................................. 4

Foundations: General Requirements .............................................................................................. 4

Shallow Foundations: Types ............................................................................................................ 4

2.2 REVIEW OF EBCS ..................................................................................................................... 5

2.2.1 UNIT WEIGHT OF CONCRETE ............................................................................................. 5

2.2.2 CLASSIFICATION OF CONCRETE WORKS ....................................................................... 5

2.2.3 GRADES OF CONCRETE .................................................................................................... 5

2.2.4 CHARACTERISTIC COMPRRESSIVE STRENGTH OF CONCRETE .................................... 5

2.2.5 CHARACTERISTIC TENSILE STRENGTH OF CONCRETE ................................................... 6

2.2.6 CHARACTERISTIC PROPERTIES OF REINFORCING STEEL ............................................ 6

2.2.7 DESIGN STRENGTH ............................................................................................................. 6

2.2.8 ACTIONS ON STRUCTURES ............................................................................................... 7
2.2.9 COMBINATION OF ACTIONS ................................................................. 7
2.2.10 DESIGN OF FLEXURAL REINFORCEMENT .............................................. 8
2.2.11 DESIGN OF SHEAR REINFORCEMENT .................................................. 8
2.2.12 PUNCHING ......................................................................................... 10
2.2.13 FOOTINGS ......................................................................................... 14
2.2.14 DETAILING PROVISIONS ................................................................. 16

3 DESIGN OF RECTANGULAR ISOLATED FOOTINGS ................................. 19

3.1 INTRODUCTION .................................................................................... 19
3.2 ASSUMPTIONS AND LIMITATIONS ....................................................... 19
3.3 LIST OF SYMBOLS SPECIFIC TO SECTION 3 ......................................... 19
3.4 PROCEDURES ....................................................................................... 20
3.5 PROPORTIONING OF FOOTINGS ......................................................... 20
3.6 DETERMINATION OF FOOTING THICKNESS ......................................... 22
  3.6.1 CHECKING FOOTING THICKNESS FOR PUNCHING SHEAR ............... 22
  3.6.2 CHECKING FOOTING THICKNESS FOR WIDE BEAM SHEAR .......... 25
3.7 REINFORCEMENT CALCULATIONS ...................................................... 26
3.8 DEVELOPMENT LENGTH CALCULATION .............................................. 27
3.9 THE SPREADSHEET PROGRAM ............................................................ 29
3.10 CONCLUSIONS ON SECTION 3 ............................................................ 33

4 DESIGN OF RECTANGULAR COMBINED FOOTINGS ............................... 34

4.1 INTRODUCTION .................................................................................... 34
4.2 ASSUMPTIONS AND LIMITATIONS ....................................................... 34
4.3 LIST OF SYMBOLS SPECIFIC TO SECTION 4 ......................................... 34
4.4 PROCEDURES ....................................................................................... 35
4.5 PROPORTIONING OF FOOTINGS .......................................................... 35
4.6 SHEAR FORCE AND BENDING MOMENT DIAGRAMS ............................ 38
4.7 DETERMINATION OF FOOTING THICKNESS ......................................... 41
<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1.3</td>
<td>ANALYSIS AND DESIGN</td>
<td>94</td>
</tr>
<tr>
<td>A.1.4</td>
<td>DESIGN REPORT</td>
<td>94</td>
</tr>
<tr>
<td>A.1.5</td>
<td>BILL OF QUANTITIES</td>
<td>98</td>
</tr>
<tr>
<td>A.1.6</td>
<td>DETAILED DRAWINGS</td>
<td>98</td>
</tr>
<tr>
<td>APPENDIX 2</td>
<td>SOLVED EXAMPLE FOR COMBINED FOOTINGS</td>
<td>101</td>
</tr>
<tr>
<td>A.2.1</td>
<td>INPUT DATA</td>
<td>101</td>
</tr>
<tr>
<td>A.2.2</td>
<td>ANALYSIS AND DESIGN</td>
<td>101</td>
</tr>
<tr>
<td>A.2.3</td>
<td>DESIGN REPORT</td>
<td>101</td>
</tr>
<tr>
<td>A.2.4</td>
<td>BILL OF QUANTITIES</td>
<td>103</td>
</tr>
<tr>
<td>A.2.5</td>
<td>WORKING DRAWING</td>
<td>103</td>
</tr>
<tr>
<td>APPENDIX 3</td>
<td>SOLVED EXAMPLE FOR STRAP FOOTINGS</td>
<td>105</td>
</tr>
<tr>
<td>A.3.1</td>
<td>INPUT DATA</td>
<td>105</td>
</tr>
<tr>
<td>A.3.2</td>
<td>ANALYSIS AND DESIGN</td>
<td>105</td>
</tr>
<tr>
<td>A.3.3</td>
<td>DESIGN REPORT</td>
<td>105</td>
</tr>
<tr>
<td>A.3.4</td>
<td>BILL OF QUANTITIES</td>
<td>107</td>
</tr>
<tr>
<td>A.3.5</td>
<td>WORKING DRAWING</td>
<td>108</td>
</tr>
<tr>
<td>APPENDIX 4</td>
<td>SAMPLE VISUAL BASIC CODE FOR COMBINED FOOTINGS</td>
<td>110</td>
</tr>
<tr>
<td>A.4.1</td>
<td>MACRO FOR EXCEL</td>
<td>110</td>
</tr>
<tr>
<td>A.4.2</td>
<td>MACRO FOR AUTOCAD 2007</td>
<td>111</td>
</tr>
</tbody>
</table>
# List of figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1</td>
<td>Critical section for shear</td>
<td>9</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Application of Punching Provisions in Non-Standard Cases</td>
<td>11</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Critical Section Remote from a Free Edge</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Critical Section in a vicinity of an opening</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Critical Section near free edges</td>
<td>13</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Rectangular isolated footings</td>
<td>20</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Pressure distributions under isolated footing</td>
<td>21</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Critical areas for punching</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Average pressures acting on the critical area</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Critical areas for punching (Case-1)</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>Critical areas for punching (Case-2)</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Critical areas for punching (Case-3)</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Critical areas for punching (Case-4)</td>
<td>25</td>
</tr>
<tr>
<td>Figure 3.9</td>
<td>Critical areas for wide beam shear</td>
<td>26</td>
</tr>
<tr>
<td>Figure 3.10</td>
<td>General look of the worksheet called “Summary”</td>
<td>30</td>
</tr>
<tr>
<td>Figure 3.11</td>
<td>Input data for the drawing process</td>
<td>30</td>
</tr>
<tr>
<td>Figure 3.12</td>
<td>General look of the worksheet called “Report”</td>
<td>31</td>
</tr>
<tr>
<td>Figure 3.13</td>
<td>General look of the worksheet called “Quantity”</td>
<td>32</td>
</tr>
<tr>
<td>Figure 3.14</td>
<td>When “isolated.dvb” is run in AutoCAD2007</td>
<td>32</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Rectangular combined footings</td>
<td>36</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Pressure distributions under combined footing</td>
<td>37</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Shear force and bending moment diagram</td>
<td>39</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Critical areas for punching</td>
<td>42</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Critical areas for punching for combined footings</td>
<td>43</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>Critical areas for punching-column1- case1</td>
<td>44</td>
</tr>
<tr>
<td>Figure 4.7</td>
<td>Critical areas for punching-column1- case2</td>
<td>44</td>
</tr>
<tr>
<td>Figure 4.8</td>
<td>Critical areas for punching-column1- case3</td>
<td>45</td>
</tr>
<tr>
<td>Figure 4.9</td>
<td>Critical areas for punching-column1- case4</td>
<td>45</td>
</tr>
<tr>
<td>Figure 4.10</td>
<td>Critical areas for punching-column1- case1</td>
<td>46</td>
</tr>
</tbody>
</table>
Figure 4.11: critical areas for punching-column1- case2.............................................................. 46
Figure 4.12: critical areas for punching-column1- case3.............................................................. 47
Figure 4.13: critical areas for punching-column1- case4.............................................................. 47
Figure 4.14: Modified critical section for shear with overlapping critical perimeters.................. 48
Figure 4.15: critical areas for punching-double column- case1 .................................................... 48
Figure 4.16: critical areas for punching-double columns- case2 .................................................. 49
Figure 4.17: critical areas for punching-double columns- case3 .................................................. 49
Figure 4.18: critical areas for punching-double columns- case4 .................................................. 50
Figure 4.19: critical areas for punching-double columns- case5 .................................................. 50
Figure 4.20: critical areas for punching-double columns- case6 .................................................. 51
Figure 4.21: critical areas for punching-double columns- case7 .................................................. 51
Figure 4.22: critical areas for punching-double columns- case8 .................................................. 52
Figure 4.23: figure 4.9 critical sections for wide beam shear ......................................................... 53
Figure 4.24: shear force & bending moment diagram ................................................................. 54
Figure 4.25: the spreadsheet program for combined footings ....................................................... 57

Figure 5.1: Strap footing .................................................................................................................. 63
Figure 5.2: Pressure distributions under strap footing ................................................................. 64
Figure 5.3: shear force and bending moment diagram ................................................................. 67
Figure 5.4: Critical Section for Punching ..................................................................................... 70
Figure 5.5: Critical Section for punching – definitions – footing1 .................................................. 71
Figure 5.6: Critical Section for punching – definitions – footing2 .................................................. 72
Figure 5.7: Critical Section for Punching around column1 case1 .................................................. 72
Figure 5.8: Critical Section for Punching around column1 case2 .................................................. 72
Figure 5.9: Critical Section for Punching around column1 case3 .................................................. 73
Figure 5.10: Critical Section for Punching around column1 case4 .................................................. 73
Figure 5.11: Critical Section for Punching around column2 case1 .................................................. 73
Figure 5.12: Critical Section for Punching around column2 case2 .................................................. 74
Figure 5.13: Critical Section for Punching around column2 case3 .................................................. 74
Figure 5.14: Critical Section for Punching around column2 case4 .................................................. 74
Figure 5.15: Shear force and bending moment diagram ................................................................. 77
Figure 5.16: shear force and bending moment diagrams ............................................................... 79
Figure 5.17: the spreadsheet program for strap footings

<table>
<thead>
<tr>
<th>List of tables</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.1: Grades of Concrete.</td>
<td>5</td>
</tr>
<tr>
<td>Table 2.2: Conversion Factors for Strength</td>
<td>6</td>
</tr>
<tr>
<td>Table 2.3: Partial Safety Factor for Materials - Class I Works</td>
<td>6</td>
</tr>
<tr>
<td>Table 2.4: Partial Safety Factor for Materials - Class II Works</td>
<td>7</td>
</tr>
<tr>
<td>Table 2.5: Minimum Cover Requirements for Concrete Members (3)</td>
<td>17</td>
</tr>
</tbody>
</table>
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
\( \gamma_m \) - Partial safety factor for materials
\( \gamma_c \) - Partial safety factor for concrete
\( \gamma_s \) - 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
\( \rho \) - Geometrical ratio of reinforcement
\( \rho_{min} \) - Minimum geometrical ratio of reinforcement
\( \rho_{max} \) - 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
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>Shear rein. spacing in the direction of the longitudinal reinforcement</td>
</tr>
<tr>
<td>$V_{rd}$</td>
<td>Shear resistance of a section</td>
</tr>
<tr>
<td>$V_c$</td>
<td>Shear carried by the concrete</td>
</tr>
<tr>
<td>$V_{sd}$</td>
<td>Shear acting along the periphery” of the critical section</td>
</tr>
<tr>
<td>$V$</td>
<td>Punching shear</td>
</tr>
<tr>
<td>$K_1, K_2$</td>
<td>Margin of strength</td>
</tr>
<tr>
<td>$S_{max}$</td>
<td>Maximum spacing between stirrups</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Ratio of long side to short side of footing</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Diameter of reinforcement</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Class</th>
<th>Permissible Grades of Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C5  C15  C20  C25  C30  C40  C50  C60</td>
</tr>
<tr>
<td>2</td>
<td>C5  C15  C20</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Size and Type of Test Specimen</th>
<th>Conversion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube (200 mm)</td>
<td>1.05</td>
</tr>
<tr>
<td>Cylinder (150 mm diameter 300 mm height)</td>
<td>1.25</td>
</tr>
</tbody>
</table>

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

$$f_{ck} = \frac{\text{Grade of concrete}}{1.25}$$  \hspace{1cm} \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.

$$f_{ctk} = 0.7 \cdot f_{ctm}$$  \hspace{1cm} \text{Eq. 2.2}

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

$$f_{ctm} = 0.3 \cdot f_{ck}^{2/3}$$  \hspace{1cm} \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/m$^3$.

