بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Graduate Studies

Development and Application of Microsoft Excel VBA A Computer programme for Structural Design of Concrete Footings

تطوير وتطبيق برنامج حاسوبي للتصميم الإنشائي للقواعد الخرسانية باستخدام مايكروسوفت اكسل فيجول بيسك

A Thesis Submitted in Partial Fulfillment for MSc Degree in Civil Engineering (Structural Engineering)

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الآيـــة

بسم الله الرحمن الرحيم

قال تعالي:﴿وَلَا تَمْشِ فِي الْأَرْضِ مَرَحًا إِنَّكَ لَنْ تَخْرِقَ

الْأَرْضَ وَلَنْ تَبْلُغَ الْجِبَالَ طُولًا (٣٧) كُلُّ ذَلِكَ كَانَ

سَيِّئُهُ عِنْدَ رَبِّكَ مَكْرُوهًا (٣٨) ذَلِكَ مِمَّا أَوْحَى إِلَيْكَ

رَبُّكَ مِنَ الْحِكْمَةِ وَلَا تَجْعَلْ مَعَ اللَّهِ إِلَهًا آخَرَ فَتُلْقَى فِي

جَهَنَّمَ مَلُومًا مَدْحُورًا (٣٩)﴾

صدق الله العظيم

سورة الإسراء الآيات (٣٧-٣٨-٣٩)

Dedication

This research thesis is dedicated to:

My parents, who continuously encouraged and supported me in countless ways,

My beloved brothers and sisters;

Acknowledgements

First and foremost, I must acknowledge my limitless thanks to Allah, the Ever Magnificent; the Ever-Thankful, for His helps and bless. I am totally sure that this work would have never become truth, without His guidance.

I owe a deep debt of gratitude to my supervisor **Dr. Abusamra Awad** for his time, encouragement, and expertise during all phases of the research for his exquisite attention to detail and for his demand for excellence.

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Abstract

Most structural engineers use Microsoft (**MS**) Excel in their work as a daily basis, this presentation will illustrate some more unique ways in which Excel can be used as a very powerful tool in structural design. The tools shown are focused around some simple code written in Visual Basic for Applications (**VBA**) to develop a computer programme, entitled **FSD**. In this study the code of VBA **FSD** programme is actually quite simple for any engineer and students to get reactions results from **ETABS** software Models by use application programming interface (**API)** function and using in design of footings.

The significance of this study was find way to save wasting time in export the results to software and errors in modeling when dealing with this soft wares that use finite elements method (**FEM**) without practical experience for the design of footings.

The main objective of the study was to provide interesting findings and will balance equations to construct shear force and bending moment in analysis raft foundations this could be by conventional rigid method passing through factors to adjust the column load and the soil pressure together.

In is this study a reinforced concrete structure of Six stores was modeled in ETABS as case study, the design footing by **CSI SAFE** software was done to verification the design in FSD proramme and Comparison of the results showed that the difference between finite element software **CSI SAFE** design and **FSD** software did not exceed 8.5% in analysis and did not exceed 30% in flexure design in all types of footing. The computer programme **FSD** can be used reliably as design software for footings according to brutish standard **BS9811-1997**.

مستخلص

معظم المهندسين الانشائيين يستخدمون برنامج الحاسوب مايكروسوفت (**Microsoft Excel**) في عملهم بصورة يومية. وتبين هذه الدراسة الخصائص المميزة والفريدة التي يوفرها برنامج (**Excel**) كاداة جيدة يمكن استخدامها في التصميم الانشائي من قبل المهندسين يرتكز محور الدراسة على الاستفادة من مميزات البرنامج في عمل برمجة باستخدام لغة (**Visual Basic**) لانشاء برنامج حاسوبي سمي(**FSD**) هذا البرنامج يمكنه استخراج ردود الافعال من برنامج (**ETABS**) واستخدامها في تصميم قواعد الاساسات الخرسانية . وتتلخص اهمية الدراسة في تحقيق طريقة لتقليل الوقت الضائع في ارسال النتائج من برنامج لاخر وتفاديء الاخطاء عند نمزجة وتصميم قواعد الاساسات باستخدام هذه البرامج التي تستخدم طريقة العناصر المحددة (**Finite Elements Method**) بدون الخبرة الكافية في التعامل معا هذه البرامج .

ومن اهم ما تم تحقيقه في هذه الدراسة ايجاد طريقة لرسم مخطط القص والعزوم عند تحليل الاساسات الحصيرية باستخدام الطريقة التقليدية الصلبة. تم عمل نموزج في برنامج (**ETABS**) لمبنى مكون من ستة طوابق كدراسة حالة . صممت القواعد بإستخدام (**CSI SAFE**) احد برامج المعروفة التي تستخدم طريقة العناصر المحددة للتحقق من النتائج التي تم الحصول عليها من برنامج (**FSD**) . أظهرت المقارنة بين النتائج أن الفرق عند استخدام برنامج (**FSD**) و(**CSI SAFE**) لم يتعدى ال 8.5% في نتائج التحليل ولم تتعدى **30%** في نتائج تسليح الرئيسي لجميع انواع القواعد. أن البرنامج الحاسوبي (**FSD**) يمكن إستخدامة بشكل موثوق به كبرنامج للتصميم الإنشائي للقواعد الخرسانية بجميع انواعها حسب المواصفات البريطانية **(BS9811-1997)**.

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A	Area of Footing
Api	Application Programming Interface
As_{Min}	Minimum Tensile Reinforcement
As	Area of Tension Reinforcement
B	Width of Footing
B	Column Width
C	Clear Cover of Concrete
D	Effective Depth or Average Effective Depth
E_X	Eccentricity in X-Direction
E_Y	Eccentricity in Y-Direction
F	The Column Load Modification Factor
F_Z	Maximum Vertical Reaction Serviceability Limit State (SLS)
F_{Zu}	Maximum Vertical Reaction Ultimate Limit State (ULS)
F. S	Factor of Safety
F_S	Sliding Resistance Force
F	Factor To Consider The Eccentricity of Punching Shear Force
f_{cu}	Characteristic Compressive Strength of Concrete
f_y	Yield Strength of Reinforcement Steel
H	Sliding Force (SLS)
H	Column Length
I_X	Moment Of Inertia About X-Axis

I_Y	Moment of Inertia About Y-Axis
K	Stiffness or Modulus of Sub-Grade Reaction
K_1	Enhancement Factor For Support Compression
L	Length of Footing
M_R	Moment Resistance of Overturning
M_O	Overturning Moment
M_X	Total Moment Of The Column Loads About X-Axis In Raft Footing
M_Y	Total Moment Of The Column Loads About Y-Axis In Raft Footing
$+M_{Ux}$	Positive Ultimate Design Moment At X-Direction
$+M_{Uy}$	Positive Ultimate Design Moment At Y-Direction
$-M_{Ux}$	Negative Ultimate Design Moment At X-Direction
$-M_{Uy}$	Negative Ultimate Design Moment At Y-Direction
N_1	Maximum Vertical Load in Column 1 in Combined Footing
N_2	Maximum Vertical Load in Column 2 in Combined Footing
N_U	Maximum Ultimate Vertical Load From Column
P_U	Ultimate Soil Pressure
Q	Column Load In Raft Strips
Q_{Avg}	Average of Summation Columns Loads In Raft Strips
Q_A	Allowable Bearing Capacity of Soil
Q_U	Ultimate Bearing Capacity of Soil
$Q_{Avg,Mod}$	The Modified Average Soil Pressure in Raft Strips
R	Summation of Columns Loads in Combined Footing
S	Span Between Column1 and Column 2 In Combined Footing

SLS	Serviceability Limit State
U_0	Column Perimeter
U_1	Column Critical Punching Shear Perimeter
ULS	Ultimate Limit State
VBA	Visual Basic For Applications
W_{U1}	Factored Load Per Length In Longitudinal Direction
W_{U2}	Factored Load Per Length In Short Direction
$\overline{X}$	Located of Summation of Columns Loads From Center Gravity
γ_c	Unit Weight of Concrete
γ_m	Partial Factor Safety of Materials
γ_S	Unit Weight of Soil
$\emptyset$	Reinforcement Bar Diameter
δ_1	Friction Angle Between Concrete and Soil
δ	Settlement of the Raft (mat)at the Same Point

Chapter One

Introduction

1.1 Introduction

Visual Basic for Applications **(VBA)** is a Microsoft Visual Basic programming system Application Edition. It is an industry standard and a powerful programming environment. It is the fastest and easiest way to create and customize Microsoft Windows applications.

Process View is shipped with Microsoft Visual Basic for Applications. **VBA** allows customizing Process View to suit specific requirements. It also offers high-level application programmability and features cross platform support for ActiveX technology for the Microsoft Windows operating systems. It is identical to VBA in Microsoft Office applications and other third-party products. VBA allows to:

• Create, debug and run custom scripts or macros.

• Write Visual Basic code for events.

• Modify native objects.

• Connect ActiveX objects to each other and to native objects.

VBA uses an event-driven model approach for development. The execution of the code is driven by events. Visual Basic interprets code as written. Code can be written, compiled and tested during development. This saves a lot of development time because you can run the application as you develop it rather than waiting to compile it later.

Footings are structural elements that transmit column or wall loads to underlying soil below the structure. Footing is designed to transmit these loads to the soil without exceeding its safe bearing capacity to prevent excessive settlement of the structure to tolerable limit, to minimize differential settlement and to prevent sliding and overturning. The settlement depends upon the intensity of the load, type of soil and foundation level. Where possibility of differential settlement occurs, the different footings should be designed in such a way to settle independently of each other.

An Application Programming Interface or **API** is the set of symbols that are exported and available to the users of a library to write their applications. The design of the APIs is arguably the most critical part of designing the library, because it affects the design of the applications built on top of them. Software is built on abstractions. Pick the right ones and programming will flow naturally from design; modules will have small and simple interfaces; and new functionality will more likely fit in without extensive reorganization. Pick the wrong ones and programming will be a series of nasty surprises.

This manual gathers together the key insights into **API** design that were discovered through many years of software development on the Qt application development framework at Troll tech. When designing and implementing a library, other factors should also be kept in mind, such as efficiency and ease of implementation, in addition to pure **API** considerations. And although the focus is on public APIs, there is no harm in applying the principles described here when writing application code or internal library code.

Foundation design involves a soil study to establish the most appropriate type of foundation and a structural design to determine footing dimensions and required amount of reinforcement.

Because compressive strength of the soil is generally much weaker than that of the concrete, the contact area between the soil and the footing is much larger than that of the columns and wall.

A computer program with **VBA** software was developed, entitled **FSD** programme, to design shallow foundation in accordance with **BS9811-1997**.

1.2. Problem Statement and Significance

The design of the foundations requires practical and scientific experience in the case of the use of computer programs that analyze and design based on the method of the finite elements method **FEM**. Using this software sometimes gives errors when modeling the foundations, this always happen in case of definition of materials for the structural elements of the models or when extracting or exporting the results of reactions from one software to another.

When dealing with package to design foundations without practical experience in the use of this software, it may result in illogical design results such as giving high values to the necessity of intensifying the area of reinforcement steel in some nodes, by developing software using Visual Basic net Microsoft language. This would enable programming, designing, computing, saving and making installable format of the program besides other features to help structural engineering those using manual design.

1.3. Research Objectives

The general objectives of the study are:

1. Develop structural computer programme (Excel VBA programme) for analysis and design footings (Shallow foundations) for personal computers that it can make flexural and shear design and draw structural details according to BS9811-1997.
2. Save time in exporting the results and modeling to software for the design of footings and make drawing for design results.

3. To better understand the differences between the results obtained using the simplified method which used in excels VBA program and results obtained from finite element Software.

1.4. Research Methodology

The method of this research is based on analysis and design of footings by developing structural computer software (Excel VBA programme) based on **BS9811-1997**. Comparison of the results obtained by excel VBA program and Finite Element Program Software (SAFE) was also done.

1.5. Research Outline

This thesis has five chapters as shown below.

Chapter one: includes the introduction of research and

Chapter two: is literature Review and previous studies.

Chapter three: includes the research methodology.

Chapter four: results and discussion design from FSD software and SAFE software.

Chapter five: summarizes the research conclusions and recommendations.

Chapter Two

Literature Review

2.1 Introduction

Visual Basic for Applications (VBA for short) is a programming environment prepared to work with Microsoft's Office applications (Word, Excel, Access and PowerPoint). Components in each application (for example, worksheets or documents) are exposed as objects to the programmer to use and manipulate to a desired end.

Almost anything can be done through the normal use of the Office application can also be automated through programming. VBA is a complete programming language, but can't be used outside the application in which it is integrated. This does not mean VBA can be integrated only with Office programs. Any software vendor that decides to implement VBA can include it with their application.