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, $\gamma_m$. Tables 2.3 and 2.4 can be used to determine the partial safety factor for material property.

$$f_d = \frac{f_k}{\gamma_m}$$  \hspace{1cm} \text{Eq. 2.4}

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

<table>
<thead>
<tr>
<th>Design Situations</th>
<th>Concrete $\gamma_c$</th>
<th>Reinforcing Steel, $\gamma_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistent and Transient</td>
<td>1.5</td>
<td>1.15</td>
</tr>
<tr>
<td>Accidental</td>
<td>1.3</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 2.4: Partial Safety Factor for Materials -Class II Works

<table>
<thead>
<tr>
<th>Design Situations</th>
<th>Concrete $\gamma_c$</th>
<th>Reinforcing Steel, $\gamma_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistent and Transient</td>
<td>1.65</td>
<td>1.2</td>
</tr>
<tr>
<td>Accidental</td>
<td>1.45</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Design Strength for Concrete**

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

(a) In compression

$$f_{cd} = 0.85 \times \frac{f_{ck}}{\gamma_c}$$  \hspace{1cm} Eq. 2.5

(b) In tension

$$f_{ctd} = 0.85 \times \frac{f_{ctk}}{\gamma_c}$$  \hspace{1cm} Eq. 2.6

Where, $\gamma_c$ 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:

$$f_{yd} = \frac{f_{yk}}{\gamma_s}$$  \hspace{1cm} Eq. 2.7

Where, $\gamma_s$ 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 *COMBINATION OF ACTIONS*

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

$$F_D = DL + LL$$  \hspace{1cm} 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.

\[ F_D = 1.4 \times (DL + LL) \]  
\[ Eq.2.9 \]

2.2.10 DESIGN OF FLEXURAL REINFORCEMENT

- The geometrical ratio of reinforcement \( \rho \) at any section of a beam is calculated by:

\[ \rho = 1 - \sqrt{1 - \frac{2 \times M_{sd}}{b \times d^2 \times f_{cd}}} \times \frac{f_{cd}}{f_{yd}} \]  
\[ Eq.2.10 \]

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 \( \rho \) is calculated by:

For beams \( \rho_{min} = \frac{0.6}{f_{yk}} \)  
\[ Eq.2.11 \]

For slab \( \rho_{min} = \frac{0.5}{f_{yk}} \)  
\[ Eq.2.12 \]

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

- Area of steel

\[ As = \rho bd \]  
\[ Eq.2.13 \]

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

- Spacing of reinforcement

\[ S = \frac{b \times \pi \times \phi^2}{As} \]  
\[ Eq.2.14 \]

Where, \( \phi \) 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 \( d \).
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 $V_{sd}$.

$$V_{RD} = 0.25 \cdot f_{cd} \cdot b_w d$$  \hspace{1cm} \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:

$$V_c = 0.25 \cdot f_{cd} \cdot k_1 k_2 b_w d$$  \hspace{1cm} \text{Eq.2.16}

Where

$$K_1 = 1 + 50\rho < 2.0$$
$$K_2 = 1.6 - d > 1 \text{ (}d \text{ in meters)}$$

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

$A_s$ is the area of the tensile reinforcement anchored beyond the intersection of the steel and the line of a possible $45^\circ$ crack starting from the edge of the section.
Spacing of stirrup

\[ S = \frac{A_v \cdot d \cdot f_{yd}}{V_{sd} - V_c} \]  \hspace{1cm} 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:

\[ \rho_{\text{min}} = \frac{0.4}{f_{yk}} \]  \hspace{1cm} Eq.2.18

Where \( f_{yk} \) is in MPa.

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

- \( S_{\text{max}} = 0.5d < 300 \text{ mm if } V_{sd} < 2/3V_{RD} \)
- \( S_{\text{max}} = 0.3d < 200 \text{ mm if } V_{sd} > 2/3V_{Rd} \)  \hspace{1cm} 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](image)

**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.

![Image](image_url)

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).
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

$$V_{eq} = \beta V_{sd}$$

Eq. 2.20

Where, $\beta = 1 + \eta \frac{e}{u} Z$

$e$ 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.

$\eta$ denotes fraction of moment which is considered transferred by eccentricity of the shear about the centroid of the critical section.

$$\eta = \frac{1}{1 + \sqrt{b2/b1}}$$

$b1$ and $b2$ are sides of the rectangle of outline $u$, $b1$ 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

$$V_{RD} = 0.25 f_{ctd} K_1 K_2 Ud$$  \hspace{1cm} \text{Eq. 2.21}

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

$$k_2 = 1.6 - d > 1.0 \text{ (} d \text{ in meters)}$$

For members where more than 50% of the bottom reinforcement is curtailed, $k_1 = 1$.

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

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

$\rho_{ex}, \rho_{ey}$ 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:

a. At the face of column, pedestal, or wall, for footings supporting a concrete column pedestal or wall.

b. Halfway between middle and edge of wall, for footings supporting a masonry wall.

c. Halfway between face of column and edge of steel base for footings supporting a column with steel base plates.

Flexural Reinforcement

1. 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.

\[
\frac{\text{Re inf. o r c e m e n t i n b a n d w i d t h}}{\text{t o t a l r e i n f o r c e m e n t i n s h o r t d i r e c t i o n}} = \frac{2}{\beta + 1}
\]

Eq. 2.22

where \(\beta\) 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 EBSC2 1995

The location of the critical section for shear in accordance with Section 4.5 of EBSC2, 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 EBSC2, 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)

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

**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.

$$f_{bd} = f_{ctd}$$  \hspace{1cm} Eq. 2.23

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

$$f_{bd} = 2f_{ctd}$$  \hspace{1cm} Eq. 2.24

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

$$f_{bd} = 0.7 \times 2 \times f_{ctd} = 1.4f_{ctd}$$  \hspace{1cm} 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 $\phi$ is:

$$l_b = \frac{\phi \times f_{yd}}{4 \times f_{bd}}$$  \hspace{1cm} 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:

$$l_{bnet} = a l_b \frac{A_{scal}}{A_{sef}} \geq l_{bmin}$$  \hspace{1cm} Eq. 2.27

where $A_{scal}$ is the theoretical area of reinforcement required for the design

$A_{sef}$ 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,

$$l_{b.min} = 0.3l_b > 10 \phi > 200mm$$  \hspace{1cm} Eq. 2.28

For bars in compression,

$$l_{b.min} = 0.6l_b > 10 \phi > 200mm$$  \hspace{1cm} 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
- $F_D$ – foundation depth
- $B_C$ – 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
- $G_S$ – unit weight of soil
- $P_{TOT}$ – total load on footing
- $M_{OX}$ – design moment in x direction
- $M_{OY}$ – design moment 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.

Loads acting on the foundation are:

1. Super structure loads: \( P \)
2. Weight of backfill soil \( SO_w \) with unit weight of soil \( GS \) and is given by:
   \[
   SO_w = (L_x L_y - C_x C_y) (FD - DE) GS \tag{Eq.3.1}
   \]
   
3. Own weight of footing \( O_w \):
   \[
   O_w = DE L_x L_y * 25 \tag{Eq.3.2}
   \]
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.

\[
P_{tot} = P + O_{wt} + SO_{wt}
\]

\[ Eq.3.3 \]

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.

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

\[ Eq.3.4 \]

\[
Q_{max} = \frac{P_{tot}}{L_x L_y} + \frac{6|M_y|}{L_y L_x^2} + \frac{6|M_x|}{L_x L_y^2} \leq BC
\]

\[ Eq.3.5 \]

\[
Q_{min} = \frac{P_{tot}}{L_x L_y} - \frac{6|M_y|}{L_y L_x^2} - \frac{6|M_x|}{L_x L_y^2} \geq 0
\]
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 $D_E$:

$$D_E = D - 0.05 - \phi/1000 \quad Eq.3.6$$

Where, $D$ is thickness of footing and $\phi$ 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:

$$P_{RESI} = 0.25 \ast F_{CTD} \ast K_1 \ast K_2 \quad Eq.3.7$$

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

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

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

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

Where, $\rho_x$ and $\rho_y$ 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.

\[
P_{sf} = \frac{1.4(PS - PAV \times ARE)}{PER \times DE} \leq P_{Rsf}
\]  
\[Eq.3.8\]

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

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

\[
PAV = \frac{\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4}{4} = \frac{P_{tot}}{l_x \times l_y}
\]  
\[Eq.3.9\]
• Calculation of punching area and perimeter involves four different cases

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

Case: \( cx + 3\text{deff} < lx \& cy + 3\text{deff} < ly \)

Perimeter: \(2cx + 2cy + 3\pi\text{deff}\) \(\text{Eq.3.10}\)

Area: \((cx + 3\text{deff})cy + (cy + 3\text{deff})cx - cxcy + \pi(3d)^2 / 4\) \(\text{Eq.3.11}\)

![Figure 3.5: critical areas for punching (Case-1)](image1)

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

Case: \( cx + 3\text{deff} < lx \& cy + 3\text{deff} > ly \)

Perimeter: \(2*ly\) \(\text{Eq.3.12}\)

Area: \((cx + 3\text{deff})*ly\) \(\text{Eq.3.13}\)

![Figure 3.6 critical areas for punching (Case-2)](image2)

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

Case: \( cx + 3\text{deff} > lx \& cy + 3\text{deff} < ly \)

Perimeter: \(2*lx\) \(\text{Eq.3.14}\)

Area: \((cy + 3\text{deff})*lx\) \(\text{Eq.3.15}\)

![Figure 3.7 critical areas for punching (Case-3)](image3)
CASE 4 Critical section is outside the footing area on all sides.

**Case:** \( cx + 3\text{deff} \geq lx \) \& \( cy + 3\text{deff} \geq ly \)

**Perimeter:** 0 \hspace{1cm} \text{Eq.3. 16}

**Area:** \( lx \times ly \) \hspace{1cm} \text{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:

\[
P_{RESI} = 0.25 \times F_{CTD} \times K_1 \times K_2 \hspace{1cm} \text{Eq.3. 18}
\]

\[
F_{cid} = \frac{0.21 \times (0.8 \times CS)^{2/3}}{1.5}
\]

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

\[
\rho = \min (0.015, \sqrt{\rho_x \times \rho_y})
\]

\[
K_2 = \max (1.6 - D_e, 1)
\]
3.6.2.2 **CALCULATION OF WIDE BEAM SHEAR FORCE ON THE CRITICAL SURFACE**

- Calculation of average pressure acting on the critical area

\[
\sigma_{avx} = \frac{P_{tot}}{lx*ly} + \frac{3*My*(2*deff+cx+lx)}{ly*lx^3}
\]

\[\text{Eq.3.19}\]

\[
\sigma_{avy} = \frac{P_{tot}}{lx*ly} + \frac{3*Mx*(2*deff+cy+ly)}{lx*ly^3}
\]

\[\text{Eq.3.20}\]

- Calculation of wide beam shear, \(\tau\), stress acting on the critical area

\[
\tau_{widebeamx} = \frac{1.4\sigma_{avx}*ly*(lx/2-deff-cx/2)}{deff*ly} \leq \tau_{all}
\]

\[\text{Eq.3.21}\]

\[
\tau_{widebeamy} = \frac{1.4\sigma_{avy}*lx*(ly/2-deff-cy/2)}{deff*lx} \leq \tau_{all}
\]

\[\text{Eq.3.22}\]

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:

\[
\sigma_{avx} = \frac{P_{tot}}{lx*ly} + \frac{3*My*(cx+lx)}{ly*lx^3}
\]

\[\text{Eq.3.23}\]