VBA is relatively easy to learn, but to use it in a new application; one must first become familiar with the object model of the application. For example, the Document and Dictionary objects are specific to the Word object model, whereas the Workbook, Worksheet and Range objects are specific to the Excel object model. As proceed, one will see that the Excel object model is fairly extensive; however, if person is familiar with Excel, he will find that using these objects is generally straightforward.

2.2 Procedural Programming

Procedural programming has been the most common programming method. Examples of procedural programming languages are PASCAL, FORTRAN, and C. In procedural programming the data and functions are separate entities within the program. Data variables have to be declared as global in order for functions in the program to have access to these variables. The use of global variables increases the possibility of functions accidentally changing the data. The data and functions of procedural programs do not model real life objects and program development is significantly more difficult. Furthermore, the maintaining of data and functions of a large complex program becomes a difficult task. For smaller programs these disadvantages are not as noticeable. Procedural programming is still widely used 1.

2.3 Type of Footings

The type of footing chosen for a particular structure is affected by the following:

- The bearing capacity of the underlying soil.
- The magnitude of the column loads.
- The position of the water table.
- The depth of foundations of adjacent buildings.

Footing may be classified as deep or shallow. If depth of the footing is equal to or greater than its width, it is called deep footing; otherwise it is called shallow footing. Shallow footings comprise the following types:

2.3.1. Isolated Footings

An isolated footing is used to support the load on a single column. It is usually either square or rectangular in plan. It represents the simplest, most economical type and most widely used footing. Whenever possible, square footings are provided so as to reduce the bending moments and shearing forces at their critical sections. Isolated footings are used in case of light column loads, when columns are not closely spaced, and in case of good homogeneous soil. Under the effect of upward soil pressure, the footing bends in a dish shaped form. An isolated footing must, therefore, be provided by two sets of reinforcement bars placed on top of the other near the bottom of the footing. In case of property line restrictions, footings may be designed for eccentric loading or combined footing is used as an alternative to isolated footing. Figure 2.1 shows square and rectangular isolated footings.

The depth to which foundations shall be carried is to satisfy the following:

a. Ensuring adequate bearing capacity.
b. In footing should be located sufficiently below maximum scouring depth.
c. The footing should be located away from top soils containing organic materials.
d. The footing should be located away from unconsolidated materials such as garbage.
e. All footings shall extend to a depth of at least 5m below natural ground level. On rock or such other weather-resisting natural ground, removal of the top soil may be all that is required .in such cases, the surface shall be cleaned, so as to provide a suitable bearing. Usually footings are located at depth of 1.5 to 2.0 meters below natural ground level.

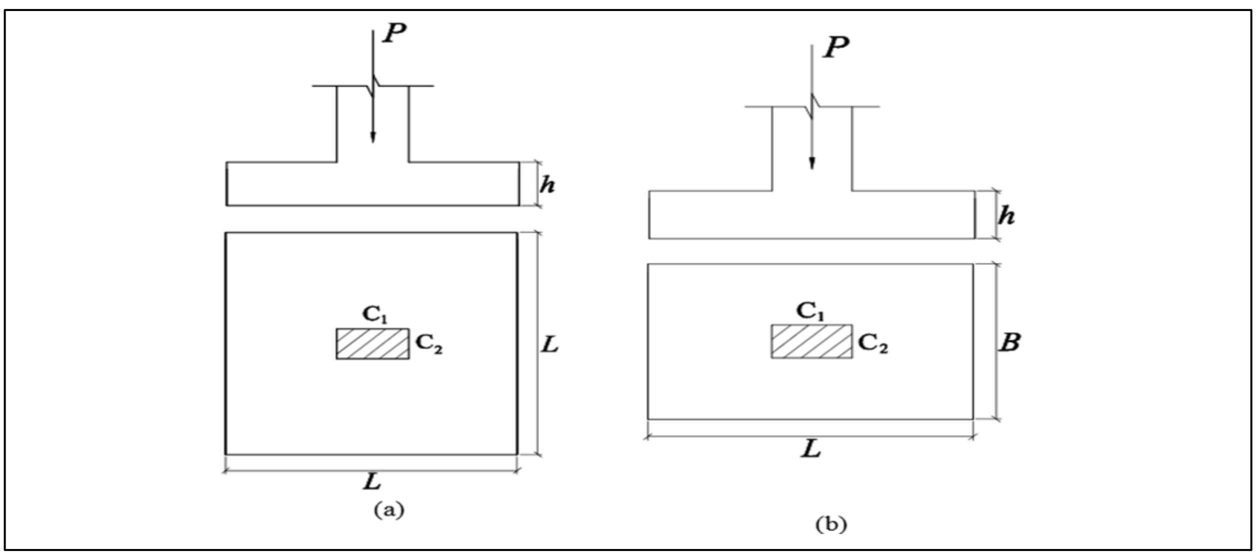

Figure 2.1 (a) Square isolated footing; (b) Rectangular isolated footing

The distribution of soil pressure under a footing is a function of the type of soil, the relative rigidity of the soil and the footing, and the depth of foundation at level of contact between footing and soil. A concrete footing on sand will have a pressure distribution similar to Figure 2.2.a. when a rigid footing is resting on sandy soil; the sand near the edges of the footing tends to displace laterally when the footing is loaded. This tends to decrease in soil pressure near the edges, whereas soil away from the edges of footing is relatively confined. On the other hand, the pressure distribution under a footing on clay is similar to Figure 2.2.b. As the footing is loaded, the soil under the footing deflects in a bowl-shaped depression, relieving the pressures under the middle of the footing. For design purposes, it is common to assume the soil pressures are linearly distributed. The distribution will be uniform if the centroid of the footing coincides with resultant of the applied loads, as shown in Figure 2.2.

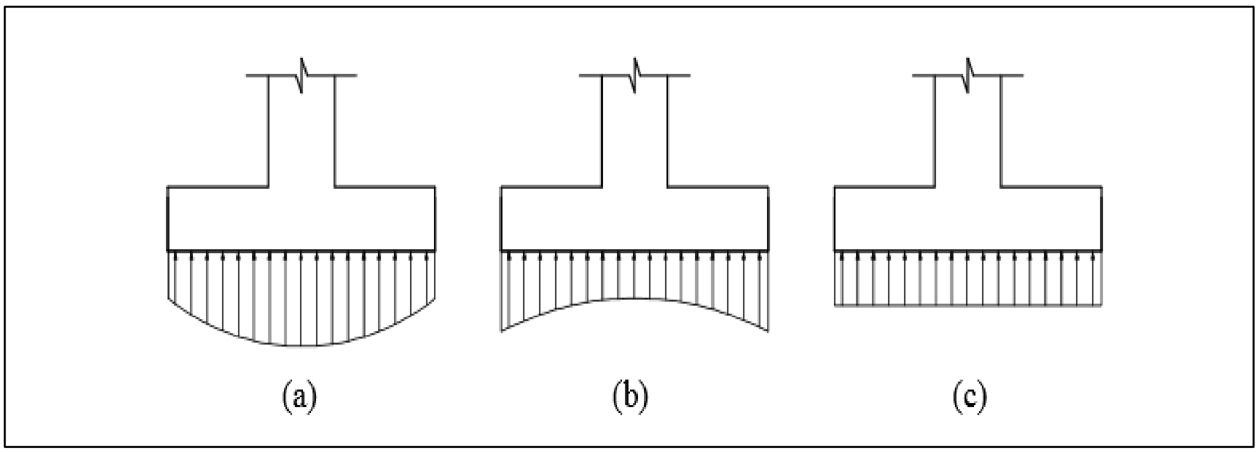

Figure 2.2: Pressure distribution under Footing; (a) footing on sand; (b) footing on clay; (c) equivalent uniform distribution

The maximum intensity of loading at the base of foundation which causes shear failure of soil is called ultimate bearing capacity of soil, denoted by $\mathbf{q_u}$ .The intensity of loading that the soil carries without causing shear failure and without causing excessive settlement is called allowable bearing capacity of soil, denoted by $\mathbf{q_a}$. It should be noted that $\mathbf{q_a}$ is a service load stress. The allowable bearing capacity of soil is obtained by dividing the ultimate bearing capacity of soil by a factor of safety on the order of 2.50 to 3.0.

The allowable soil pressure for soil may be either gross or net pressure permitted on the soil directly under the base of the footing. The gross pressure represents the total stress in the soil created by all loads above the base of the footing. These loads include(a) column service loads; (b) the weight of the footing; and (c) the weight of the soil on the top of the footing, or

$$q_{gross} = q_{soil} + q_{footing} + q_{column} \qquad 2.1$$

For moment and shear calculations, the upward and downward pressures of the footing mass and the soil mass get cancelled. Thus, a net soil pressure is used instead of the gross pressure value, or

$$q_{net} = q_{gross} - q_{footing} - q_{soil} \qquad 2.2$$

Figure 2.3 shows schematic representation of allowable gross and net soil pressures.

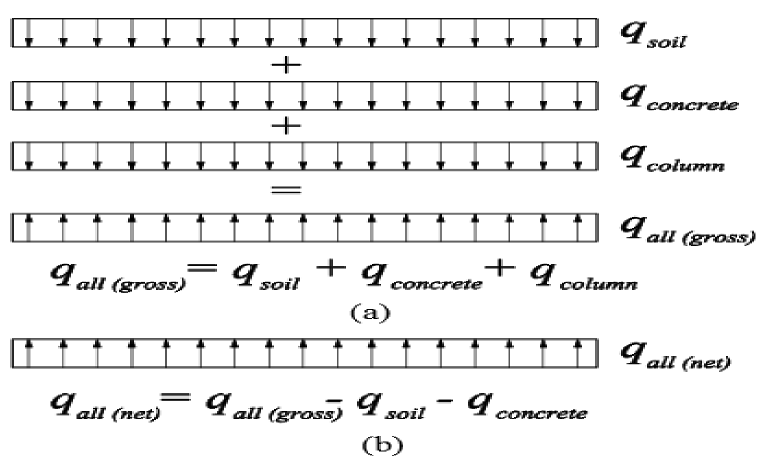

Figure 2. 3: Gross and net soil pressures; (a) gross soil pressure ;(b) net soil pressure

If the resultant of the loads acting at the base of the footing coincides with the centroid of the footing area, the footing is concentrically loaded and a uniform distribution of soil pressure is assumed in design, as shown in Figure 2.4. The magnitude of the pressure intensity is given by

$$q = \frac{\boldsymbol{P}}{\boldsymbol{A}} \tag{2.3}$$

Where A is the bearing area of the footing, and P is the applied load.

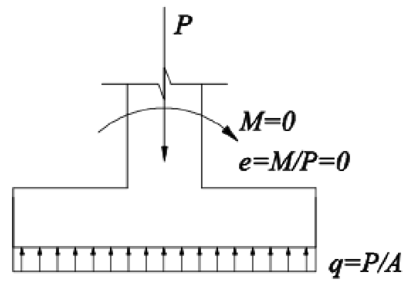

Figure 2. 4: **Concentrically loaded footing**

Although it is always desirable to load footings axially to ensure uniform settlement and to minimize soil pressures, footings are often designed for both axial load and moment. Moment may be caused by lateral forces due to wind or earthquake and by lateral soil pressures. If the resultant of the loads acting at the base of the footing does not coincide with the centroid of the footing area, the footing will be eccentrically loaded and the distribution of the soil pressure will not be uniform. Depending on the extent of the eccentricity of the load relative to the dimensions of the base area, one of the following cases may occur:

Case (a): e ≤ L/ 6

The resultant lies within the middle third of the length of the footing. In this case the pressure distribution on the soil is given by

$$q_{max} = \frac{P}{A}\left(1+\frac{6e}{L}\right) \tag{2.4}$$

$$q_{min} = \frac{P}{A}\left(1-\frac{6e}{L}\right) \tag{2.5}$$

Where L is the length of the footing, and e is the eccentricity of load. In this case, compressive stresses develop over the entire base of the footing, as shown in Figure 2.5.