In the Y direction:

\[
\sigma_{avy} = \frac{P_{tot}}{lx*ly} + \frac{3*Mx*(cy+ly)}{lx*ly^3}
\]

\[\text{Eq.3.24}\]
• Calculation of Design Bending Moment

In the X direction: \[ M_{ox} = \frac{\sigma_{\text{average}} * (lx/2 + cx/2)^2}{2} * 1.4 \] \hspace{1cm} \text{Eq. 3.25}

In the Y direction: \[ M_{oy} = \frac{\sigma_{\text{average}} * (ly/2 + cy/2)^2}{2} * 1.4 \] \hspace{1cm} \text{Eq. 3.26}

• Calculation of reinforcement

1. Flexural reinforcement for X direction bottom

\[ \rho = \sqrt{\frac{1 - 2M_{ox}}{f_{cd} * 1000 * d_{ef}^2}} \] \hspace{1cm} \text{Eq. 3.27}

\[ \rho_{\text{min}} = \frac{0.6}{f_{yk}} \] \hspace{1cm} \text{Eq. 3.28}

\[ A_s = \max(\rho, \rho_{\text{min}}) * 1000 * d_{ef} \] \hspace{1cm} \text{Eq. 3.29}

2. Flexural reinforcement for Y direction bottom

\[ \rho = \sqrt{\frac{1 - 2M_{oy}}{f_{cd} * 1000 * d_{ef}^2}} \] \hspace{1cm} \text{Eq. 3.27}

\[ \rho_{\text{min}} = \frac{0.6}{f_{yk}} \] \hspace{1cm} \text{Eq. 3.28}

\[ A_s = \max(\rho, \rho_{\text{min}}) * 1000 * d_{ef} \] \hspace{1cm} \text{Eq. 3.29}

3.8 DEVELOPMENT LENGTH CALCULATION

The design bond strength \( f_{bd} \)

\[ f_{bd} = 1.4 * f_{cd} \] \hspace{1cm} \text{Where} \ f_{cd} \ \text{is the tensile strength of concrete.} \hspace{1cm} \text{Eq. 3.33}

The basic anchorage length \( l_b \) for a bar of diameter \( \phi \) is:

\[ l_b = \frac{\Phi f_{yd}}{4 f_{bd}} \] \hspace{1cm} \text{Eq. 3.34}

The required anchorage length \( l_{\text{net}} \) depends on the type of anchorage and on the stress in the reinforcement and can be calculated as:
\[ l_{bnet} = a l_b \frac{A_{s,cal}}{A_{s,ef}} \geq l_{b,\text{min}} \quad \text{Eq. 3.35} \]

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

\( l_{b,\text{min}} \) is the minimum anchorage length

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

\[ l_{bnet} = a l_b = 0.7 l_b = 0.7 * \frac{\Phi}{4} * \frac{f_{yd}}{1.4 * f_{cld}} \geq l_{b,\text{min}} \quad \text{Eq. 3.36} \]

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

\[ l_{b,\text{min}} = 0.3 * l_b > 10 \phi > 200 \text{mm} \quad \text{Eq. 3.37} \]
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, summary 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.

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.

![Figure 3.101: general look of the worksheet called “Summary”](image)

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.

![Figure 3.112: input data for the drawing process.](image)

Figure 3.112: input data for the drawing process.
### Footing Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superstructure load, $P_t$ (kN)</td>
<td>2171.27</td>
</tr>
<tr>
<td>Moment (kN.m)</td>
<td>0.004</td>
</tr>
<tr>
<td>My (kN.m)</td>
<td>1.332</td>
</tr>
<tr>
<td>Column width, $a$ (m)</td>
<td>0.40</td>
</tr>
<tr>
<td>Foundation depth, $D$ (m)</td>
<td>1.00</td>
</tr>
<tr>
<td>Ultimate bearing capacity, $V_u$ (kN)</td>
<td>3000</td>
</tr>
<tr>
<td>Footing dimension, $b$, $a$, $L$, $t$ (m)</td>
<td>3.50, 2.50, 0.45</td>
</tr>
<tr>
<td>Footing Area, $A_f$ (m$^2$)</td>
<td>6.25</td>
</tr>
<tr>
<td>Effective depth, $d$ (m)</td>
<td>0.508</td>
</tr>
<tr>
<td>Own Weight of footing, $W_o$ (kN)</td>
<td>100</td>
</tr>
<tr>
<td>Unit weight of soil, $y_s$ (kN/m$^3$)</td>
<td>18.00</td>
</tr>
<tr>
<td>Soil Weight, $W_s$ (kN)</td>
<td>39</td>
</tr>
<tr>
<td>Total load on footing, $P_t$ (kN)</td>
<td>1856</td>
</tr>
<tr>
<td>Checking bearing pressure (kPa)</td>
<td>268.7</td>
</tr>
<tr>
<td>Max. soil pressure, $Q_{max}$ (kPa)</td>
<td>298.4</td>
</tr>
<tr>
<td>Min. soil pressure, $Q_{min}$ (kPa)</td>
<td>294.9</td>
</tr>
<tr>
<td>Tensile strength of mix, $f_{tu}$ (MPa)</td>
<td>1.01</td>
</tr>
<tr>
<td>Allowable punching resistance of concrete, $V_{pu}$ (kN/m)</td>
<td>277.7</td>
</tr>
<tr>
<td>Allowable web beam shear resistance of concrete, $V_{pu}$ (kN/m)</td>
<td>277.7</td>
</tr>
<tr>
<td>Punching shear force, $V_p$ (kN)</td>
<td>851.0</td>
</tr>
<tr>
<td>Punching shear stress, $V_{pu}$ (kN/m)</td>
<td>164.2</td>
</tr>
<tr>
<td>Wide beam shear force, $V_{wu}$ (kN/m)</td>
<td>385.9</td>
</tr>
<tr>
<td>Wide beam shear stress, $V_{wu}$ (kN/m)</td>
<td>262.5</td>
</tr>
<tr>
<td>Max. Design Moment, $M_d$ (kN.m)</td>
<td>181.5</td>
</tr>
<tr>
<td>Design safe strength (kPa)</td>
<td>341</td>
</tr>
<tr>
<td>rho (Kg/m$^3$)</td>
<td>0.155</td>
</tr>
<tr>
<td>Diameter of steel (mm)</td>
<td>12</td>
</tr>
<tr>
<td>Single Area, $A_s$ (mm$^2$)</td>
<td>113.10</td>
</tr>
<tr>
<td>Area of steel required, $A_{req}$ (mm$^2$)</td>
<td>0.509</td>
</tr>
<tr>
<td>Minimum Reinforcement, $A_{min}$ (mm$^2$)</td>
<td>735.0</td>
</tr>
<tr>
<td>Provisional area of steel, $A_s$ (mm$^2$)</td>
<td>909.2</td>
</tr>
<tr>
<td>Spacing, $s$ (mm)</td>
<td>2</td>
</tr>
<tr>
<td>Allowable bending stress, $f_{b}$ (MPa)</td>
<td>240</td>
</tr>
<tr>
<td>Number of bars / meter length</td>
<td>5.0</td>
</tr>
<tr>
<td>Actual bending stress, $f_{b,act}$ (MPa)</td>
<td>2.06</td>
</tr>
<tr>
<td>Bond changing</td>
<td>0.00</td>
</tr>
<tr>
<td>Adjusted spacing (mm)</td>
<td>180</td>
</tr>
<tr>
<td>Number of bars / meter length</td>
<td>9</td>
</tr>
<tr>
<td>Actual bending stress, $f_{b,act}$ (MPa)</td>
<td>1.75</td>
</tr>
<tr>
<td>Bond re-changing</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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.

![Figure 3. 134: general look of the worksheet called “Quantity”](image)

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](image)
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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$BC$</td>
<td>Allowable bearing capacity of underlying soil</td>
</tr>
<tr>
<td>$GS$</td>
<td>Unit weight of backfill soil</td>
</tr>
<tr>
<td>$CC$</td>
<td>center to center distance between columns</td>
</tr>
<tr>
<td>$FD$</td>
<td>foundation depth</td>
</tr>
<tr>
<td>$CL_{x1}$</td>
<td>dimension of column 1 in the x direction</td>
</tr>
<tr>
<td>$CL_{y1}$</td>
<td>dimension of column 1 in the y direction</td>
</tr>
<tr>
<td>$CL_{x2}$</td>
<td>dimension of column 2 in the x direction</td>
</tr>
<tr>
<td>$CL_{y2}$</td>
<td>dimension of column 2 in the y direction</td>
</tr>
<tr>
<td>$PS_1$</td>
<td>Unfactored Superstructure axial load from column 1</td>
</tr>
<tr>
<td>$PS_2$</td>
<td>Unfactored Superstructure axial load from column 2</td>
</tr>
<tr>
<td>$M1x$</td>
<td>Unfactored superstructure moment from column 1 in the x direction</td>
</tr>
<tr>
<td>$M1y$</td>
<td>Unfactored superstructure moment from column 1 in the y direction</td>
</tr>
<tr>
<td>$M2x$</td>
<td>Unfactored superstructure moment from column 2 in the x direction</td>
</tr>
</tbody>
</table>
M2y - Unfactored superstructure moment from column 2 in the y direction
CS, SS - grade of concrete, grade of reinforcing steel
LEN₁ - length from left edge of footing to center of column 1
LEN₂ - length from center of column 2 to right edge of footing
Ly - length of footing in the y direction
Lx - Length of footing in the x direction
CEN - Centroid of superstructure loads from left edge of footing
D - Total depth of footing
De - 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 PROPORIONING 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 $P_{tot}$:
   $$P_{tot} = P_{s1} + P_{s2}$$  \hspace{1cm} \text{Eq.4.1}

2. Weight of backfill soil $SO_{wt}$:
   $$SO_{wt} = (L_x * L_y - CL_{x1} * CL_{y1} - CL_{x2} * CL_{y2}) * (FD - D) * GS$$  \hspace{1cm} \text{Eq.4.2}

3. Own weight of footing $O_{wt}$:
   $$O_{wt} = 25 * L_x * L_y * D$$  \hspace{1cm} \text{Eq.4.3}
Where, $GS$ is unit weight of backfill soil. For other notations refer to figure 4.1.

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.

$$Q_{\text{max,min}} = \frac{P}{A} \pm \frac{M_x}{I_x} \pm \frac{M_y}{I_y}$$  \hspace{1cm} Eq.4.4

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

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

Where, $BC$ is allowable bearing capacity of soil. For other notations refer to figure 4.2.
The basic steps in the proportioning of combined footing are:

**STEP1.** Assume \( LEN1 \)

**STEP2.** Calculate \( CEN \):

\[
CEN = PS_1 \times LEN1 + PS_2 \times (LEN1 + CC) + \frac{|M_{1x} + M_{2y}|}{PS_1 + PS_2}
\]

Eq. 4.7

**STEP3.** Calculate \( L_x \)

\[
L_x = 2 \times CEN
\]

Eq. 4.8

**STEP4.** Calculate \( L_y \)

\[
Q_{\text{max}} = \frac{P_{\text{tot}} + SO_{\text{wt}} + O_{\text{wt}}}{L_x L_y} + \frac{6|M_{1x} + M_{2x}|}{L_x L_y^2} = BC
\]

Eq. 4.9

\[
P_{\text{tot}} = PS_1 + PS_2
\]

Eq. 4.10

\[
SO_{\text{wt}} = (L_x \times L_y - CL_{x_1} \times CL_{y_1} - CL_{x_2} - CL_{y_2}) \times (FD - D) \times Gs
\]

Eq. 4.11

\[
O_{\text{wt}} = 25 \times L_x \times L_y \times D
\]

Eq. 4.12

Equating… Eq. 4.10, Eq. 4.11 & Eq. 4.12 onto Eq. 4.9 gives
\[
BC = \frac{PS_1 + PS_2 + 25L_xL_yD + (L_xL_y - CL_{x1}CL_{y1} - CL_{x2}CL_{y2})*(FD - D)*Gs}{L_xL_y}
+ \frac{6|M_{1x} + M_{2x}|}{L_xL_y^2}
\]
\textit{Eq.4.13}

Rearranging and solving for \(L_y\).
\[
A*L_y^2 + B*L_y + C = 0
\]
\textit{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.** Check if \(Q_{\text{min}} > 0\)
\[
Q_{\text{min}} = \frac{P_{\text{tot}} + SO_{\text{wtr}} + O_{\text{wtr}} - 6|M_{1x} + M_{2x}|}{L_xL_y} \geq 0
\]
\textit{Eq.4.15}

\[
P_{\text{tot}} = PS_1 + PS_2
\]
\[
SO_{\text{wtr}} = (L_xL_y - CL_{x1}CL_{y1} - CL_{x2}CL_{y2})*(FD - D)*Gs
\]
\[
O_{\text{wtr}} = 25L_xL_yD
\]

Equating...
\[
Q_{\text{min}} = \frac{PS_1 + PS_2 + 25L_xL_yD + (L_xL_y - CL_{x1}CL_{y1} - CL_{x2}CL_{y2})*(FD - D)*Gs}{L_xL_y}
- \frac{6|M_{1x} + M_{2x}|}{L_xL_y^2} \geq 0
\]
\textit{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.

![Diagram of shear force and bending moment diagram]

- The distributed load from the constant pressure is

\[
BCA = \frac{P_{\text{tot}}}{L_y \cdot L_x} \quad \text{Eq.}4.17
\]

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

\[
X = LEN_1 - CL_{s1} / 2 \quad \text{Eq.}4.18
\]

\[
SF1 = BCA \cdot L_y \cdot (LEN_1 - CL_{s1} / 2) \quad \text{Eq.}4.19
\]

\[
MO1 = 0.5 \cdot SF1 \cdot (LEN_1 - CL_{s1} / 2) \quad \text{Eq.}4.20
\]

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

\[
X = LEN_1 \quad \text{Eq.}4.21
\]

\[
SF2 = BCA \cdot L_y \cdot LEN_1 \quad \text{Eq.}4.22
\]

\[
SF3 = BCA \cdot L_y \cdot LEN_1 - PS_1 \quad \text{Eq.}4.23
\]

\[
MO2 = 0.5 \cdot SF2 \cdot LEN_1 \quad \text{Eq.}4.24
\]
\[ MO2^\prime = 0.5 \* SF2 \* LEN_1 + M_{1y} \]  
\[ Eq.4.25 \]

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

\[ X = LEN_1 + CL_{x1} / 2 \]  
\[ Eq.4.26 \]

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

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

- Maximum Bending Moment

\[ XC_1 = \frac{-SF3}{SF6 - SF3} \* CC \]  
\[ Eq.4.29 \]

\[ MO4 = MO2^\prime + SF3 \* XC_1 / 2 \]  
\[ Eq.4.30 \]

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

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

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

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

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

\[ X = LEN_1 + CC \]  
\[ Eq.4.34 \]

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

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

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

\[ MO6^\prime = MO6 + M_{2y} \]  
\[ Eq.4.38 \]

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

\[ X = LEN_1 + CC + CL_{x2} / 2 \]  
\[ Eq.4.39 \]

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

\[ MO7 = MO6^\prime - SF8 \* CL_{x2} / 2 + (SF7 - SF8) \* CL_{x2} / 4 \]  
\[ Eq.4.41 \]

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

\[ X = L_x \]  
\[ Eq.4.42 \]

\[ SF = SF7 + BCA \* L_y \* LEN_2 = 0 \]  
\[ Eq.4.43 \]

\[ MO8 = MO6^\prime + SF7 \* LEN_2 / 2 \approx 0 \]  
\[ Eq.4.44 \]
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, $D_e$

$$D_e = D - 0.05 - \frac{\phi}{1000}$$  \hspace{1cm} \text{Eq. 4.45}

Where $D$ is total depth of footing and $\phi$ 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:

$$P_{RESI} = 0.25 \times F_{CTD} \times K_1 \times K_2$$  \hspace{1cm} \text{Eq. 4.46}

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

$$K_1 = \min (1 + 50\rho, 2)$$
\[
\rho = \min\left(0.015, \sqrt{\rho_x \rho_y}\right)
\]

\[
K_2 = \max\left(1.6 - D_e, 1\right)
\]

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.

\[\text{Critical section (Area=ARE, Perimeter=PER)}\]

Figure 4. 4: critical areas for punching

- Taking \(\sum F_z = 0\), see figure 4.4.

\[
PSF = 1.4 \times \frac{(PS - BCA \times ARE)}{PER \times D_e}
\]  
*Eq.4.47*

- Calculation of punching shear stress for column1

\[
PSF1 = 1.4 \times \frac{(PS1 - BCA \times ARE1)}{PER1 \times D_e}
\]  
*Eq.4.48*

- Calculation of punching shear stress for column2

\[
PSF2 = 1.4 \times \frac{(PS2 - BCA \times ARE2)}{PER2 \times D_e}
\]  
*Eq.4.49*

- Calculation of punching shear stress for double column

\[
PSF3 = 1.4 \times \frac{(PS1 + PS2 - BCA \times ARE3)}{PER3 \times DE}
\]  
*Eq.4.50*
4.7.1.2.1 **CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION**

4.7.1.2.1.1 **DEFINITIONS**

![Diagram showing critical areas for punching for combined footings]

Figure 4.5: critical areas for punching for combined footings

\[
PERC = 0.75 \times \pi \times D_e \\
RED = (2.25 - 0.5625\pi) \times D_e^2 \\
FTF = CC + CL_{x_1}/2 + CL_{x_2}/2 \\
LCH = 1.5 \times D_e + CL_{x_1}/2 \\
RCH = 1.5 \times D_e + CL_{x_2}/2 \\
TCH1 = 1.5 \times D_e + CL_{y_1}/2 \\
TCH2 = 1.5 \times D_e + CL_{y_2}/2 \\
TCH = \text{MAX}(TCH1, TCH2) \\
C_{y_{av}} = (CL_{y_1} + CL_{y_2})/2 
\]

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

\[ LCH + TCH1 < LEN1 \text{..} \& \text{..} LCH + TCH1 < L_y / 2 \]

\[ \text{Perimeter: } \quad \text{PER1} = 2 \times CL_x + 2 \times CL_y + 4 \times PERC \]

\[ \text{Area: } \quad \text{ARE1} = 4 \times LCH \times TCH1 - 4 \times RED \]

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.

\[ LCH + TCH1 \geq LEN1 \text{..} \& \text{..} LCH + TCH1 < L_y / 2 \]

\[ \text{Perimeter: } \quad \text{PER1} = 2 \times (LEN1 + CL_x / 2) + 2 \times PERC + CL_y \]

\[ \text{Area: } \quad \text{ARE1} = 2 \times (LEN1 + LCH) \times TCH1 - 2 \times RED \]
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.

\[ LCH + TCH1 < LEN_1, \quad \text{&} \quad LCH + TCH1 \geq L_y / 2 \]  

*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.

\[ LCH + TCH1 \geq LEN_1, \quad \text{&} \quad LCH + TCH1 \geq L_y / 2 \]  

*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

\[
RCH + TCH_2 < LEN_2 \text{..} & .. RCH + TCH_2 < L_y / 2
\]

Eq.4.72

**Perimeter**: \( PER_2 = 2 \times CL_{x2} + 2 \times CL_{y2} + 4 \times PERC \)

Eq.4.73

**Area**: \( ARE_2 = 4 \times RCH \times TCH_2 - 4 \times RED \)

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.

\[
RCH + TCH_2 \geq LEN_2 \text{..} & .. RCH + TCH_2 < L_y / 2
\]

Eq.4.75

**Perimeter**: \( PER_2 = 2 \times (LEN_2 + CL_{x2} / 2) + 2 \times PERC + CL_{y2} \)

Eq.4.76

**Area**: \( ARE_2 = 2 \times (LEN_2 + RCH) \times TCH_2 - 2 \times RED \)

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.

\[ RCH + TCH2 < LEN_{1..} \land RCH + TCH2 \geq L_y/2 \]  \hspace{1cm} \text{Eq.4.78}

**Perimeter:** \[ PER2 = 2 \times L_y \]  \hspace{1cm} \text{Eq.4.79}

**Area:** \[ ARE2 = 2 \times RCH \times L_y \]  \hspace{1cm} \text{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.

\[ RCH + TCH2 \geq LEN_{1..} \land RCH + TCH2 \geq L_y/2 \]  \hspace{1cm} \text{Eq.4.81}

**Perimeter:** \[ PER2 = L_y \]  \hspace{1cm} \text{Eq.4.82}

**Area:** \[ ARE2 = (LEN_{1..} + RCH) \times L_y \]  \hspace{1cm} \text{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 - case 1

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

\[
LCH + TCH_1 < LEN_1 \quad \& \quad RCH + TCH_2 < LEN_2 \quad \& \quad TCH + \min(LCH, RCH) + CC / 2 < L_y / 2
\]

**Perimeter:**

\[
PER_3 = 4 \times PERC + 2 \times FTF + CL_{y1} + CL_{y2} \quad \text{Eq. 4.84}
\]

**Area:**

\[
ARE_3 = (FTF + 3 \times DE) \times (CYAV + 3 \times DE) - 4 \times RED \quad \text{Eq. 4.85}
\]
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.

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

**Perimeter:**

\[
\text{PER}_3 = 2 \times (FTF + \text{LEN}_1 - CL_{s1} / 2) + 2 \times \text{PERC} + CL_{y2}
\]  
*Eq. 4.86*

**Area:**

\[
\text{ARE}_3 = (FTF + \text{LEN}_1 - CL_{s1} / 2 + 1.5 \times DE) \times (TCH_1 + TCH2) - 2 \times \text{RED}
\]  
*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.

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

**Perimeter:**

\[
\text{PER}_3 = 2 \times (FTF + \text{LEN}_2 - CL_{s2} / 2) + 2 \times \text{PERC} + CL_{y1}
\]  
*Eq. 4.88*

**Area:**

\[
\text{ARE}_3 = (FTF + \text{LEN}_2 - CL_{s2} / 2 + 1.5 \times DE) \times (TCH_1 + TCH2) - 2 \times \text{RED}
\]  
*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.

\[ LCH + TCH1 \geq LEN1 \ldots RCH + TCH2 \geq LEN2 \ldots TCH + \min(LCH, RCH) + CC / 2 < L_y / 2 \]

**Perimeter**: \[ PER3 = 2 \cdot L_x \] \[ Eq.4.90 \]

**Area**: \[ ARE3 = L_x \cdot (TCH1 + TCH2) \] \[ Eq.4.91 \]

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.

\[ LCH + TCH1 < LEN1 \ldots RCH + TCH2 < LEN2 \ldots TCH + \min(LCH, RCH) + CC / 2 \geq L_y / 2 \]

**Perimeter**: \[ PER3 = 2 \cdot L_y \] \[ Eq.4.92 \]

**Area**: \[ ARE3 = L_y \cdot (CC + LCH + RCH) \] \[ Eq.4.93 \]
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.

\[
LCH + TCH_1 \geq LEN_1 \text{, } \& \text{ } RCH + TCH_2 < LEN_2 \text{, } \& \text{ } TCH + \min(LCH, RCH) + CC / 2 \geq L_y / 2
\]

**Perimeter**: \( PER_3 = L_y \) \( Eq.4.94 \)

**Area**: \( ARE_3 = (FTF + 1.5 \times DE + LEN_1 - CL_{x1} / 2) \times L_y \) \( Eq.4.95 \)

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.

\[
LCH + TCH_1 < LEN_1 \text{, } \& \text{ } RCH + TCH_2 \geq LEN_2 \text{, } \& \text{ } TCH + \min(LCH, RCH) + CC / 2 \geq L_y / 2
\]

**Perimeter**: \( PER_3 = L_y \) \( Eq.4.98 \)

**Area**: \( ARE_3 = (FTF + LEN_2 + 1.5 \times DE - CL_{x2} / 2) \times L_y \) \( Eq.4.97 \)
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, \( P_{RES} > W_{SF} \), on all critical surfaces, where, \( P_{RES} \) 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:

\[
P_{RES} = 0.25 * F_{cd} * k_1 * k_2
\]

\[
F_{cd} = \frac{0.21 * (0.8 * CS)^{2/3}}{1.5}
\]

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

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

\[
K_2 = \max(1.6 - D_e, 1)
\]
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.