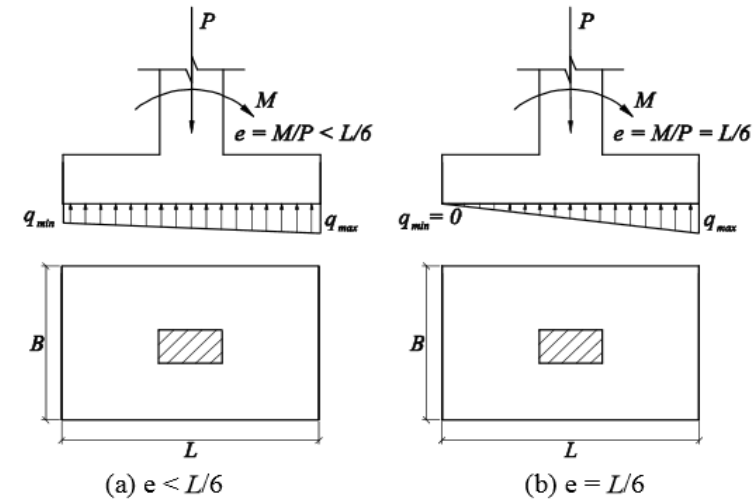

Figure 2.5: Eccentrically loaded footings (e ≤ L/6)

Case (b): e > L/ 6

Large eccentricities cause tensile stresses on part of the base area of the footing. Since soil cannot resist tensile stresses, redistribution of stresses is necessary to maintain equilibrium. The maximum pressure associated with this stress redistribution is established by knowing that the centroid of the soil pressure is located directly under the vertical component of the applied load. With the dimensions of the footing established and the eccentricity of the vertical load known, the distance between the resultant of the applied load P and the outside edge a can be established. The length of base on which the triangular distribution of soil pressure acts is equal to 3a. Equating the resultant of the soil pressure to the applied forces gives

$$P = \frac{q_{max}\, 3aB}{2} \qquad 2.6$$

$$q_{max} = \frac{2P}{3aB} \qquad 2.7$$

Where a = L/ 2 − e, and B is the width of footing, as shown in Figure 2.6

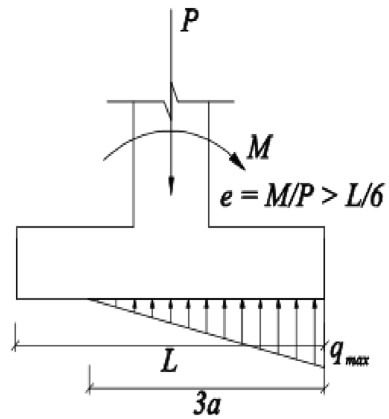

Figure 2.6: **Eccentrically loaded footing (e > L/6)**

2.3.2 Combined footing

Whenever two or more columns in a straight line are carried on a single spread footing, it is called a combined footing. Isolated footings for each column are generally the economical. Combined footings are provided only when it is absolutely necessary, as

- When two columns are close together, causing overlap of adjacent isolated footings.
- Where soil bearing capacity is low, causing overlap of adjacent isolated footings.
- Proximity of building line or existing building or sewer, adjacent to a building column.

Types of Combined footings are:

● May be rectangular, trapezoidal or Tee-shaped in plan. The geometric proportions and shape are so fixed that the centroid of the footing area coincides with the resultant of the column loads. This results in uniform pressure below the entire area of footing.

● Trapezoidal footing is provided when one column load is much more than the other. As a result, the both projections of footing beyond the faces of the columns will be restricted.

● Rectangular footing is provided when one of the projections of the footing is restricted or the width of the footing is restricted

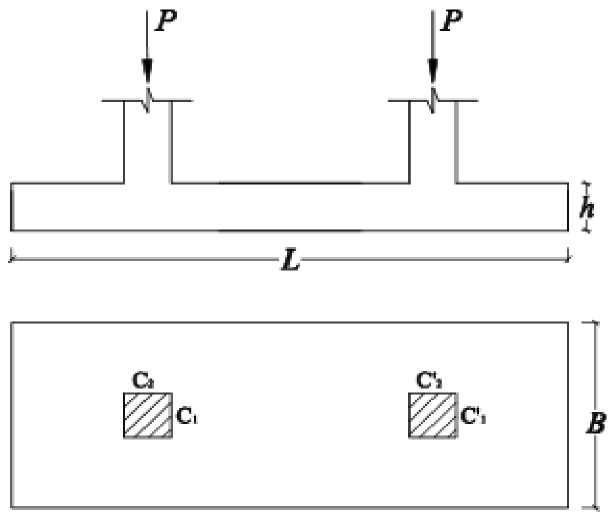

Figure 2. 7: **Rectangular Combined footing with loads**

● Longitudinally, the footing acts as an upward loaded beam spanning between columns and cantilevering beyond. Using statics, the shear force and bending moment diagrams in the longitudinal direction are drawn. Moment is checked at the faces of the column. Shear force is critical at distance ‘d’ from the faces of columns or at the point of contra flexure. Two-way shear is checked under the heavier column. Show in Figure 2.8.

● The footing is also subjected to transverse bending and this bending is spread over a transverse strip near the column as shown in Figure 2.9.

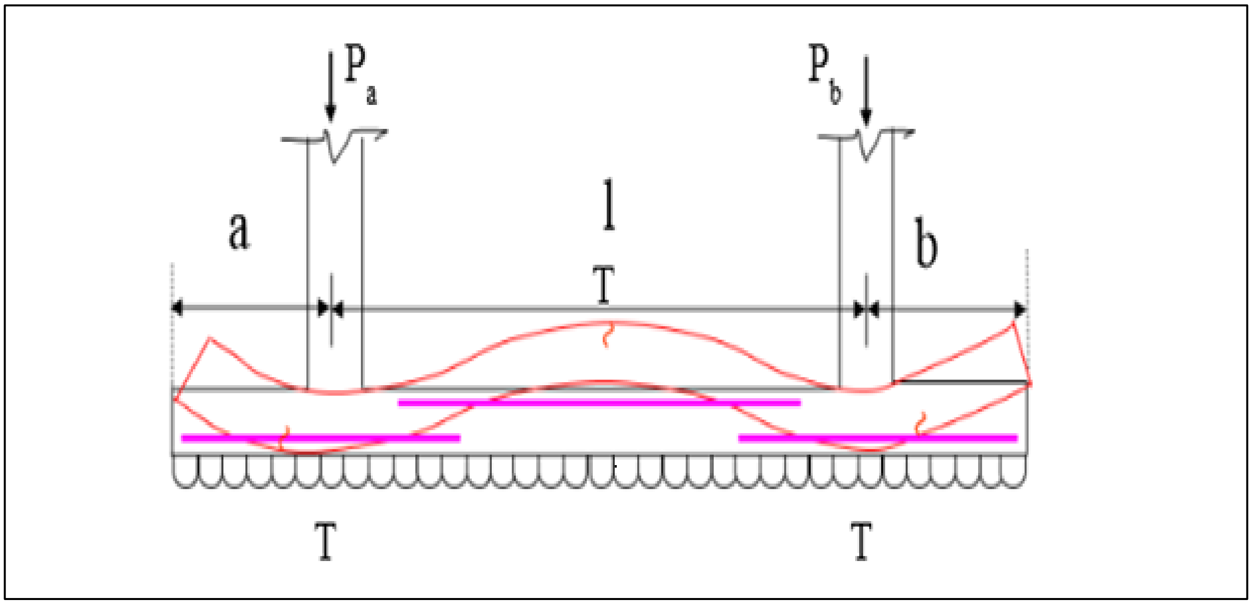

Figure 2. 8: **Longitudinal Bending**

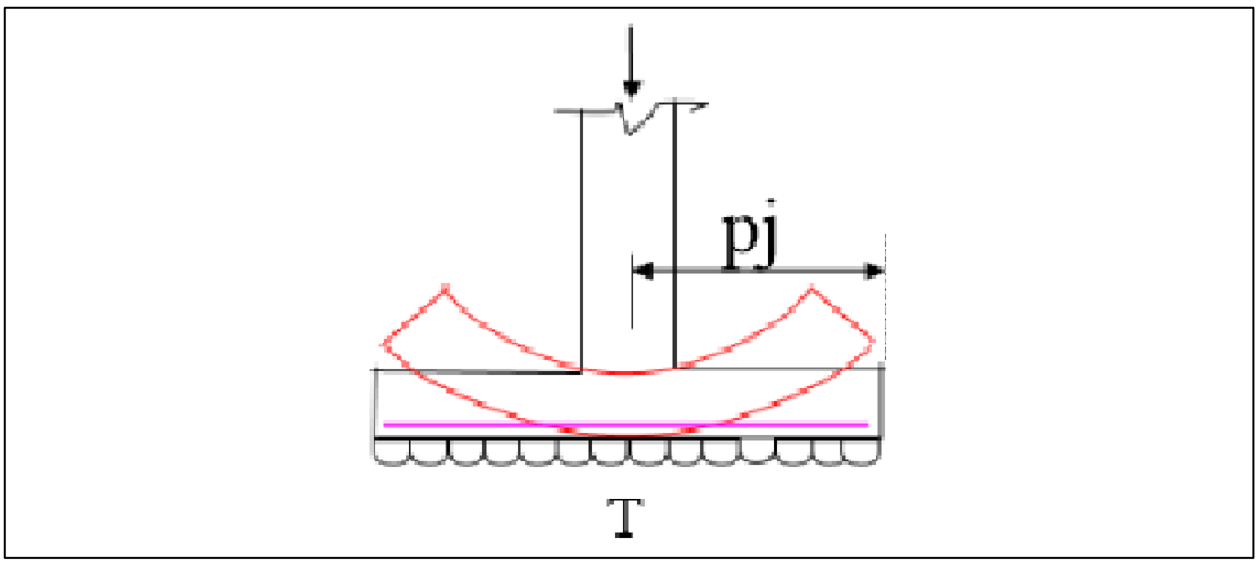

Figure 2.9: **Transverse Bending**

2.3.3 Raft footing

This is a footing that covers the entire area that structure. This footing is used when very heavy loads of building are to be transmitted to the underlying soil having very low and differential bearing capacities. Due to its rigidity, it minimizes differential settlement as shown in Figure 2.10.

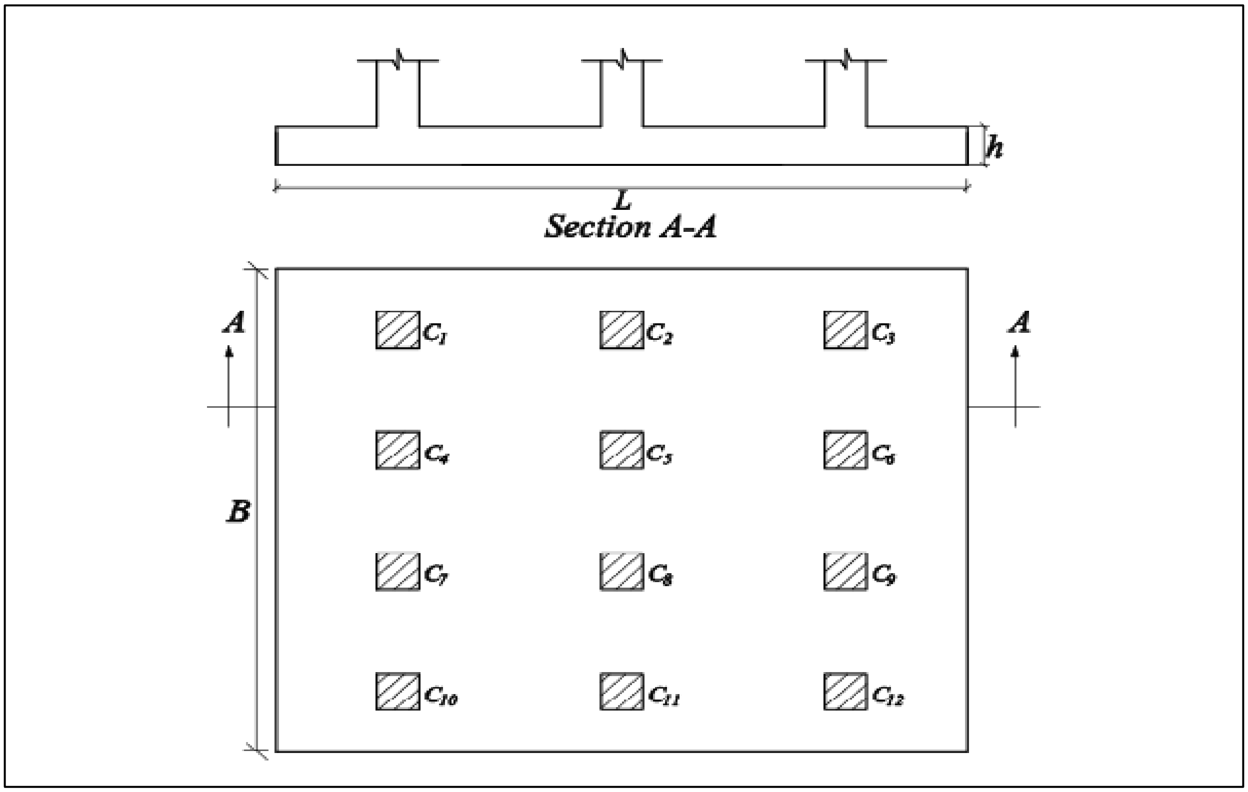

Figure 2.10: Raft Footing

The problem of analysis and design of mat foundation had attracted the attention of engineers and researchers for a long time. This is because mat foundations are frequently associated with major multistoried structures founded on different types of soils.