![Diagram showing critical sections for wide beam shear](image)

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 column 1 (section B-B)

   \[ \text{AREA} = (\text{LEN}_1 - CL_{s1} / 2 - DE) \times L_y \]

   \[ \text{PERIMETER} = L_y \]

   \[ \text{WSF1} = \frac{1.4 \times BCA \times \text{AREA}}{\text{PERIMETER} \times DE} \]

   \[ = \frac{1.4 \times BCA \times (\text{LEN}_1 - CL_{s1} / 2 - DE) \times L_y}{L_y \times DE} \geq 0 \quad \text{Eq.4.101} \]

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

   \[ \text{AREA} = (\text{LEN}_2 - CL_{s2} / 2 - DE) \times L_y \]

   \[ \text{PERIMETER} = L_y \]

   \[ \text{WSF2} = \frac{1.4 \times BCA \times \text{AREA}}{\text{PERIMETER} \times DE} \]

   \[ = \frac{1.4 \times BCA \times (\text{LEN}_2 - CL_{s2} / 2 - DE) \times L_y}{L_y \times DE} \geq 0 \quad \text{Eq.4.102} \]
3. Calculation of wide beam shear stress at top & bottom (section A-A)

\[ \text{AREA} = \left( \frac{L_y}{2} - \frac{CYAV}{2} - DE \right) \times L_x \]

\[ \text{PERIMETER} = L_x \]

\[ WSF3 = \frac{1.4 \times BCA \times \text{AREA}}{\text{PERIMETER} \times DE} \]

\[ = \frac{1.4 \times BCA \times \left( \frac{L_y}{2} - \frac{CYAV}{2} - DE \right) \times L_x}{L_x \times DE} \geq 0 \]

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.

![Shear Force & Bending Moment Diagram](image)

Figure 4.24: shear force & bending moment diagram

1. Flexural reinforcement for Y direction top

   Minimum reinforcement is provided here.
Software Development for Design of Shallow Foundations

\[
\rho_{\text{min}} = \frac{0.6}{f_{yk}}
\]

\[
As = \rho_{\text{min}} * 1000 * D_c
\]

2. Flexural reinforcement for Y direction bottom

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

\[
\rho = \frac{1 - \sqrt{1 - 2M_{o_yb}}}{f_{cd} * 1000 * d_{ef}}
\]

\[
\rho_{\text{min}} = \frac{0.6}{f_{yk}}
\]

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

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

\[
M_{o_xt} = 1.4 * \frac{MO4}{L_y} * 10^6
\]

\[
\rho = \frac{1 - \sqrt{1 - 2M_{o_xt}}}{f_{cd} * 1000 * d_{ef}}
\]

\[
\rho_{\text{min}} = \frac{0.6}{f_{yk}}
\]

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

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

\[
M_{o_{xb}} = 1.4 * \max(MO1, MO3, MO5, MO7) / L_y * 10^6
\]

\[
\rho = \frac{1 - \sqrt{1 - 2M_{o_{xb}}}}{f_{cd} * 1000 * d_{ef}}
\]

\[
\rho_{\text{min}} = \frac{0.6}{f_{yk}}
\]

\[
As = \max(\rho, \rho_{\text{min}}) * 1000 * d_{ef}
\]
4.9 DEVELOPMENT LENGTH CALCULATION

The design bond strength $f_{bd}$

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

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

The basic anchorage length $l_b$ for a bar of diameter $\phi$ 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:

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

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

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

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

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

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

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

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

### COMBINED FOOTING DESIGN

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<thead>
<tr>
<th>Company</th>
<th>AALU</th>
<th>Project</th>
<th>Residential</th>
<th>Designed By</th>
<th>Run</th>
<th>Date</th>
<th>November 28, 2009</th>
</tr>
</thead>
</table>

#### INPUT DATA

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<th>Allowable B.C.</th>
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<th>Foundation Depth</th>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
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<td>18</td>
<td>P1</td>
<td>P2</td>
</tr>
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<td>18</td>
<td>928.95</td>
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</tbody>
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<table>
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<th>Column 2</th>
</tr>
</thead>
<tbody>
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<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Concrete D</td>
<td>40</td>
<td>40</td>
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</table>

#### SHEAR RESISTANCE

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<th>k2</th>
<th>k1</th>
<th>rhoy</th>
<th>tcd</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.00</td>
<td>1.06</td>
<td>0.001</td>
<td>11.3</td>
</tr>
</tbody>
</table>

#### UNFACTORED LOADS

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<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
<tbody>
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<td>M1x</td>
<td>30</td>
</tr>
<tr>
<td>M2x</td>
<td>20</td>
</tr>
</tbody>
</table>

#### FOUNDATION REINFORCEMENT

- **Summary:**
  - Concrete (m³): 9.33
  - Steel (Kg): 581.68
  - Quantity & Cost: 35,060.57
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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>Allowable bearing capacity of underlying soil</td>
</tr>
<tr>
<td>GS</td>
<td>Unit weight of backfill soil</td>
</tr>
<tr>
<td>CC</td>
<td>Center to center distance between columns</td>
</tr>
<tr>
<td>FD</td>
<td>Foundation depth</td>
</tr>
<tr>
<td>(CL_{x1})</td>
<td>Dimension of column 1 in the x direction</td>
</tr>
<tr>
<td>(CL_{y1})</td>
<td>Dimension of column 1 in the y direction</td>
</tr>
<tr>
<td>(CL_{x2})</td>
<td>Dimension of column 2 in the x direction</td>
</tr>
<tr>
<td>(CL_{y2})</td>
<td>Dimension of column 2 in the y direction</td>
</tr>
<tr>
<td>(PS_1)</td>
<td>Unfactored Superstructure axial load from column 1</td>
</tr>
<tr>
<td>(PS_2)</td>
<td>Unfactored Superstructure axial load from column 2</td>
</tr>
<tr>
<td>(M_{1x})</td>
<td>Unfactored superstructure moment from column 1 in the x direction</td>
</tr>
<tr>
<td>(M_{1y})</td>
<td>Unfactored superstructure moment from column 1 in the y direction</td>
</tr>
<tr>
<td>(M_{2x})</td>
<td>Unfactored superstructure moment from column 2 in the x direction</td>
</tr>
<tr>
<td>(M_{2y})</td>
<td>Unfactored superstructure moment from column 2 in the y direction</td>
</tr>
<tr>
<td>CS</td>
<td>Grade of concrete</td>
</tr>
<tr>
<td>SS</td>
<td>Grade of steel</td>
</tr>
<tr>
<td>(LEN_1)</td>
<td>Length of footing 1 in the x direction</td>
</tr>
<tr>
<td>(LEN_2)</td>
<td>Length of footing 2 in the x direction</td>
</tr>
<tr>
<td>(L_y)</td>
<td>Length of footing 1 &amp; 2 in the y direction</td>
</tr>
<tr>
<td>(D_{tot1})</td>
<td>Total depth of footing 1</td>
</tr>
<tr>
<td>(D_{tot2})</td>
<td>Total depth of footing 2</td>
</tr>
<tr>
<td>(D_{ef1})</td>
<td>Effective depth of footing 1</td>
</tr>
<tr>
<td>(D_{ef2})</td>
<td>Effective depth of footing 2</td>
</tr>
<tr>
<td>(H)</td>
<td>Total depth of strap</td>
</tr>
<tr>
<td>(B)</td>
<td>Width of strap</td>
</tr>
<tr>
<td>(OWT_1)</td>
<td>Own weight of footing 1</td>
</tr>
<tr>
<td>(OWT_2)</td>
<td>Own weight of footing 2</td>
</tr>
<tr>
<td>(SWT_1)</td>
<td>Weight of backfill above footing 1</td>
</tr>
<tr>
<td>(SWT_2)</td>
<td>Weight of backfill above footing 2</td>
</tr>
<tr>
<td>(STRWT)</td>
<td>Weight of strap</td>
</tr>
</tbody>
</table>
Table of mathematical symbols:

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

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 footing 1, $SWT_1 = GS \times (FD - D_{tot1}) \times (LEN_1 \times L_y - CL_{x1} \times CL_{y1})$ **Eq.5.1**
   b) On top of footing 2, $SWT_2 = GS \times (FD - D_{tot2}) \times (LEN_2 \times L_y - CL_{x2} \times CL_{y2})$ **Eq.5.2**
3. Own weight of footing
   a) Weight footing 1, $OWT_1 = 25 \times D_{tot1} \times LEN_1 \times L_y$ **Eq.5.3**
   b) Weight footing 2, $OWT_2 = 25 \times D_{tot2} \times LEN_2 \times L_y$ **Eq.5.4**
4. Weight of strap, $STRWT = 25 \times H \times B \times (CC - CL_{x1} / 2 - CL_{x2} / 2)$  \hspace{1cm} 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.

$$Q_{max,min} = \frac{P}{A} \pm \frac{M_x \times C_x}{I_x} \pm \frac{M_y \times C_y}{I_y}$$  \hspace{1cm} Eq. 5.6
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.

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

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

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

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

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 $RE_{A1}$ & $RE_{A2}$

Taking $\sum M$ about $RE_{A2}=0$,

$$RE_{A1} = \frac{PS_i \times CC + \left|M_{1_x} + M_{2_y}\right|}{X_r}$$  \hspace{1cm} Eq. 5.12

Taking $\sum F_z=0$

$$RE_{A2} = PS_i + PS_2 - RE_{A1}$$  \hspace{1cm} Eq. 5.13

**STEP4.** Calculate $L_y$

$$\frac{RE_{A1} + SWT_1 + OWT_1 + STRWT/2}{LEN_1 \times L_y} + \frac{6 \times \left|M_{1_x}\right|}{LEN_1 \times L_y^2} = BC$$  \hspace{1cm} Eq. 5.14

Where,

$$SWT_1 = GS \times (FD - D_{tot}) \times (LEN_1 \times L_y - CL_{x1} \times CL_{y1})$$

$$OWT_1 = 25 \times D_{tot} \times LEN_1 \times L_y$$

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

**Equating…**

$$\frac{RE_{A1} + GS \times (FD - D_{tot}) \times (LEN_1 \times L_y - CL_{y1} \times CL_{x1}) + 25 \times D_{tot} \times L_y \times LEN_1}{LEN_1 \times L_y} + \frac{25 \times H \times B \times (CC - CL_{x1}/2 - CL_{x2}/2) / 2}{LEN_1 \times L_y^2} + \frac{6 \times \left|M_{1_x}\right|}{LEN_1 \times L_y^2} = BC$$  \hspace{1cm} Eq. 5.15

**Rearranging..**

$$A \times L_y^2 + B \times L_y + C = 0$$  \hspace{1cm} Eq. 5.16

Where;

$$A = BC \times LEN_1 - LEN_1 \times GS \times (FD - D_{tot}) - 25 \times LEN_1 \times D_{tot}$$  \hspace{1cm} Eq. 5.17

$$B = CL_{x1} \times CL_{y1} \times GS \times (FD - D_{tot}) - 12.5 \times B \times H \times (CC - CL_{x1}/2 - CL_{x2}/2) - RE_{A1}$$  \hspace{1cm} Eq. 5.18

$$C = -6 \times \left|M_{1_x}\right|$$  \hspace{1cm} Eq. 5.19

**Solving for $L_y$..**

$$L_y = \frac{-B + \sqrt{B^2 - 4 \times A \times C}}{2 \times A}$$  \hspace{1cm} Eq. 5.20
STEP 5. Calculate $LEN_2$

\[
\frac{REA_2 + SWT_2 + OWT_2 + STRWT / 2}{LEN_2 * L_y} + \frac{6|M_{2x}|}{LEN_2 * L_y^2} = BC
\]

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...

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

Rearranging and solving for $LEN_2$...