The mat foundation is one type of shallow foundations and widely used in the world. This study focused on optimizing conventional rigid method, this method is characterized by its simplicity and ease in execution. On the other hand, the resultant of column loads for each of the strips doesn't coincide with the resultant of soil pressure and therefore this can be attributed to the shear forces present at the interfaces of the consecutive strips. Consequently, this leads to a violation of the equilibrium equations summation of forces in the vertical direction and the summation of moments around any point are not adjacent or even close to zero, indeed a few researchers had tried in the past to find a solution for this fictitious problem.

The conventional rigid method is characterized by its straightforwardness and ease in implementation by civil engineering design practitioners. In contrast, the resultant of column loads for each of the strips is not equal and does not coincide with the resultant of soil pressure and this can be attributed to the shear forces present at the interfaces of the successive adjacent strips.

This study focused on optimizing conventional rigid method, this method is characterized by its simplicity and ease in execution. On the other hand, the resultant of column loads for each of the strips doesn't coincide with the resultant of soil pressure and therefore this can be attributed to the shear forces present at the interfaces of the consecutive strips.

Consequently, this leads to a violation of the equilibrium equations summation of forces in the vertical direction and the summation of moments around any point are not adjacent or even close to zero, indeed a few researchers had tried in the past to find a solution for this fictitious problem. For instance, proposed two sets of modification factors, one for column loads and the other for soil pressures at both ends of each of the individual strips.

These modifications factors result in satisfying equilibrium equation of vertical forces, summation of forces in the vertical direction is close to zero, therefore the construction of shear force diagrams can be worked out but this is not the case when engineer try to construct a moment diagram as the equilibrium equation is not satisfied as the summation of moments around any point do not go to zero. As a result, constructing a correct bending moment diagram is a challenge. This is because the factors applied are not suited to balance the total resultant force of columns from top to the resultant force of the applied pressure under mat as both forces are never passing through the same line of action.

This study will offer a solution to crack down the problem when constructing bending moment diagram for each individual strip for the mat by finding out factors that will make the resultant force of columns from top and the resultant force of the applied pressure under mat are equal and overlap.

The researcher will supply a solution based on the finding factors that modify column loads and soil pressure separately and to construct two individual shears and bending moments as result followed by proposing a new suggested better fit solution for the analysis of the conventional rigid method. In additions FSD software will analyze mat foundation strips using the mentioned above proposed optimum solution by the researcher.

In a comparison to the approximate flexible method, the conventional rigid method requires larger amounts of flexural reinforcement because the distribution of soil pressure is only permitted in one direction not in both directions as of that in approximate flexible method therefore it is clear evidence that the obtained steel reinforcements employing approximate flexible method will be with no doubt less that of using the conventional method.

The flexible method requires the determination of coefficients of subgrade reaction K, in order to carry out the analysis. The coefficient of subgrade reaction is a mathematical constant that denotes the foundation's stiffness. The coefficient of subgrade reaction is the unit pressure required to produce a unit settlement.

The value of the coefficient of subgrade reaction varies from place to another and not constant for a given soil, it depends upon a number of factors such as length, width and shape of foundation and also the depth of embedment of the foundation and usually determined using empirical equations in terms of the allowable bearing capacity of the soil.

The conventional rigid method is based on Winkler's concept of shear free elastic springs in conjunction with the assumption of the mat as rigid which leads to determine contact pressure distribution.

Winkler (1867) developed a model to simulate Soil-Structure Interaction. The interaction basic assumption is based on the idea that the soil-foundation interaction force p at a point on the surface is directly proportion to the vertical displacement ΔZ of the point as shown in Figure 2.11. Thus,

$$\mathrm{K} = P\Delta Z \qquad 2.8$$

Where K is the stiffness or modulus of sub-grade reaction.

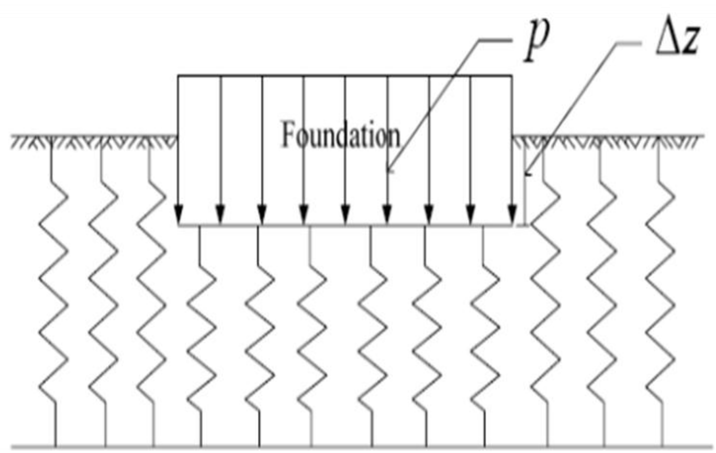

Figure 2.11: Foundation Layout

The analysis and design of mat foundations is carried out using different methods and techniques such as the conventional rigid method, the approximate flexible method, the finite difference method and the finite element method as can be seen in Figure 2.12.

The coefficient of subgrade reaction known as subgrade modulus or modulus of subgrade reaction is a mathematical constant that denotes the foundation's stiffness. The common symbol for this coefficient is k; it defined as the ratio of the pressure against the mat to the settlement at a given point,

$$K = \frac{q}{\delta} \quad 2.9$$

The coefficient of subgrade reaction is the unit pressure required to produce a unit settlement and the value of the coefficient of subgrade reaction is not a constant for a given soil; it depends upon a number of factors such as length, width and shape of foundation in addition to the depth of embedment of the foundation and the range of The coefficient of subgrade reaction for soil show in **table2.1.**

This proposed solution will consider both the columns loads on the strip and the applied soil pressure under the mat for the same strip at once, this strip will be modified by finding the average loads and factors for the applied column loads to make the value of the resultant of column loads equal and coincide with that of the average loads and factors for the applied soil pressure under the strip in addition to putting together the resultant of the soil reaction equal and coincide with the average applied column loads where the influence point for the average column load is at midpoint between the influence points of column loads and soil reaction before applying the modifications factors.

Two factors will be applied to make the resultant of the modified column load equal and coincide with the average loads, the first factor will be multiplied with the columns loads on the left side of the resultant of the modified column loads while the second factor will be multiplied by the columns loads on the right side of the resultant of modified column loads then finding the values of the maximum and minimum pressure under the studied strip at both ends. The constructed shear force and bending moment diagrams can then be easily sketched.

Table2.1: Coefficient of subgrade reaction K for different soils

Type of Soil	Condition Of Soil	Value of K (kN/m^3)
Dry or moist Sand	Lose	800 to25000
	Medium	25000 to125000
	Dense	125000 to375000
Saturated Sand	Lose	10000 to15000
	Medium	35000 to4000
	Dense	130000 to150000
Clay	Stiff	12000 to25000
	Very Stiff	25000to50000
	Hard	>50000

2.4 Previous Studies

There have been many advances in information technology and educational institutions have worked to utilize these advances. Educational institutions have realized the importance of creating new methods for teaching engineering concepts and have turned to technology to aid in their development. When teaching complex engineering concepts and theories in standard lecture environments, students do not always easily grasp the information being presented. However, when these concepts and theories were presented in a virtual environment and there was interaction with instructive programs, Haque found that a student's understanding of the material was improved. Hence, demonstrating the effectiveness and the need for interactive programs.

With the development of the World Wide Web (WWW), information can be easily accessed through the Internet. The Internet has become a useful tool which provides quick, easy and relatively inexpensive access to interactive learning. Another advantage to interactive learning through the Internet from web-based documents is that it allows students to learn at their own pace.

Haque 2001 conducted research to create an innovative structural design concept visualization methodology on a web-based interactive virtual environment. He developed a web-based interactive virtual environment for the design of flexural and shears behavior of reinforced concrete beams using Java and Virtual Reality Modeling Languages (VRML). This visual environment used for reinforced beams can be applied to other design concepts to enhance a student's subject visualization and conceptual understanding.

Mishra 2001 developed applets to monitor a flagpole. This purpose of this research was to develop technology to monitor structures under duress, such as during an earthquake by providing real time information. The applets created for the flagpole perform analysis and obtain information from archived data. One of the analysis applets includes real time stress/ strain limits of the flagpole. Another applet shows a visual representation of the flagpole and its real time deflections.

Jiang 2002 created three virtual laboratory modules which educate students on reinforced concrete structures. These modules are based on applets, which perform the calculations involved in the analysis of reinforced concrete sections. One module allows the user to explore the flexural design of rectangular singly reinforced concrete beams. Another module shows the axial force, moment, curvature relationships for rectangular beam and column sections. The last module explores the relationship of uniaxial stress-strain for confined and unconfined reinforced concrete.

Gao 2003 developed a Java-powered virtual laboratory for nonlinear structural dynamic analysis. This visual environment allows users to understand structural dynamic concepts related to designing structures for seismic loads. The number of stories, the floor mass, stiffness, and damping coefficients of each story of the structure can be selected by the user. Features of the program include graphs of the dynamic analysis results and an animation of the virtual building.

Rojiani 2001 developed several web based instructional units using Java These instructional units, embedded in WWW pages where they are called applets, were developed to assist undergraduate students in the conceptualization of structural mechanics. The applets developed included shear, moment and deflection of beams; computation of section properties of sections built up from standard geometric shapes; and shear center for open and closed section thin-walled tubes. These interactive applets were made accessible to any student with a computer and Internet access.

An overview of object oriented programming was presented in this chapter. The most commonly used procedural programming paradigm was presented. The characteristics of object oriented programming including classes, objects, inheritance, encapsulation, abstraction and polymorphism were briefly discussed. The advantages and disadvantages of object oriented programming were also presented. A brief description of the Java programming language was also presented. In the last section, a review of the application of Java in structural engineering was presented.

Soggy, Robert (2012) Solutions for soil and structural systems using excel and VBA programs. A practical guide to analyzing soil and structural systems using Excel spreadsheets and VBA macro programs (in open–source code).

ATENA user Richard Malm (2014) says in his Ph.D. thesis: “One advantage using ATENA for the finite element analysis is that it calculates all material properties based on the cube strength with equations from Model Code 2010. Another great advantage with this program is that it is specially designed for concrete, which makes it easier for the user since good default values are given. The main advantage is that, even though the analysis described severe cracking, the program never had problems finding a convergent solution. A novice user can rather easy create advanced models in ATENA."

With ATENA one can simulate real behavior of concrete and reinforced concrete structures including concrete cracking, crushing and reinforcement yielding. ATENA gives person the power to check and verify your structural design in a user friendly graphical environment.

LUSAS is a trademark and trading name of Finite Element Analysis Ltd. , Last modified: February 17, 2017. Civil & Structural LT provides quick and easy to use linear static analysis using 2D/3D structural beams and grillages.

This LT version will be of particular interest to companies wishing to standardize and expand on their use of LUSAS software throughout their organization and with Standard and Plus versions provides a ‘one stop solution’ for all analysis requirements.

Because all levels of the products use the same user interface and terminology, training costs can be minimized and users can be introduced to LUSAS at the most appropriate level for the work they need to do. There is also full data compatibility across the product range allowing easy migration of a model to a more advanced analysis when required without any data conversion or remodeling.

JBeam4.0.0 2012-01-01by Schwebke software development is a Java 6 application for introductory level two-dimensional static and dynamic structural analysis. It supports arbitrary hinged Euler-Bernoulli and Timoshenko beams and truss elements.

Truss works allows users to easily create and analyze 3D structures using the Direct Stiffness Method. It models truss structures that can carry axial loads. The click and drag interface lets one input two-dimensional structures, but the program can take in and perform calculations for three-dimensional structures as well using a text based XML input. Also included is a database of steel cross-sections and their corresponding geometric properties developed by a colleague and adapted for the programs, as well as material properties of the most commonly used engineering materials, the program is intended to be free to use, the primary target audience being undergraduate engineering students and faculty.

Chapter Three

Research Methodology

3.1 Introduction

Procedural Programming (PP) has been the methodology of choice for the development of most engineering software. However, there has been a recent interest in developing engineering software using the Object Oriented Programming (OOP) methodology. This is due to the fact that OOP has significant advantages over procedural programming. One advantage of OPP is that it uses single entities called objects, which combine data and functions (Objects represent real life objects). For instance, in the programs written for this research, objects such as a joint, a support, and a member were developed.