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

STEP 6. Check if $Q_{min} > 0$

\[
Q_{min1} = \frac{REA_1 + GS * (FD - D_{tot1}) * (LEN_1 * L_y - CL_{x1} * CL_{y1}) + 25 * D_{tot1} * L_y * LEN_1}{LEN_1 * L_y} + \frac{25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2) / 2}{LEN_1 * L_y} \geq 0
\]

\[
Q_{min2} = \frac{REA_2 + GS * (FD - D_{tot2}) * (LEN_2 * L_y - CL_{y2} * CL_{x2}) + 25 * D_{tot2} * L_y * LEN_2}{LEN_2 * L_y} + \frac{25 * H * B * (CC - CL_{x1} / 2 - CL_{x2} / 2) / 2}{LEN_2 * L_y} \geq 0
\]

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](image)

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

  \[
  Q_1 = \frac{REA_1}{L_y \cdot LEN_1} \cdot L_y = \frac{REA_1}{LEN_1} \quad Eq.5.26
  \]

  \[
  Q_2 = \frac{REA_2}{L_y \cdot LEN_2} \cdot L_y = \frac{REA_2}{LEN_2} \quad Eq.5.27
  \]

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

  \[
  X = CL_{c1} / 2 \quad Eq.5.28
  \]

  \[
  SF1 = \frac{REA_1}{LEN_1} \cdot CL_{c1} / 2 \quad Eq.5.29
  \]

  \[
  SF2 = SF1 - PS_1 \quad Eq.5.30
  \]
\[ MO_1 = SF_1 + CL_{x_1} / 4 \]  \hspace{1cm} \text{Eq.5.31}

\[ MO'_1 = MO_1 + M_{1y} \]  \hspace{1cm} \text{Eq.5.32}

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

\[ X = CL_{x_1} \]  \hspace{1cm} \text{Eq.5.33}

\[ SF_3 = SF_2 + REA_1 / LEN_1 * CL_{x_1} / 2 \]  \hspace{1cm} \text{Eq.5.34}

\[ MO_2 = MO_1' + (SF_2 + SF_3) / 2 * CL_{x_1} / 2 \]  \hspace{1cm} \text{Eq.5.35}

- Maximum Bending Moment

\[ XC_1 = \frac{-SF_2}{SF_4 - SF_2} * (LEN_1 - CL_{x_1} / 2) \]  \hspace{1cm} \text{Eq.5.36}

\[ MO_3 = MO_1' + SF_2 * XC_1 / 2 \]  \hspace{1cm} \text{Eq.5.37}

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

\[ X = LEN_1 \]  \hspace{1cm} \text{Eq.5.38}

\[ SF_4 = SF_2 + REA_1 / LEN_1 * (LEN_1 - CL_{x_1} / 2) \]  \hspace{1cm} \text{Eq.5.39}

\[ MO_4 = MO_3 + SF_4 * (LEN_1 - CL_{x_1} / 2 - XC_1) / 2 \]  \hspace{1cm} \text{Eq.5.40}

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

\[ X = CC + CL_{x_1} / 2 - LEN_2 / 2 \]  \hspace{1cm} \text{Eq.5.41}

\[ SF_4 = SF_2 + REA_2 / LEN_2 * (LEN_2 / 2 - CL_{x_1} / 2) \]  \hspace{1cm} \text{Eq.5.42}

\[ MO_5 = MO_4 + SF_4 * (CC + CL_{x_1} / 2 - LEN_1 - LEN_2 / 2) \]  \hspace{1cm} \text{Eq.5.43}

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

\[ X = CC + CL_{x_1} / 2 - CL_{x_2} / 2 \]  \hspace{1cm} \text{Eq.5.44}

\[ SF_5 = SF_4 + REA_2 / LEN_2 * (LEN_2 / 2 - CL_{x_2} / 2) \]  \hspace{1cm} \text{Eq.5.45}

\[ MO_6 = MO_5 + (SF_4 + SF_5) / 2 * (LEN_2 / 2 - CL_{x_2} / 2) \]  \hspace{1cm} \text{Eq.5.46}

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

\[ X = CC + CL_{x_1} / 2 \]  \hspace{1cm} \text{Eq.5.47}

\[ SF_6 = SF_4 + REA_2 / LEN_2 * LEN_2 / 2 \]  \hspace{1cm} \text{Eq.5.48}

\[ SF_7 = SF_6 - PS_2 \]  \hspace{1cm} \text{Eq.5.49}

\[ MO_7 = MO_5 + (SF_4 + SF_6) / 2 * LEN_2 / 2 \]  \hspace{1cm} \text{Eq.5.50}
\[ MO7' = MO7 + M_{2y} \quad \text{Eq. 5.51} \]

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

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

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

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

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

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

\[ SF = SF7 + REA_2 / LEN_2 * LEN_2 / 2 = 0 \quad \text{Eq. 5.56} \]

\[ MO9 = MO7' + SF7 * LEN_2 / 4 \quad \text{Eq. 5.57} \]

5.7 **DETERMINATION OF FOOTING THICKNESS**

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

a) One way shear also known as wide beam shear or diagonal compression shear

b) 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

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

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

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

\( \Phi_1 \) & \( \Phi_2 \) 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. EBSCS 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

\[ P_{RES1} = 0.25 \times F_{cd} \times k_{1L} \times k_{2L} \]

\[ F_{cd} = \frac{0.21 \times (0.8 \times CS)^{2/3}}{1.5} \]

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

\[ \rho = \min(0.015, \sqrt{\rho x_1, \rho y_1}) \]

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

- Calculation of punching shear resistance for footing2

\[ P_{RES2} = 0.25 \times F_{cd} \times k_{1R} \times k_{2R} \]

\[ F_{cd} = \frac{0.21 \times (0.8 \times CS)^{2/3}}{1.5} \]

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

\[ \rho = \min(0.015, \sqrt{\rho x_2, \rho y_2}) \]

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

5.7.1.2 Calculation of Punching Shear Stress on Critical Surfaces

![Critical Section for Punching](image)

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.

\[
PSF = 1.4 \cdot \frac{RE_A}{LEN \cdot L_y} \cdot \frac{ARE}{PER \cdot D_{ef}} \quad Eq.5.62
\]

Calculation of punching shear stress for footing1

\[
PSF_1 = 1.4 \cdot \frac{RE_{A1}}{LEN_{1} \cdot L_y} \cdot \frac{ARE_{1}}{PER_{1} \cdot D_{ef_{1}}} \quad Eq.5.63
\]

Calculation of punching shear stress for footing2

\[
PSF_2 = 1.4 \cdot \frac{RE_{A2}}{LEN_{2} \cdot L_y} \cdot \frac{ARE_{2}}{PER_{2} \cdot D_{ef_{2}}} \quad Eq.5.64
\]

5.7.1.2.1 CALCULATION OF AREA & PERIMETER OF THE CRITICAL REGION

5.7.1.2.1.1 DEFINITIONS

\[
LCH = CL \cdot s_1 + 1.5 \cdot D_{ef_{1}} \quad Eq.5.65
\]

\[
TCH_1 = CL \cdot s_1 / 2 + 1.5 \cdot D_{ef_{1}} \quad Eq.5.66
\]

\[
PERC_1 = 0.75 \cdot \pi \cdot D_{ef_{1}} \quad Eq.5.67
\]

\[
RED_1 = (2.25 - 0.5625 \cdot \pi) \cdot D_{ef_{1}}^2 \quad Eq.5.68
\]

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

\[ LCH < LEN_1 \text{ & } THC1 < \frac{L_y}{2} \]  

PERIMETER:

\[ PER1 = 2 * CL_{x1} + CL_{y1} + 2 * PERC1 \]  

AREA:

\[ ARE1 = 2 * LCH * TCH1 - 2 * RED1 \]

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.

\[ LCH < LEN_1 \text{ & } THC1 \geq \frac{L_y}{2} \]  

PERIMETER:

\[ PER1 = L_y \]  

AREA:

\[ ARE1 = LCH * L_y \]

Figure 5. 8: Critical Section for Punching around column1 case2
CASE: Critical area outside footing1 on the left and right sides of the footing.

\[ LCH \geq LEN_1 \text{ & THC}_1 < L_{y}/2 \quad \text{Eq. 5.79} \]

**PERIMETER:**

\[ PER1 = 2 \times LEN_1 \quad \text{Eq. 5.80} \]

**AREA:**

\[ ARE1 = 2 \times TCH_1 \times LEN_1 \quad \text{Eq. 5.81} \]

Figure 5.9: Critical Section for Punching around column1 case3

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

\[ LCH \geq LEN_1 \text{ & THC}_1 \geq L_{y}/2 \quad \text{Eq. 5.82} \]

**PERIMETER:**

\[ PER1 = 0 \quad \text{Eq. 5.83} \]

**AREA:**

\[ ARE1 = 0 \quad \text{Eq. 5.84} \]

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.

\[ RCH < LEN_2/2 \text{ & THC}_2 < L_{y}/2 \quad \text{Eq. 5.85} \]

**PERIMETER:**

\[ PER2 = 2 \times CL_{x_2} + 2 \times CL_{y_2} + 4 \times PERC_2 \quad \text{Eq. 5.86} \]

**AREA:**

\[ ARE2 = 4 \times RCH \times TCH_2 - 4 \times RED_2 \quad \text{Eq. 5.87} \]

Figure 5.11: Critical Section for Punching around column2 case1
**CASE:** Critical area outside of footing on top and bottom sides of the footing.

\[
RCH < \frac{LEN_2}{2} & THC \geq \frac{L_y}{2} \quad Eq. 5.88
\]

**PERIMETER:**

\[
PER_2 = 2 * L_y 
\quad Eq. 5.89
\]

**AREA:**

\[
ARE_2 = 2 * RCH * L_y 
\quad Eq. 5.90
\]

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

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

\[
RCH \geq \frac{LEN_2}{2} & THC < \frac{L_y}{2} \quad Eq. 5.91
\]

**PERIMETER:**

\[
PER_2 = 2 * LEN_2 
\quad Eq. 5.92
\]

**AREA:**

\[
ARE_2 = 2 * THC * LEN_2 
\quad Eq. 5.93
\]

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

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

\[
RCH \geq \frac{LEN_2}{2} & THC \geq \frac{L_y}{2} \quad Eq. 5.94
\]

**PERIMETER:**

\[
PER_2 = 0 
\quad Eq. 5.95
\]

**AREA:**

\[
ARE_2 = 0 
\quad Eq. 5.96
\]

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. EBSCS 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.

5.7.2.1 **CALCULATION OF WIDE BEAM SHEAR RESISTANCE**

- Calculation of wide beam shear resistance for footing1

$$P_{RESI} = 0.25 * F_{cld} * k_{1L} * k_{2L}$$  \hspace{1cm} \text{Eq.5.97}

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

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

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

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

- Calculation of wide beam shear resistance for footing2

$$P_{RES2} = 0.25 * F_{cld} * k_{1R} * k_{2R}$$  \hspace{1cm} \text{Eq.5.98}

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

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

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

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

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 footing

\[ W_{SF1} = 1.4 \times \frac{REA}{L_y \times LEN_1} \times \frac{AREA}{PERIMETER \times D_{ef1}} \]

\[ AREA = L_y \times (LEN_1 - CL_{x1} - D_{ef1}) \]

\[ PERIMETER = L_y \]

\[ W_{SF1} = 1.4 \times \frac{REA}{L_y \times LEN_1} \times \frac{L_y \times (LEN_1 - CL_{x1} - D_{ef1})}{L_y \times D_{ef1}} \]

\[ Eq. 5.99 \]

• Calculation of wide beam shear stress for top & bottom of footing

\[ W_{SF1} = 1.4 \times \frac{REA}{L_y \times LEN_1} \times \frac{AREA}{PERIMETER \times D_{ef1}} \]

\[ AREA = LEN_1 \times (L_y / 2 - CL_{y1} / 2 - D_{ef1}) \]

\[ PERIMETER = LEN_1 \]

\[ W_{SF1} = 1.4 \times \frac{REA}{L_y \times LEN_1} \times \frac{LEN_1 \times (L_y / 2 - CL_{y1} / 2 - D_{ef1})}{LEN_1 \times D_{ef1}} \]

\[ Eq. 5.100 \]

• Calculation of wide beam shear stress for right of footing

\[ W_{SF2} = 1.4 \times \frac{REA}{L_y \times LEN_2} \times \frac{AREA}{PERIMETER \times D_{ef2}} \]

\[ AREA = L_y \times (LEN_2 / 2 - CL_{x2} / 2 - D_{ef2}) \]

\[ PERIMETER = L_y \]

\[ W_{SF2} = 1.4 \times \frac{REA}{L_y \times LEN_2} \times \frac{L_y \times (LEN_2 / 2 - CL_{x2} / 2 - D_{ef2})}{L_y \times D_{ef2}} \]

\[ Eq. 5.101 \]

• Calculation of wide beam shear stress for top & bottom of footing

\[ W_{SF2} = 1.4 \times \frac{REA}{L_y \times LEN_2} \times \frac{AREA}{PERIMETER \times D_{ef2}} \]

\[ AREA = LEN_2 \times (L_y / 2 - CL_{y2} / 2 - D_{ef2}) \]

\[ PERIMETER = LEN_2 \]
\[ W_{SF2} = 1.4 \times \text{REA2} \times \frac{L_y \times L_{EN2}}{\text{LEN}_2} \times \left( \frac{L_y}{2} - \frac{CL_{y2}}{2} - D_{ef2} \right) \]

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. \( \text{max}(CL_{y1}, CL_{y2}) \). 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.