In large engineering programs using PP, the program can become quite complex with separate entities. With OPP, the program is easier to understand and manage. Another advantage is that OPP possesses characteristics such as inheritance, abstraction and encapsulation. These characteristics allow programs to be reusable and easier to maintain. Furthermore, most OPP languages provide class libraries that reduce the time and effort of developing applications.

Building Information Modeling (BIM) is the usage of computer programs that have the ability to communicate to each other either through application programming interface (API) or through compatible file formats.

BIM that will be used as a popular example throughout the thesis is the architect using Autodesk to develop the concept and working design, the structural engineer using ETABS analysis and design software, BIM can be any number of different software communicating with each other but the quick and easy access to information is the main focus.

BIM advantages are not limited to only the architects, engineers, even people without professional training can benefit from the organization of a large amount of information in an easy-to-view three-dimensional model.

This chapter describes the methodology followed to achieve the objective of this research which is summarized in three stages as illustrated on the flow chart shown in Figure 3.1. The first stage comprised the creation footing analysis and design program for this study by aid of many software application programs namely; Excel VBA code, **ETABS** (API) and **CAD** (API).

The second stage of the study involved the data analysis and results of footing. The FSD program can automatically open the model created on **ETABS** and run the analysis by button existing on the program. The results of analysis obtained from **ETABS** will then export to **FSD programme**.

The third stage of the study included the design of footing based on the results of the analysis obtained from **ETABS**. The results that have been obtained from the analysis must be studied carefully based on the objectives.

The fourth stage of the study involved the output of **FSD programme** which consist of displaying the results of the design results on **CAD** drawing and **PDF** file.

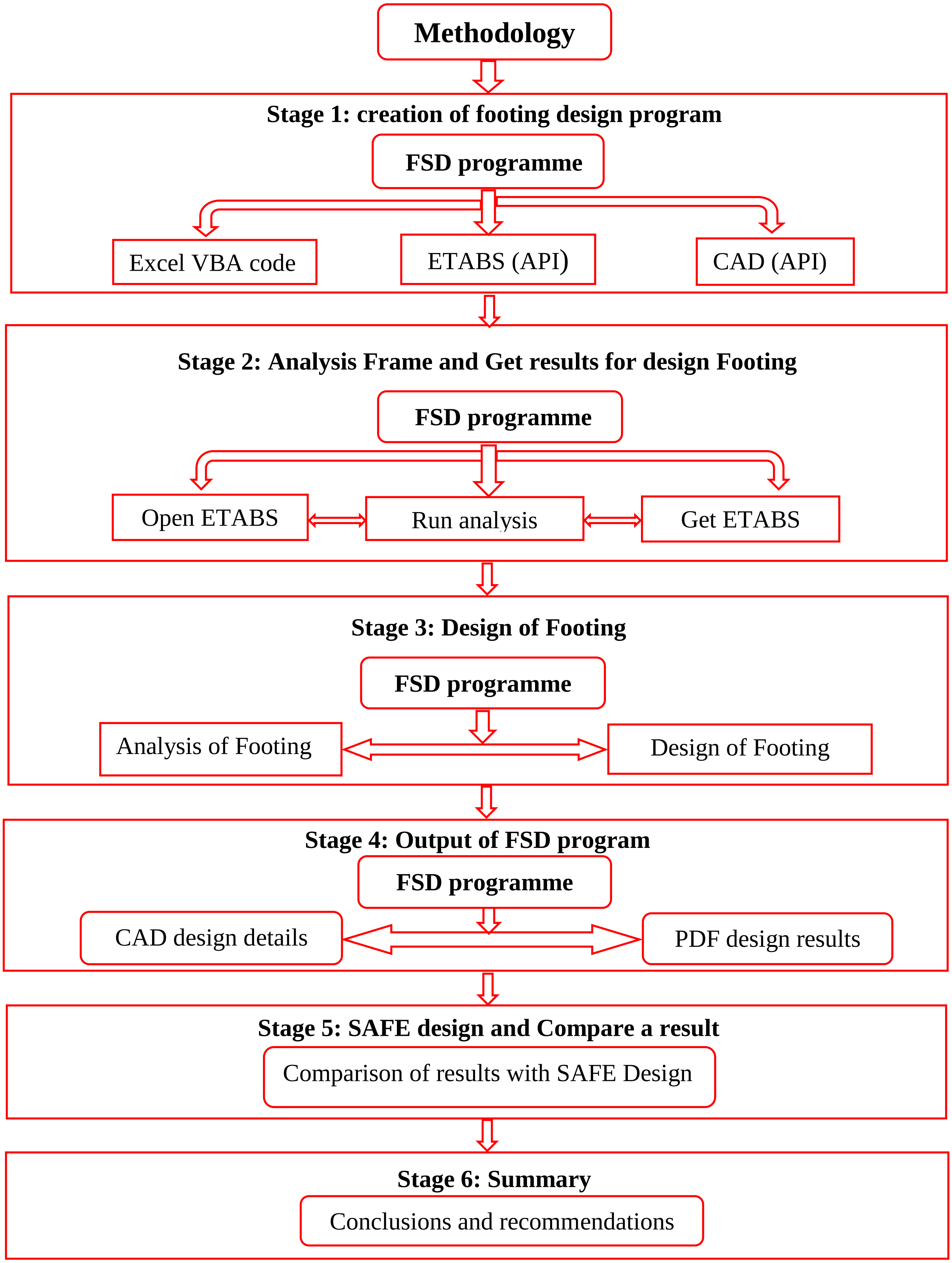

Figure 3.1: Flow Chart of the Methodology

3.2 Process of FSD Programme

The Process of work revolves around 5 main aspects as shown in Figure 3.2. The first step is created ETABS model and save it. The second step **FSD** Programme is run analysis throw ETABS. Thirdly, **FSD** Programme design is run. Fourthly, design result presented in CAD VBA code to sketch the structural detailing. Finally, **FSD** programm**e** Design Results printed in PDF format.

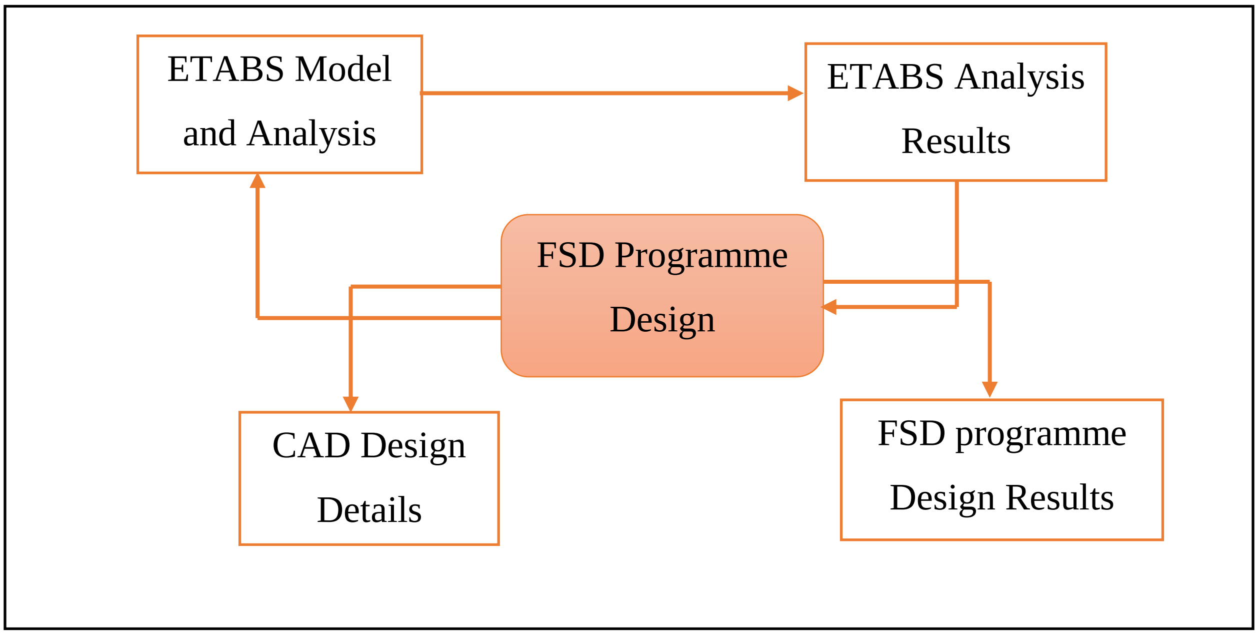

Figure 3. 2: Process of FSD program

3.3 Theoretical Methodology

In order to be able to perform the structural analysis, firstly, the structure will be modeled on **ETABS** for better understanding of its operation mode and the reactions exerted on the supporting members of **ETABS** Model. The results would also be especially useful in the **FSD** Program design for the footings.

Secondly, the **FSD Program** will be open the ETABS model and run analysis throw **ETABS** API function and VBA code in the program. Thirdly, the **FSD** Program design the footing by using VBA code of procedures design footing according to British Standard (BS). Fourthly, use the program design result in CAD

VBA code to sketch the structural detailing. Fifthly, export the model analysis result from ETABS to **SAFE** and design footing on it to compare **FSD** results with **SAFE** software, the **FSD** program displays the design results such as in PDF format.

3.3.1 Modeling on ETABS

The following provides a broad overview of the basic modeling, analysis, design and detailing processes:

- Specific model initialization; Select the Base Units and Design Codes, Use the grid Dimensions (Plan) area of the form to define a grid line system, Use the Story Dimensions area of the form to define the number and height of stories.
- Change for unique name in base joint by given the corner joint first litter (C) and middle joint (M) and (E) for edge joint. The second litter for all joint had same litter (C) to refer to column.
- Define the model properties; material, frame section, and slab sections; and load patterns, combinations (SLS) for Serviceability limit state and (ULS) for ultimate limit state.
- Draw model, Select Objects and Assignment operations include properties, restraints.
- Assign load for model; the load patterns defined in the previous section are required in order to be able to assign loads to joints, frames, and shells.
- Set the mesh options; if the model is floor objects that have plate bending behavior such as cast-in- place slabs, review the meshing options before running the analysis
- After a complete structural model has been created using the preceding commands, the model can be analyzed to determine the resulting displacements, forces/stresses and reactions. The program saves the data.

3.3.2 Steps and Equations of Analysis and Design in FSD Programme Calculations

3.3.2.1 Isolated footing

Step 1: Get maximum reactions from column (ETAB analysis result)

F_z = maximum vertical reaction serviceability limit state (SLS)

F_{zu} = maximum vertical reaction ultimate limit state (ULS)

- **Find Area of footing:**

$$A=\frac{F_z}{q_{all}} \qquad 3.1$$

For square footing

$B=\sqrt{A}$ L=B

For rectangular footing assume value for B (meters)

$$L=\frac{A}{B}$$

Step 2: Calculate bearing pressure under footing at corners:

A. In serviceability limited state:

- For type 1 axial load plus biaxial moment:

$$P_1=\left(\frac{F_Z}{LB}\right)+\left(\frac{6M_Y}{BL^2}\right)+\left(\frac{6M_x}{LB^2}\right) \qquad 3.2$$

$$P_2=\left(\frac{F_Z}{LB}\right)+\left(\frac{6M_Y}{BL^2}\right)-\left(\frac{6M_x}{LB^2}\right) \qquad 3.3$$

$$P_3=\left(\frac{F_Z}{LB}\right)-\left(\frac{6M_Y}{BL^2}\right)-\left(\frac{6M_x}{LB^2}\right) \qquad 3.4$$

$$P_4=\left(\frac{F_Z}{LB}\right)-\left(\frac{6M_Y}{BL^2}\right)+\left(\frac{6M_x}{LB^2}\right) \qquad 3.5$$

- **For type 2 axial load plus moment about x-direction:**

P_1=P_4=$\left(\frac{F_Z}{LB}\right)$ + $\left(\frac{6M_x}{LB^2}\right)$ 3.6

P_2=P_3=$\left(\frac{F_Z}{LB}\right)$–$\left(\frac{6M_x}{LB^2}\right)$ 3.7

- **For type 3: Axial load plus moment about Y-direction:**

P_1=P_4=$\left(\frac{F_Z}{LB}\right)$- $\left(\frac{6M_Y}{BL^2}\right)$ 3.8

P_2=P_3=$\left(\frac{F_Z}{LB}\right)$ -$\left(\frac{6M_Y}{BL^2}\right)$ 3.9

- **For type4: Axial load:**

P=$\left(\frac{F_Z}{LB}\right)$ 3.10

B. In ultimate limited state:

- **For type1: axial load plus biaxial moment:**

P_1=$\left(\frac{F_{Zu}}{LB}\right)$ + $\left(\frac{6M_{Yu}}{BL^2}\right)$ +$\left(\frac{6M_{xu}}{LB^2}\right)$ 3.11

P_2=$\left(\frac{F_{Zu}}{LB}\right)$ +$\left(\frac{6M_{Yu}}{BL^2}\right)$ -$\left(\frac{6M_{xu}}{LB^2}\right)$ 3.12

P_3=$\left(\frac{F_{Zu}}{LB}\right)$- $\left(\frac{6M_{Yu}}{BL^2}\right)$ -$\left(\frac{6M_{xu}}{LB^2}\right)$ 3.13

P_4= $\left(\frac{F_{Zu}}{LB}\right)$ -$\left(\frac{6M_{Yu}}{BL^2}\right)$ +$\left(\frac{6M_{xu}}{LB^2}\right)$ 3.14

- **For type 2: Axial load plus moment about x-direction:**

P_1=P_4=$\left(\frac{F_{Zu}}{LB}\right)$ + $\left(\frac{6M_{xu}}{LB^2}\right)$ 3.15

P_2=P_3=$\left(\frac{F_{Zu}}{LB}\right)$–$\left(\frac{6M_{xu}}{LB^2}\right)$ 3.16

For type2: Axial load plus moment about Y-direction:

P_1=P_4=$\left(\frac{F_{Zu}}{LB}\right)$- $\left(\frac{6M_{Yu}}{BL^2}\right)$ 3.17

P_2=P_3=$\left(\frac{F_{Zu}}{LB}\right)$ -$\left(\frac{6M_{Yu}}{BL^2}\right)$ 3.18

For type4 axial load:

P_u=$\left(\frac{F_{Zu}}{LB}\right)$ 3.19

Step 4: Stability of footing:

- **Check for bearing capacity:**

Maximum pressure in serviceability limit state (SLS) ≥ $q_{allowable}$ "that is ok".