1. Checking if the strap is singly reinforced
   - At \( \text{MO3} \), refer to figure 5.15.
     \[
     H_{ef} = \sqrt{\frac{1.4 \times |\text{MO3}|}{0.2952 \times B \times f_{cd}}} + 70 \text{mm} \geq H + \max(D_{rot1} - D_{rot2}, 0) \]
     \[ Eq.5.103 \]
   - At \( \text{MO6} \), refer to figure 5.15.
     \[
     H_{ef} = \sqrt{\frac{1.4 \times |\text{MO6}|}{0.2952 \times B \times f_{cd}}} + 70 \text{mm} \geq H + \max(D_{rot2} - D_{rot1}, 0) \]
     \[ Eq.5.104 \]
• **At MO4 or MO5**, refer to figure 5.15.

\[
H_{\text{eff}} = \sqrt{\frac{1.4 \cdot \max(MO4, MO5)}{0.2952 \cdot B \cdot f_{\text{cd}}}} + 70mm \geq H
\]

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 \( V_{sd} \).

\[
V_{Rd} = 0.25 \cdot f_{\text{cd}} \cdot B \cdot H_{\text{eff}}
\]

Eq.5.106

• **At SF3**, refer to figure 5.15.

\[
H_{\text{eff}} = H + \max(0, D_{\text{tor1}} - D_{\text{tor2}}) - 70mm
\]

Eq.5.107

\[
V_{Rd} = 0.25 \cdot f_{\text{cd}} \cdot B \cdot H_{\text{eff}} \geq 1.4 \cdot SF3
\]

Eq.5.108

• **At SF6**

\[
H_{\text{eff}} = H + \max(0, D_{\text{tor2}} - D_{\text{tor1}}) - 70mm
\]

Eq.5.109

\[
V_{Rd} = 0.25 \cdot f_{\text{cd}} \cdot B \cdot H_{\text{eff}} \geq 1.4 \cdot SF6
\]

Eq.5.110

• **At SF4**, refer to figure 5.15.

\[
H_{\text{eff}} = H - 70mm
\]

Eq.5.111

\[
V_{Rd} = 0.25 \cdot f_{\text{cd}} \cdot B \cdot H_{\text{eff}} \geq 1.4 \cdot \left|SF4\right|
\]

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

\[ M_{oST} = 1.4 \times MO3 \times 10^6 \quad \text{Eq.5.113} \]

\[ \rho = \frac{1 - \sqrt{1 - 2M_{oST}}}{f_{cd} \times B \times H_{ef}^2} \]

\[ \rho_{\text{min}} = \frac{0.6}{f_{yk}} \]

\[ A_s = \max(\rho, \rho_{\text{min}}) \times B \times H_{ef} \]

Figure 5.16: shear force and bending moment diagrams

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

\[ M_{oSB} = 1.4 \times \max(MO2, MO5, 0) \times 10^6 \quad \text{Eq.5.114} \]
\[ \rho = \frac{1 - \sqrt{1 - 2M_{oSB}}}{\sqrt{f_{cd} * B * H_{ef}^2}} \]

\[ \rho_{min} = \frac{0.6}{f_{yk}} \]

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

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

\[ M_{o1YB} = 1.4 \left( \frac{REA_i}{L_y * LEN_1} + \frac{12 * \left| M_{1x} \right| * (L_y / 4 + CL_{y1} / 4)}{LEN_1 * L_y^3} \right) \frac{LEN_1 * (L_y / 2 - CL_{y1} / 2)^2}{2} \]

Eq. 5.115

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

\[ \rho_{min} = \frac{0.6}{f_{yk}} \]

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

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

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

Eq. 5.116

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

\[ \rho_{min} = \frac{0.6}{f_{yk}} \]
As = max(\(\rho, \rho_{\text{min}}\)) * \(L_y * D_{ef2}\)

6. Flexural reinforcement for footing2, Y direction bottom

\[
M_{o2YB} = 1.4 * \left( \frac{\text{REA}_2}{L_y * \text{LEN}_2} + \frac{12 * |M_2| \left( \frac{L_y}{4 + CL_{y2} / 4} \right) * \text{LEN}_2 * \left( L_y / 2 - CL_{y2} / 2 \right)^2}{\text{LEN}_2 * L_y^3} \right) / 2
\]

Eq. 5.117

\[
\rho = \frac{1 - \sqrt{1 - 2M_{o2YB}}}{f_{cd} * \text{LEN}_2 * D_{ef2}^2}
\]

\[
\rho_{\text{min}} = \frac{0.6}{f_{yk}}
\]

\[
As = \max(\rho, \rho_{\text{min}}) * \text{LEN}_2 * D_{ef2}
\]

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

\[
SF10 = SF2 + \frac{(CL_{s1} / 2 + H_{ef}) * \text{REA}_1}{\text{LEN}_1}
\]

Eq. 5.118

Shear force at HEF distance from face of column 2

\[
SF11 = SF4 + \frac{(\text{LEN}_2 / 2 - CL_{s2} / 2 - H_{ef}) * \text{REA}_2}{\text{LEN}_2}
\]

Eq. 5.119

Design shear force

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

Eq. 5.120

Concrete carrying capacity

\[
V_c = 0.25 * f_{cd} * K_1 * K_2 * B * H_{ef}
\]

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
\[ \rho_{\text{min}} = 0.4 / f_{yk} \]

Eq. 5.126

\[ S_{\text{max}} = \frac{A_v * f_{yk}}{0.4 * H_{ef}} \]

Eq. 5.127

### 5.10 DEVELOPMENT LENGTH CALCULATION

The design bond strength \( f_{bd} \)

\[ f_{bd} = 1.4 * f_{cd} \]

Eq. 5.128

Where \( f_{cd} \) is the tensile strength of concrete.

The basic anchorage length \( l_b \) for a bar of diameter \( \phi \) is:
\[ l_b = \Phi \frac{f_{yd}}{4 \, f_{bd}} \]

\textit{Eq.5.130}

The required anchorage length \( l_{b,\text{net}} \) depends on the type of anchorage and on the stress in the reinforcement and can be calculated as:

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

where \( A_{s,\text{cal}} \) is the theoretical area of reinforcement required by the design, \( A_{s,\text{ef}} \) is the area of reinforcement actually provided:

- \( a = 1.0 \) for straight bar anchorage in tension or compression
- \( a = 0.7 \) for anchorage in tension with standard hooks

\( l_{b,\text{min}} \) is the minimum anchorage length

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

\[ l_{b,\text{net}} = a l_b = 0.7 l_b = 0.7 \frac{\Phi}{4} \frac{f_{yd}}{1.4 f_{ctd}} \geq l_{b,\text{min}} \quad \text{Eq.5.132} \]

\[ \frac{A_{s,\text{cal}}}{A_{s,\text{ef}}} \approx 0 \text{ near the edges therefore } l_{b,\text{net}} = l_{b,\text{min}} \]

\[ l_{b,\text{min}} = 0.3 l_b > 10 \phi > 200 \text{mm} \quad \text{Eq.5.133} \]

\textbf{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.
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 \( L1 \); this spreadsheet can help the user determine \( L1 \) 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


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.
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.

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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.

![Figure A.1.5: Grouping of footings](image)

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 summery 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 before analysis and design](image)

![Summary of footing design after analysis and design](image)

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.
Figure A.1.8: Brief design report of footing 1.

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<td><strong>Min. soil pressure, $q_{smin}$</strong></td>
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<td></td>
<td>$40$</td>
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<td><strong>Max. soil pressure, $q_{smax}$</strong></td>
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<tr>
<td><strong>Total load on footing, $W_t$</strong></td>
<td>$910$</td>
<td></td>
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<tr>
<td><strong>Checking bearing pressure, $p_{c}$</strong></td>
<td>$287.0$</td>
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<tr>
<td><strong>Max. soil pressure, $q_{s}$</strong></td>
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<td><strong>Min. soil pressure, $q_{s}$</strong></td>
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<tr>
<td><strong>Temple strength of conc, $f_{c}$</strong></td>
<td>$1.53$</td>
<td></td>
</tr>
<tr>
<td><strong>Allowable punching resistance of concrete, $V_{cp}$</strong></td>
<td>$338.0$</td>
<td></td>
</tr>
<tr>
<td><strong>Allowable wide beam shear resistance of concrete, $V_{c}$</strong></td>
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<td><strong>Punching shear, $V_{p}$</strong></td>
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<td><strong>Name of Beam, $W_{g}$</strong></td>
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<td><strong>Name of Beam, $W_{b}$</strong></td>
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<tr>
<td><strong>Max. Design Moment, $M_{d}$</strong></td>
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<td><strong>Design yield strength, $f_y$</strong></td>
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<td><strong>Diameter of Steel, $d$</strong></td>
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<tr>
<td><strong>Bar Area, $A_{s}$</strong></td>
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<td><strong>Area of Steel Required, $A_{r}$</strong></td>
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<td><strong>Provided Area of Steel, $A_{p}$</strong></td>
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<td><strong>Spacing, $s$</strong></td>
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<td><strong>Allowable bond stress, $f_{b}$</strong></td>
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<td><strong>Number of bars/ meter length</strong></td>
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<tr>
<td><strong>Actual bond stress, $f_{b}$</strong></td>
<td>$1.78$</td>
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<td><strong>Bond, $F_{b}$</strong></td>
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<td><strong>Adjusted Spacing (mm)</strong></td>
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<td><strong>Number of bars/ meter length</strong></td>
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<td><strong>Actual bond, $f_{b}$</strong></td>
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<tr>
<td><strong>Bond Re-checking</strong></td>
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</tbody>
</table>
Figure A.1.9: Brief design report of footing 2.
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.

![Bill of quantities for footing 1](image1)

Figure A.1.11: Bill of quantities for footing 1.

![Bill of quantities for footing 2](image2)

Figure A.1.12: Bill of quantities for footing 2.

![Bill of quantities for footing 3](image3)

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.
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   Mx=4.711   My=6.489
   - P2=2918.82   Mx=4.174   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. L₁, in our case the boundary is not close to column 1. Therefore the software should determine optimum value for L₁.
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 L₁. The “optimize” button is used to determine L₁ if the user has the freedom to choose L₁.