- **Calculate factor of safety against sliding**

F.S= $\frac{F_s}{H} \geq 1.5$ 3.20

$F_s = F_Z \times \mu$ 3.21

$\mu = \tan\delta$ 3.22

- **calculate factor of safety of overturning moment**

$M_0 = M_x$ or M_y

F.S = $\frac{M_R}{M_0} \geq 2$ 3.23

$M_R = 0.5B \times F_z$ or 3.24

$M_R = 0.5B \times F_{zu}$ 3.25

Step5: Calculate ultimate design moment (M_U) at critical section (column face)

$$M_{ux} = \frac{P_{uavg} \times B \times [(L-h)/2]^2}{2} \qquad 3.26$$

$$M_{uy} = \frac{P_{uavg} \times L \times [(B-b)/2]^2}{2} \qquad 3.27$$

Step 6: Calculate ultimate shear

a. At d from column face

At x-direction

$$v_u = \left[\left(\frac{L-h}{2}\right) - d\right] \times P_{uavg} \qquad 3.28$$

At y-direction

$$v_u = \left[\left(\frac{B-h}{2}\right) - d\right] \times P_{u\,avg} \qquad 3.29$$

Step 7: Flexural design

Calculate area of tension reinforcement and distribution

$$k = \frac{M_u}{f_{cu} B d^2} \leq 0.156 \qquad 3.30$$

$$z = d\left[0.5 + \sqrt{\left(0.25 - \frac{K}{0.9}\right)}\right] \leq 0.95d \qquad 3.31$$

$$As = \frac{M}{0.95 f_y z} \qquad 3.32$$

- **Check minimum reinforcement for flexure**

Minimum tensile reinforcement in both directions (**f_y= 460N/mm^2**).

Provide this minimum reinforcement also top of the foundation where top reinforcement is required for flexure.

$$As_{min} = 0.0013Bh \qquad 3.33$$

Check: $A_s \geq As_{min}$

Step 8: Check shear stress

i.One-way shear (At d from column face)

- **X-direction**

$v_1 = \frac{V_u}{Bd} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser. 3.34

- **Y-direction**

$v_2 = \frac{V_u}{Bd} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser. 3.35

Where

- **The concrete punching shear factored strength is taken as**

$v_c = \frac{0.79K_1K_2}{\gamma_m}\left(\frac{100A_S}{bd}\right)^{1/3}\left(\frac{400}{d}\right)^{1/4}$ (BS 3.4.5.4 Table 3.8) 3.36

And is conservatively taken as 1 (BS 3.4.5.8)

$k_2 = \left(\frac{f_{cu}}{25}\right)^{1/3} \geq 1$ (BS 3.4.5.4 Table 3.8) 3.37

$\gamma_m = 1.25$ (BS 3.4.5.2) 3.38

- **However, the following limitations also apply**:

$0.15 \leq \frac{100\,As}{bd} \leq 3$ (BS 3.4.5.4 Table 3.8) 3.39

$\left(\frac{400}{d}\right)^{1/4} \geq 1$ (BS 3.4.5.4) 3.40

Check:

$v_1 \leq 2v_c$

$v_2 \leq 2v_c$

- **punching shear (two way)**

a. at column perimeter

$v_0 = \frac{N_u}{U_0 d} \leq 0.8\sqrt{f_{cu}}$ or $5N/mm^2$ whichever is the lesser 3.41

$v_0 \leq v_c$

$U_0 = 2\ (h + b)$

b. at 1.5d from column face

$v_1 = \frac{N_u}{U_1 d} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm2 whichever is the lesser 3.42

$v_1 \leq v_c$

Where

$U_1 = (U_0 + 12d)$

3.3.2.2 Combined footing:

Step1: Find maximum reactions from column (ETAB analysis result)

Step2: Dimensions of footing

Find maximum vertical load in column 1 (N_1) and column 2 (N_2)

$N_1 = F_{z1}$+self-weight footing

$N_2 = F_{z2}$+self-weight of footing

Area= $\frac{N_1+N_1}{q_{all}}$ 3.43

- **Find located R of service load**

$\overline{X} = \frac{N_2 \times s}{R}$ 3.44

$R = N_1 + N_2$

- **Length and width of footing**

Assume E_{x1}

L=$[E_{x1} + \bar{X}]\times 2$ 3.45

$E_{x2}=L - S - E_{x1}$ 3.46

Width=B= $\frac{A}{L}$ 3.47

Step3: Ultimate pressure (P_u)

Find maximum ultimate vertical load in column 1 (N_{u1}) and column 2 (N_{u2})

$N_{u1}=F_{zu1}$+ self-weight of combined footing

$N_{u2}=F_{zu2}$+ self-weight of combined footing

$P_u= \frac{N_{u1}+N_{u2}}{BL}$ 3.48

- **Factored load per length in longitudinal direction**

$W_{u1} = P_u\times B$ 3.49

- **Factored load per length in longitudinal direction**

$W_{u2} = P_u\times L$ 3.50

Step 4: Shear force and bending moment diagram: from diagram

- **Bending Moment:**

1. Moment at face of column1 (M_1)

2. Moment at face of column 2 (M_2)

3. Moment at mid span between columns(M_3)

- **Shear Force:**

v_{u3}= Shear force at column $1 - \mathrm{W_{u1}}(\mathrm{d} + \mathrm{h})$ 3.51

v_{u4} =Shear at column $2 - \mathrm{W_{u2}}(\mathrm{d} + \mathrm{h})$ 3.52

Step5: Flexural design

- Bending moment due to ultimate loads ($\mathrm{M_u}$)

For Bottom take $\mathrm{M_u}$ is max moment from M_1 and $\mathrm{M_2}$

For top take $\mathrm{M_u}$ moment at mid span between columns $\mathrm{M_3}$

- Calculate area of tension reinforcement and distribution

$$K = \frac{\mathrm{M_u}}{f_{cu}\mathrm{Bd^2}} \leq 0.156 \quad 3.53$$

$$z = d\left[0.5 + \sqrt{\left(0.25 - \frac{K}{0.9}\right)}\right] \leq 0.95d$$

$$A_s = \frac{\mathrm{M_u}}{0.95 f_y \mathrm{z}} \ \mathrm{mm^2} \quad 3.54$$

$\frac{A_s}{B} \rightarrow \mathrm{mm^2/m}$

- **Check minimum reinforcement for flexure**
- Minimum tensile reinforcement in both directions (f_y= 460N/mm^2).

As_{min}=0.0013Bh

Check: $\mathrm{A_s} \geq \mathrm{As}_{min}$

- Reinforcement in transverse bending

$$M_4 = W_{u2} \times \left[\frac{B-b}{2}\right]^2 \quad 3.55$$

$$\mathrm{A_s} = \frac{\mathrm{M_4}}{0.95 f_y z} \ \mathrm{mm^2} \quad 3.56$$

$\frac{A_S}{L} \rightarrow$ mm^2/m

- Minimum tensile reinforcement ($\boldsymbol{f_y}$= 460N/mm^2).

As_{min}= 0.0013Lh 3.57

Check: $A_s \geq As_{min}$

- **Check shear stress**

One-way shear (At d from column face)

Shear stress for column 1:

- **X-direction**

$v_1 = \frac{V_{u1}}{Bd} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser.

- **Y-direction**

$v_2 = \frac{V_{u1}}{Ld} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser.

Shear stress for column 2:

- **X-direction**

$v_2 = \frac{V_{u2}}{Bd} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser

- **Y-direction**

$v_2 = \frac{V_{u2}}{Ld} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser

The concrete punching shear factored strength is taken as

$$v_c = \frac{0.79K_1K_2}{\gamma_m}\left(\frac{100A_S}{bd}\right)^{1/3}\left(\frac{400}{d}\right)^{1/4}$$

Check:

$v_1 \leq 2v_c$

$v_2 \leq 2v_c$

- **punching shear (two way)**
- **at column perimeter**

$v_0 = \frac{N_u}{U_0 d} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser

$v_0 \leq v_c$

- **at 1.5d from column face**

$v_1 = \frac{N_u}{U_1 d} \leq 0.8\sqrt{f_{cu}}$ or 5N/mm^2 whichever is the lesser.

$v_1 \leq v_c$

Where

$U_1 = (U_0 + 12d)$

3.3.2.3 Raft footing:

Step1: Determine the line of action of all the loads acting on the mat

$$Q = Q_1 + Q_2 + Q_3 = \sum Q_i \quad 3.58$$

The eccentricities e_x and e_x are found by summing moment about any convenient location (usually a line of column).

About X' and Y' coordinates

$$\bar{x} = \frac{Q_1 X1 + Q_2 X2 + Q_2 X3}{\sum Q} \quad 3.59$$

$$e_x = \bar{x} - \frac{B}{2} \quad 3.60$$

$$\bar{y} = \frac{Q_1 y_1 + Q_2 y_2 + Q_3 y_3}{\sum Q} \quad 3.61$$

$$e_y = \bar{y} - \frac{L}{2} \quad 3.62$$

Step2: Determine the allowable pressure q on the soil below the mat at corner

Points and check whether the pressure values are less than the allowable bearing pressure

$$q = \frac{Q}{A} \pm \frac{M_X Y}{I_x} \pm \frac{M_y X}{I_y} \quad 3.63$$

Where

$$I_x = \frac{BL^3}{12} \quad 3.64$$

$$I_y = \frac{LB^3}{12} \quad 3.65$$

$$M_x = \sum Q.\, e_y \quad 3.66$$

$$M_y = \sum Q.\, e_x \quad 3.67$$

Step3: Determine the mat thickness based on punching shear at critical column based on column load and shear perimeter.

Step4: Divide the mat into strips in x and y directions. Each strip is assumed to act as independent beam subjected to the contact pressure and the columns loads.

Step5: Determine the modified column load

As explained below, it is generally found that the strip does not satisfy static equilibrium, i.e. the resultant of column loads and the resultant of contact pressure are not equal and they do not coincide. The reason is that the strips do not act independently as assumed and there are some shear transfers between adjoining strips. Considering the strip carrying column loads Q_1, Q_2 and Q_3 as seen in Figure

3.1, let B_1be the width of the strip and let the average soil pressure on the strip q_{ava} and let B the length of the strip.

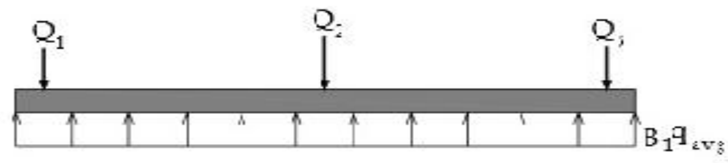

Figure 3.3 :A layout of strip

$$Q_{avg} = \left[\frac{\sum Qi + q_{avg} B_1 B}{2} \right] \quad 3.68$$

The modified average soil pressure ($q_{avg,mod}$) is given by

$$q_{avg,mod} = q_{avg} \left[\frac{Q_{avg}}{q_{avg} B_1 B} \right] \quad 3.69$$

The column load modification factor F is given by

$$F = \left[\frac{Qavg}{Q_1 + Q_2 + Q_3} \right] \quad 3.70$$

All the column loads are multiplied by F for that strip. For this strip, the column loads are $F_{Q1}F_{Q2}$ and F_{Q3}, the modified strip is shown in Figure 3.4.

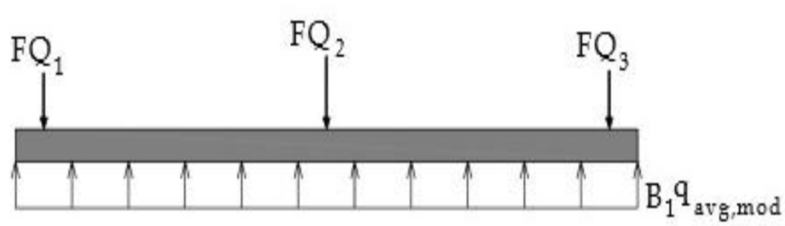

Figure 3.4: A modified strips layout

Step6: The bending moment and shear force diagrams are drawn for the modified column loads and the modified average soil pressure $q_{ava,mod}$. That is for all strips in x-direction and strips in y-direction.

Step7: Design the individual strips for the bending moment and shear force.

- **Bending moment due to ultimate loads (M_u)**

From diagram of bending moment, the moments of x and y strips will be used to design the top and the bottom reinforcement for the raft. The maximum moments in each direction will be used to design the reinforcement in all raft strips.

Take maximum moment M_{ux} at strips in x-direction and maximum moment M_{uy} at strips in y-direction.

- **Calculate area of tension reinforcement and distribution**
- **X-Strip design:**

Positive moments (Top reinforcement)

$$k = \frac{+M_{ux}}{f_{cu} B d^2} \leq 0.156$$

$$z = d\left[0.5 + \sqrt{\left(0.25 - \frac{K}{0.9}\right)}\right] \leq 0.95d$$

$$A_s = \frac{+M_{ux}}{0.95 f_y z} \text{ mm}^2$$

$$\frac{A_s}{B} \rightarrow \text{mm}^2/\text{m}$$

- **Check minimum reinforcement for flexure**

Minimum tensile reinforcement in both directions (**f_y= 460N/mm²**).

As_{min}=0.0013Bh

Check: $A_s \geq As_{min}$

- **Negative moments (Bottom Reinforcement):**

$$K = \frac{-M_{ux}}{f_{cu} B d^2} \leq 0.156$$

$$z = d\left[0.5 + \sqrt{\left(0.25 - \frac{K}{0.9}\right)}\right] \leq 0.95d$$

$$A_s = \frac{-M_{uy}}{0.95 f_y z} \text{ mm}^2$$

$$\frac{A_s}{B} \rightarrow \text{mm}^2/\text{m}$$

- **Check minimum reinforcement for flexure**

Minimum tensile reinforcement in both directions (f_y= 460N/mm^2).

As_{min}=0.0013Bh

Check: $A_s \geq As_{min}$

- **Y-strip Design:**

Positive moments (Top Reinforcement):

$$k = \frac{+M_{uy}}{f_{cu}Bd^2} \leq 0.156$$

$$z = d\left[0.5 + \sqrt{\left(0.25 - \frac{K}{0.9}\right)}\right] \leq 0.95d$$

$$A_s = \frac{+M_{uy}}{0.95 f_y z} \text{ mm}^2$$

$$\frac{A_s}{B} \rightarrow \text{mm}^2/\text{m}$$

- **Check minimum reinforcement for flexure**

Minimum tensile reinforcement in both directions (**f_y= 460N/mm^2**).

As_{min}=0.0013Bh

Check: $A_s \geq As_{min}$

Negative moments (Bottom Reinforcement):

$$K = \frac{-M_{uy}}{f_{cu}Bd^2} \leq 0.156$$

$$z = d\left[0.5 + \sqrt{\left(0.25 - \frac{K}{0.9}\right)}\right] \leq 0.95d$$

$$A_s = \frac{-M_{uy}}{0.95 f_y z} \text{ mm}^2$$

$$\frac{A_s}{B} \rightarrow \text{mm}^2/\text{m}$$

- **Check minimum reinforcement for flexure**

Minimum tensile reinforcement in both directions (f_y= 460N/mm^2).

As_{min}= 0.0013Bh

Check: $A_s \geq As_{min}$

- **Check punching shear (two way)**

Given the punching shear force and the fractions of moments transferred by eccentricity of shear about the bending axis, the nominal design shear stress, V_{max}, is calculated as:

$$V_{eff,x} = V\left[f + \frac{1.5M_x}{V_y}\right] \quad \text{(BS 3.7.6.2, 3.7.6.3)} \quad 3.71$$

$$V_{eff,y} = V\left[f + \frac{1.5M_y}{V_x}\right] \quad \text{(BS 3.7.6.2, 3.7.6.3)} \quad 3.72$$

$$v_{max} = \max\begin{cases}\frac{V_{eff,x}}{ud} \\ \frac{V_{eff,y}}{ud}\end{cases} \quad \text{(BS 3.7.7.3)} \quad 3.73$$

Where,

$$f = \begin{cases}1.00 & \text{for interior columns} \\ 1.25 & \text{for edge columns} \\ 1.25 & \text{for corner columns}\end{cases} \quad \text{(BS 3.7.6.2, 3.7.6.3)} \quad 3.74$$

- **The shear stress carried by the concrete v_c, is calculate as**:

$$v_c = \frac{0.79\mathrm{K_1K_2}}{\gamma_\mathrm{m}}\left(\frac{100\mathrm{A_S}}{\mathrm{bd}}\right)^{1/3}\left(\frac{400}{\mathrm{d}}\right)^{1/4}$$

Check:

$$v_{max} \leq v_c$$

3.3.3 Modeling and Design Footing in CSI Safe Software

SAFE is a software application based on the finite element method for the engineering analysis, design and detailing of reinforced-concrete and post tensioned slabs, beams and foundations. **SAFE** is a sophisticated, yet easy to use special purpose analysis and design program developed specifically for concrete Slab/Beam, Basement/Foundation system.

SAFE couples powerful object-based modeling tools with an intuitive graphical interface, allowing the user to quickly and efficiently model slabs of regular or arbitrary geometry with openings, drop panels, ribs, edge beams and slip joints supported by columns, walls or soil. The analysis is based upon the finite element method in a theoretically consistent fashion that properly accounts for the effects of twisting moments. Meshing is automated based upon user specified parameters.

Foundations are modeled as plates or thick plates on elastic foundations, where the compression only soil springs are automatically discretized based upon a modulus of subgrade reaction that is specified for each foundation object.

In this Part of the methodology, isolated footing or single footing, combined footing and mat or raft foundation are modeled and design by using **SAFE** software application.

3.3.4 FSD Programing

The FSD programme was created to work alongside ETAB and include variety of feature allowing's an engineer effectively to optimize design of footing.

The FSD programme include license to an application program interfaces (API) for ETAB. This allows for direct links between information in ETAB.

3.3.4.1 Steps of FSD Programme Using API Function

In order to get start, the user must select ETAB model to open, after this is done the FSD open the model selected and been to gather frame, area, coordinate, group and load combination information from ETAB. This gives the user the power to run analysis for the model through API Function written in the FSD programme VBA code in application.

3.3.4.2 FSD Programme VBA Procedure

The basic unit of VBA code it is block of code that tell Excel what to do for design footing. The FSD Programme in Excel is tools that include the VBA IDE (Integrated Development Environment), controls and functions available through the main Excel application and VBA Programing Environment.

3.3.4.3 Designing the FSD Programme

In designing program, the researcher considers the user interfaces program, input and output the location of the code (for example event procedure of active X Controls) and use configuration of the other program.

The researcher starts by making very simple user form interfaces for the FSD Programme. The interface uses command button, list box, text box, combo box and image have altered there.

3.3.4.4 Variables and Data Types

The researcher use focus on spreadsheet cells to introduce variables. Spreadsheet cells are temporary storage containers for input that can be used in number of different format and calculations of design footing in FSD Program.

- **Declaring Variables**

Option Explicit is used to the declared variable in general declarations section of module window to force explicit variable declarations. The following the variable name, the data type is specific for the variable this tell what kind of data can be stored in this variable and How much the Memory must be reserved for it.

- **Sub Procedures**

All procedures are really sub (short for subroutine) procedure.

3.3.5 Case Study one (ETABS Model)

In is this study, a reinforced concrete structure of Six stories was modeled in ETABS as shown in Figure 3.5. The plan of the structure is irregular grid system had different spacing x-direction and Y-direction as show in Figure 3.6.

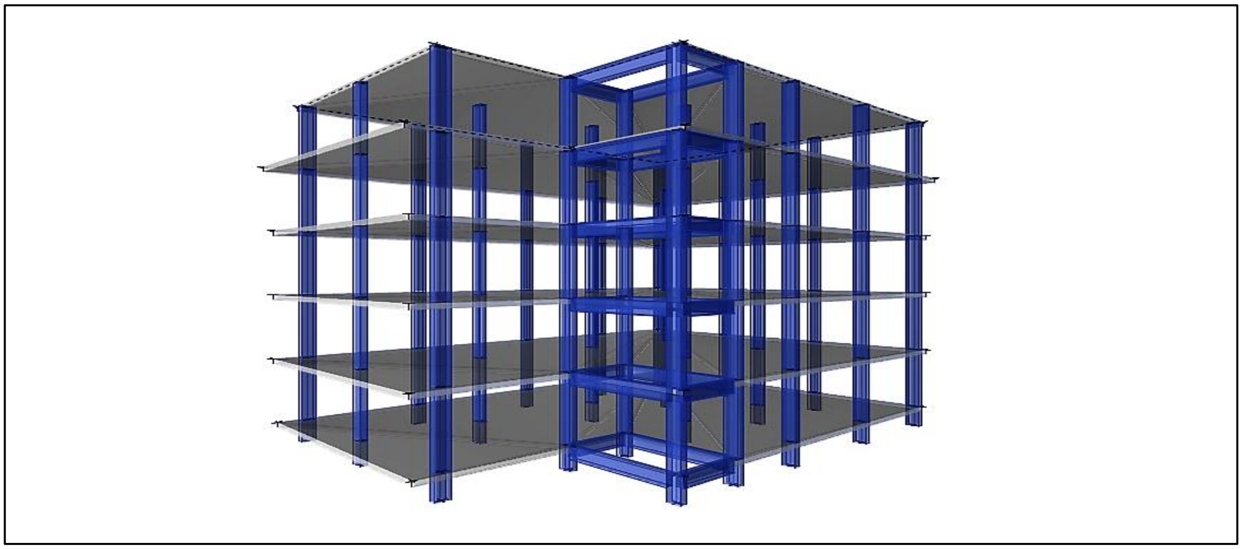

Figure 3.5 : **ETABS Model 3D View**

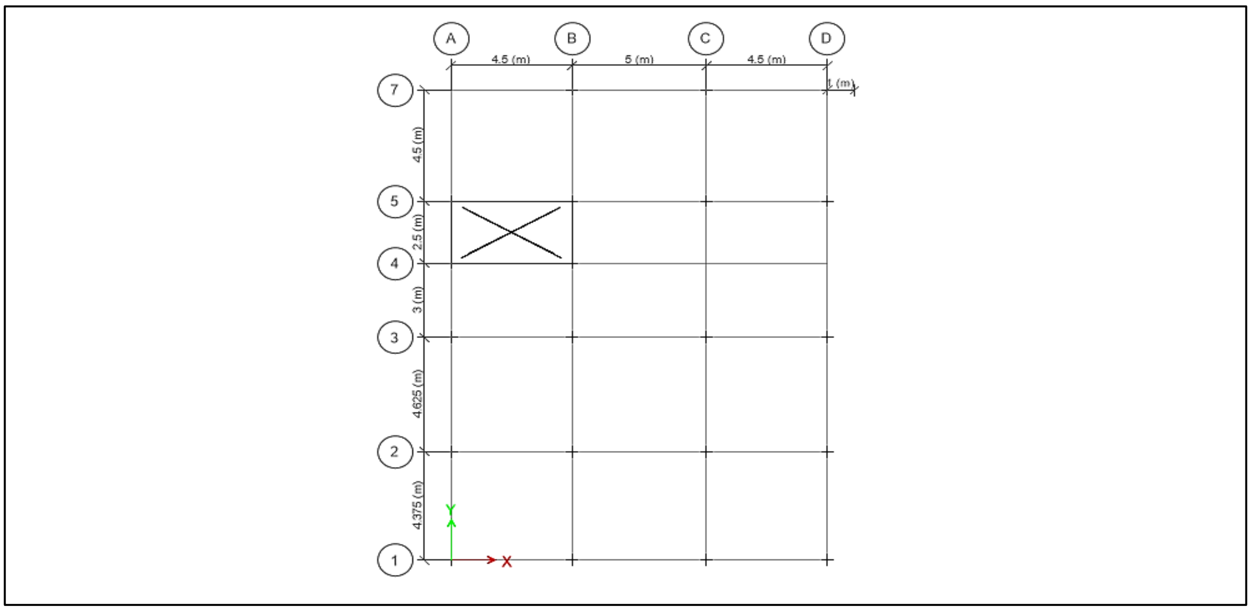

Figure 3.6 : ETABS Model Plan View

3.3.5.1 Isolated Footing Input Design and Parameter

f_{cu} =25 MPa

f_y = 460 MPa

C =50mm

q_{all} = 200 kPa

∅ =16 mm

γ_c = 25 kN/m^3

γ_S = 18 kN/m^3

h = 500mm

b =250mm

H "overall depth of footing"