A.2.3 DESIGN REPORT

Figure A.2.1 shows a brief design report of combined footings.
### Combined Footing Design

#### Input Data

<table>
<thead>
<tr>
<th>Soil Data</th>
<th>Dimensions</th>
<th>Unfactored Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable B.C.</td>
<td>300</td>
<td>Column Spacing 5</td>
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<tr>
<td>Load</td>
<td>18</td>
<td>Foundation Depth 1.5</td>
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#### Footing Geometry

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<th>Footing</th>
<th>Footing Load</th>
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</thead>
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<tr>
<td>L1</td>
<td>0.30</td>
</tr>
<tr>
<td>L2</td>
<td>2.40</td>
</tr>
<tr>
<td>D</td>
<td>1.25</td>
</tr>
<tr>
<td>dfe</td>
<td>1.18</td>
</tr>
<tr>
<td>Lx</td>
<td>7.8</td>
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<tr>
<td>Ox</td>
<td>3.9</td>
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#### Proportioning

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<thead>
<tr>
<th>Column 1 for Punching</th>
<th>Column 2 for Punching</th>
<th>Double Column for Punching</th>
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</thead>
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<tr>
<td>Area</td>
<td>6.38</td>
<td>Area</td>
</tr>
<tr>
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<td>Punching Stress</td>
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#### Reinforcement Calculation

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<th>rho</th>
<th>h0</th>
<th>dia</th>
<th>c/c</th>
<th>Length</th>
<th>Number</th>
<th>Kg</th>
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<tr>
<td>X direction Top</td>
<td>-745.24</td>
<td>400</td>
<td>0.15</td>
<td>0.13</td>
<td>16</td>
<td>100</td>
<td>10</td>
<td>24</td>
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<tr>
<td>Y direction Top</td>
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<td>400</td>
<td>0.12</td>
<td>0.13</td>
<td>16</td>
<td>130</td>
<td>19</td>
<td>39</td>
<td>1.5783</td>
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<tr>
<td>X direction Bottom</td>
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<td>0.03</td>
<td>0.13</td>
<td>16</td>
<td>130</td>
<td>4.5</td>
<td>61</td>
<td>1.5783</td>
</tr>
<tr>
<td>Y direction Bottom</td>
<td>166.02</td>
<td>400</td>
<td>0.03</td>
<td>0.13</td>
<td>16</td>
<td>130</td>
<td>4.5</td>
<td>61</td>
<td>1.5783</td>
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#### Summary

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<th>Quantity &amp; Cost</th>
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<td>Concrete (m³)</td>
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<td>Steel (Kg)</td>
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A.2.4 BILL OF QUANTITIES

Figure A.2.2 shows bill of quantities for combined footings.

![Bill of Quantities Table]

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.

![Input Data Table]

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
   \[ P_1 = 503.9 \quad M_x = 1.25 \quad M_y = 0.896 \]
   \[ P_2 = 805.25 \quad M_x = 1.35 \quad M_y = 0.28 \]

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 \( L_1 \). The “optimize” button is used to determine \( L_1 \) 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.
### A.3.4 BILL OF QUANTITIES

Figure A.3.2 shows bill of quantities for strap footings.

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Footing 1</th>
<th>Footing 2</th>
<th>Strap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pcs.</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L</td>
<td>0.9</td>
<td>L</td>
<td>1.25</td>
</tr>
<tr>
<td>B</td>
<td>1.75</td>
<td>B</td>
<td>1.75</td>
</tr>
<tr>
<td>D</td>
<td>0.4</td>
<td>D</td>
<td>0.4</td>
</tr>
<tr>
<td>m³</td>
<td>0.63</td>
<td>m³</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.57</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Formwork</th>
<th>Footing 1</th>
<th>Footing 2</th>
<th>Strap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pcs.</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L</td>
<td>0.9</td>
<td>L</td>
<td>1.25</td>
</tr>
<tr>
<td>B</td>
<td>1.75</td>
<td>B</td>
<td>1.75</td>
</tr>
<tr>
<td>D</td>
<td>0.4</td>
<td>D</td>
<td>0.4</td>
</tr>
<tr>
<td>m²</td>
<td>2.12</td>
<td>m²</td>
<td>2.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C-5 lean concrete</th>
<th>Footing 1</th>
<th>Footing 2</th>
<th>Strap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pcs.</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L</td>
<td>0.9</td>
<td>L</td>
<td>1.25</td>
</tr>
<tr>
<td>B</td>
<td>1.75</td>
<td>B</td>
<td>1.75</td>
</tr>
<tr>
<td>m²</td>
<td>1.58</td>
<td>m²</td>
<td>2.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pit excavation</th>
<th>Footing 1</th>
<th>Footing 2</th>
<th>Strap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pcs.</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L</td>
<td>1.4</td>
<td>L</td>
<td>1.75</td>
</tr>
<tr>
<td>B</td>
<td>2.25</td>
<td>B</td>
<td>2.25</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>D</td>
<td>2</td>
</tr>
<tr>
<td>m³</td>
<td>6.30</td>
<td>m³</td>
<td>7.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Backfill</th>
<th>Footing 1</th>
<th>Footing 2</th>
<th>Strap</th>
</tr>
</thead>
<tbody>
<tr>
<td>pit</td>
<td>6.30</td>
<td>Pcs.</td>
<td>7.88</td>
</tr>
<tr>
<td>concrete</td>
<td>0.63</td>
<td>L</td>
<td>0.88</td>
</tr>
<tr>
<td>m³</td>
<td>5.67</td>
<td>m³</td>
<td>7.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17.55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steel</th>
<th>Pos.</th>
<th>F1 Xdir</th>
<th>F1 Y dir</th>
<th>F2 Xdir</th>
<th>F2 Y dir</th>
<th>Top Strap</th>
<th>bott strap</th>
<th>stirrup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pcs.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>5</td>
<td>3</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>1.4</td>
<td>2.25</td>
<td>1.75</td>
<td>2.25</td>
<td>6.05</td>
<td>6.05</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Dia</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>16</td>
<td>14</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Kg</td>
<td>9.94</td>
<td>17.98</td>
<td>15.54</td>
<td>23.97</td>
<td>47.74</td>
<td>21.93</td>
<td>32.06</td>
<td>169.17</td>
</tr>
</tbody>
</table>

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.

![Figure A.3.3: Input data for producing working drawing](image)

<table>
<thead>
<tr>
<th>SF-1</th>
<th>Depth 1</th>
<th>0.40</th>
<th>Depth 2</th>
<th>0.40</th>
<th>Spacing bn columns</th>
<th>4.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footing 1 Width</td>
<td>Column 1 Width</td>
<td>Footing 2 Width</td>
<td>Column 2 Width</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-Dir</td>
<td>Y-Dir</td>
<td>X-Dir</td>
<td>Y-Dir</td>
<td>X-Dir</td>
<td>Y-Dir</td>
<td>X-Dir</td>
</tr>
<tr>
<td>0.90</td>
<td>1.75</td>
<td>0.25</td>
<td>0.4</td>
<td>1.25</td>
<td>1.75</td>
<td>0.25</td>
</tr>
<tr>
<td>Reinf. X-Dir F1</td>
<td>Reinf. Y-Dir F1</td>
<td>Reinf. X-Dir F2</td>
<td>Reinf. Y-Dir F2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diam</td>
<td>Spacing</td>
<td>Diam</td>
<td>Spacing</td>
<td>Diam</td>
<td>Spacing</td>
<td>Diam</td>
</tr>
<tr>
<td>12</td>
<td>260</td>
<td>12</td>
<td>110</td>
<td>12</td>
<td>200</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>Depth</td>
<td>No.</td>
<td>Diam</td>
</tr>
<tr>
<td>0.40</td>
<td>0.70</td>
<td>5</td>
<td>16</td>
</tr>
</tbody>
</table>
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: ll = Worksheets(1).Cells(9, 6).Value / 2 + 0.05 * (i - 1)
        Next i
        Worksheets(1).Cells(15, 3).Value = ll
        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 Acad TextStyle
  Bold = False
  Dim Bold2 As Boolean
  SavetypeFace = typeFace
typeFace = "Arial"
ThisDrawing.ActiveTextStyleSetFont typeFace, _
    Bold, Italic, Charset, PitchandFamily

Dim scalefactor As Double
Set newTextStyle = ThisDrawing.TextStyles.Add("TITLE")
Set newTextStyle = ThisDrawing.TextStyles.Add("bartext")
ThisDrawing.ActiveTextStyleSetFont 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 line = ThisDrawing.ModelSpace/AddLightWeightPolyline(pt): line.Layer = "TEX":
line.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 line = ThisDrawing.ModelSpace/AddLightWeightPolyline(pt): line.Layer = "TEX":
line.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":

May, 2011
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
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) = 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
d 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
d 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 + 0.025 * 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

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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
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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":
Software Development for Design of Shallow Foundations

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        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
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) = \frac{wfx}{2} - \frac{xcol}{2}; \ \text{endPoint}(1) = \frac{wfy}{2} - \frac{ycol}{2}; \ \text{endPoint}(2) = 0
startPoint(0) = \frac{wfx}{2} - \frac{xcol}{2}; \ \text{startPoint}(1) = \frac{wfy}{2} + \frac{ycol}{2}; \ \text{startPoint}(2) = 0
st(0) = \frac{wfx}{2} - \frac{xcol}{2} - 0.06 \times sc; \ \text{st}(1) = \frac{wfy}{2} + \frac{ycol}{2}; \ \text{st}(2) = 0

Set \text{dimObj} = \text{ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)}
\text{dimObj.DimensionLineColor} = \text{acRed}; \ \text{dimObj.Arrowhead1Type} = \text{acArrowOblique}:
\text{dimObj.Arrowhead2Type} = \text{acArrowOblique}; \ \text{dimObj.Layer} = "\text{TEX}"
\text{dimObj.ArrowheadSize} = 0.075 \times sc; \ \text{dimObj.ExtensionLineColor} = \text{acRed}:
\text{dimObj.ExtensionLineExtend} = 0.07 \times sc; \ \text{dimObj.TextHeight} = 0.075 \times sc
\text{dimObj.VerticalTextPosition} = \text{acAbove}; \ \text{dimObj.DimensionLineExtend} = 0.075 \times sc
\text{If} \ \text{mm.Value} = \text{True} \ \text{Then}
\text{dimObj.PrimaryUnitsPrecision} = \text{acDimPrecisionZero}
\text{End If}
\text{If} \ \text{cm.Value} = \text{True} \ \text{Then}
\text{dimObj.PrimaryUnitsPrecision} = \text{acDimPrecisionOne}
\text{End If}
\text{If} \ \text{m.Value} = \text{True} \ \text{Then}
\text{dimObj.PrimaryUnitsPrecision} = \text{acDimPrecisionThree}
\text{End If}

endPoint(0) = wfx; \ \text{endPoint}(1) = -1.35 \times sc - df; \ \text{endPoint}(2) = 0
startPoint(0) = wfx; \ \text{startPoint}(1) = -1.35 \times sc; \ \text{startPoint}(2) = 0
st(0) = wfx + 0.32 \times sc; \ \text{st}(1) = -1.35 \times sc; \ \text{st}(2) = 0

Set \text{dimObj} = \text{ThisDrawing.ModelSpace.AddDimAligned(startPoint, endPoint, st)}
\text{dimObj.DimensionLineColor} = \text{acRed}; \ \text{dimObj.Arrowhead1Type} = \text{acArrowOblique}:
\text{dimObj.Arrowhead2Type} = \text{acArrowOblique}; \ \text{dimObj.Layer} = "\text{TEX}"
\text{dimObj.ArrowheadSize} = 0.075 \times sc; \ \text{dimObj.ExtensionLineColor} = \text{acRed}:
\text{dimObj.ExtensionLineExtend} = 0.07 \times sc; \ \text{dimObj.TextHeight} = 0.075 \times sc
\text{dimObj.VerticalTextPosition} = \text{acAbove}; \ \text{dimObj.DimensionLineExtend} = 0.075 \times sc
\text{If} \ \text{mm.Value} = \text{True} \ \text{Then}
\text{dimObj.PrimaryUnitsPrecision} = \text{acDimPrecisionZero}
\text{End If}
If cm.Value = True Then
    dimObj.PrimaryUnitsPrecision = acDimPrecisionOne
End If
If mm.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.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) = 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.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.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
TextoString = "%%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
d 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.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
d 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.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.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
dc point(0) = wfx; dc point(1) = -1.38 * sc - df; dc point(2) = 0
Set lineObj = ThisDrawing.ModelSpace.AddLine(startPoint, dc point): 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
tex tObj.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