Middle = 0.5m

Edge = 0.4m

Corner =0.35m

3.3.5.2 Combined Footing Input Design and Parameter

f_{cu} =25 MPa

f_y = 460 MPa

C =50mm

q_{all}= 200 kPa

∅ = 16 mm

γ_c = 25 kN/m^3

γ_S = 18 kN/m^3

h =500mm

b =250mm

H = 0.4m

3.3.5.3 Raft Footing Input Design and Parameter

f_{cu} =25 MPa

f_y =460 MPa

C =50mm

q_{all} = 160 kPa

$\emptyset$ = 20 mm

γ_c = $25kN/m^3$

γ_S = $18kN/m^3$

h =500mm

b =250mm

H =800mm

3.3.6 Case Study two (STAAD. Foundation V8i verification Manual)

3.3.6.1 Isolated footing

In is this study,

Specification:

q_{all} = 200 kN/m^2

A = 2.5m ×2.5m

H=0.5m

f_y = 460 MPa

f_{cu} = 35 MPa

F_z = 1100 kN (800 Dead load + 300 Live load)

M_x = 0 kN.m M_y = 0 kN.m

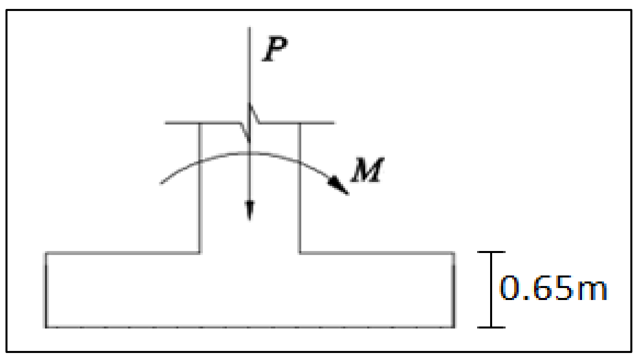

Figure 3.7 : Isolated footing sections for design

3.3.6.1 Combined footing:

(a) Specification

q_{all} = 150 kN/m^2

f_y = 450 MPa

f_{cu} = 25 MPa

c1 = c2 = c3 = c4 = 0.3 m

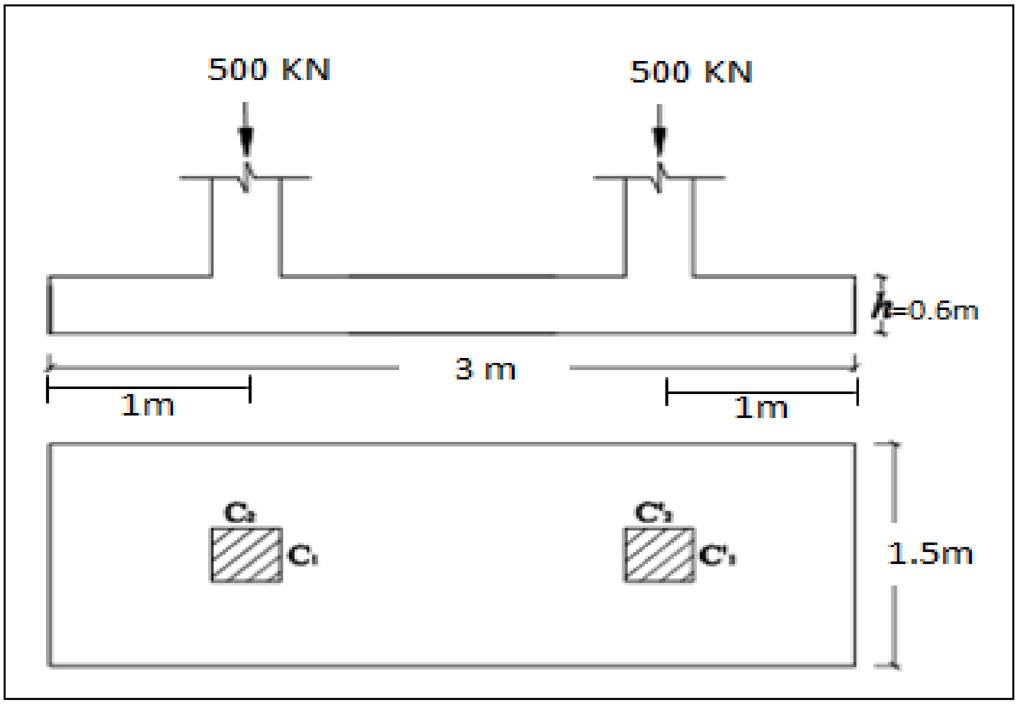

Figure 3.8 : Combined footing sections for design

Chapter Four

Results and Discussion

4.1 Results

As presented in Chapter three, the follow up specifies design of all type of shallow footing by taking base reaction from **ETABS** Model and show what's suitable type of footing. The results obtained from **FSD** programme and **CSI SAFE** are presented and discussed in this chapter.

4.1.1 FSD Programme Design Results of Case Study One

4.1.1.1 Isolated Footing

After running **FSD**, first Step is to design isolated footing. One click (ETABS MODEL) button on main form to access **ETABS** model file (*.edb) and Run Automatic analysis for the model and save the load cases and load combination which used in **ETABS** analysis. The analysis results were shown in Table A.1 and Table A.2 for load combination (SLS) and (ULS) respectively.

Results of FSD software for isolated footing dimensions, design shear force and bending moment**,** flexural and reinforcement, shear stress and Punching shear check for concrete shear strength were presented in Table A.3 - Table A.7

4.1.1.2 Combined Footing

After running **FSD** programme, Automatic analysis for the model and save the load cases and their combinations, which were produced from **ETABS**. The analysis result of columns had small span between them show in Tables A.8 and A.9 for load combination (SLS) and (ULS) respectively.

Results of **FSD** output design for shear force and bending moment, footing dimensions and flexural reinforcement were presented in Tables A.10 to Table A.12.

4.1.1.3 Raft Footing Result

The results of raft footing using **FSD** programme and **CSI SAFE** were studied. For comparison of results, it was selected two strips in x- direction and y- direction for both **FSD** programme and **CSI SAFE**. The results of **FSD** programme for design shear force and bending moment, footing dimensions and flexural reinforcement were presented in Tables A.13- A.15.

4.1.2 CSI SAFE Design Results of Case Study One

4.1.2.1 Isolated Footing

Results of CSI SAFE for footing dimensions, design shear force and bending moment, flexural and reinforcement, shear stress and Punching Shear Check for Concrete Shear Strength were presented in Tables A.16–A.20.

4.1.2.2 Combined Footing

Result of **SAFE** Output for design shear force and bending moment, footing dimensions and flexural reinforcement were presented in Tables A.21-A.23**.**

4.1.2.3 Raft Footing Result

The results of **SAFE** software for design shear force and bending moment, footing dimensions and flexural reinforcement for raft footing were presented in Tables A.24. to A.26.

4.1.3 FSD Programme Results of Case Study Two

4.1.3.1 Isolated Footing

For more verification some examples were taken from STAAD- Foundation V8i verification Manual for isolated footing and combined one. Result of FSD programme Output for Shear Force and Bending Moment, footing dimensions, flexural reinforcement and shear stress were presented in Table A.27- A.30.

4.1.3.2 Combined Footing

Result of **FSD** output for design shear force and bending moment, footing dimensions and flexural reinforcement in Table A.31- A.34.

4.1.4 STAAD- Foundation Verification Manual Results of Case Study Two

4.1.4.1 Isolated Footing

Result of STAAD- Foundation V8i verification Manual for Shear Force and Bending Moment, footing dimensions, flexural reinforcement and shear stress were presented in Table A.35-A.39.

4.1.4.2 Combined Footing

Result of STAAD-Foundation V8i verification Manual output for design shear force and bending moment, footing dimensions and flexural reinforcement in Table A.40-A.42.

4.2 Results Presenting

The Bar Charts are used to show comparison results between **FSD** Programme and **SAFE** software. For different results of bending moment and flexural design of isolated Footing middle footing, Edge footing and corner footing were shown in bar charts of Figure 4.1, Figure 4.2 and Figure 4.3.

Comparison results of bending moment and Flexural design of Combined Footing was shown in bar chart of Figure 4.4 for long direction and Short direction. The bar chart in Figure 4.5 displays comparison results of bending moment and flexural design for X-Strip, and Figure 4.6 displays the comparison results of bending moment and flexural design for Y-Strip. The Bar chart in Figure 4.7 displays comparison results of punching shear for isolated footing. Figure 4.8 shows comparison result of punching shear for combined Footing and charts in Figure 4.9 displays comparison results punching shear for Raft footing.

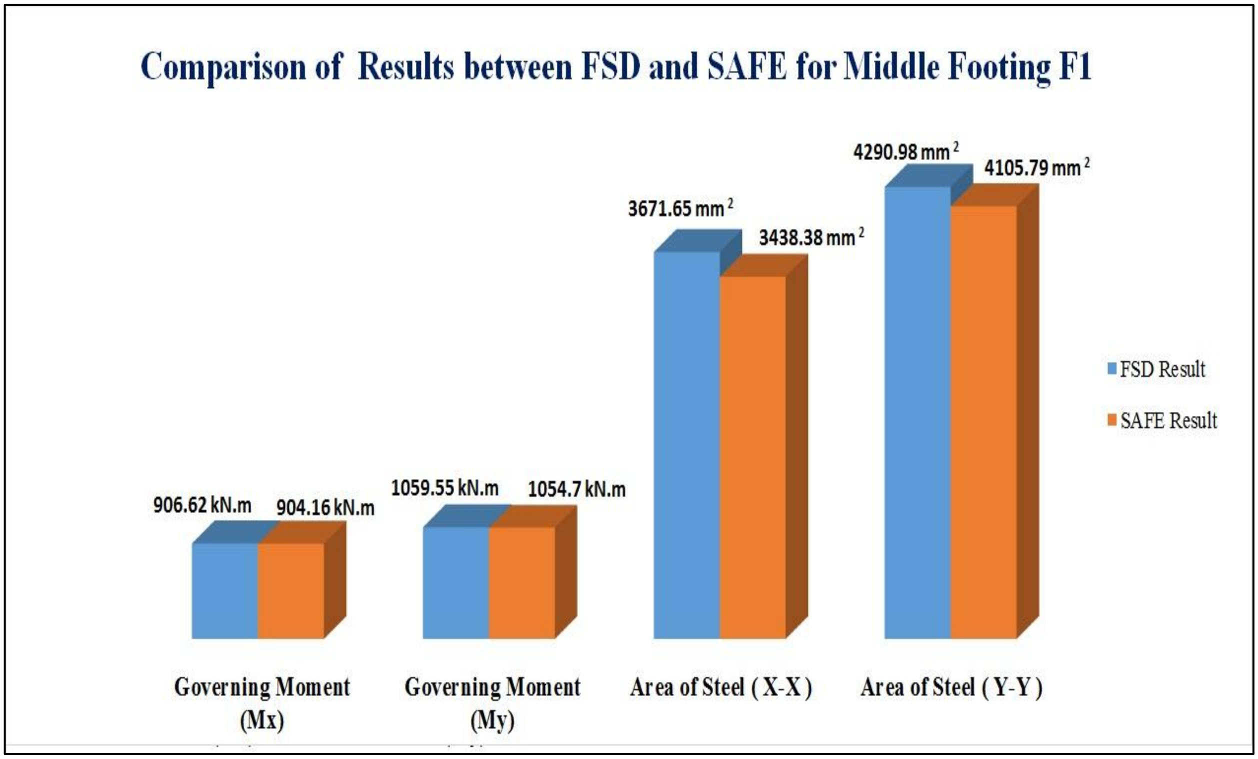

Figure 4.1: Comparison of Bending Moment and Flexural Design F1

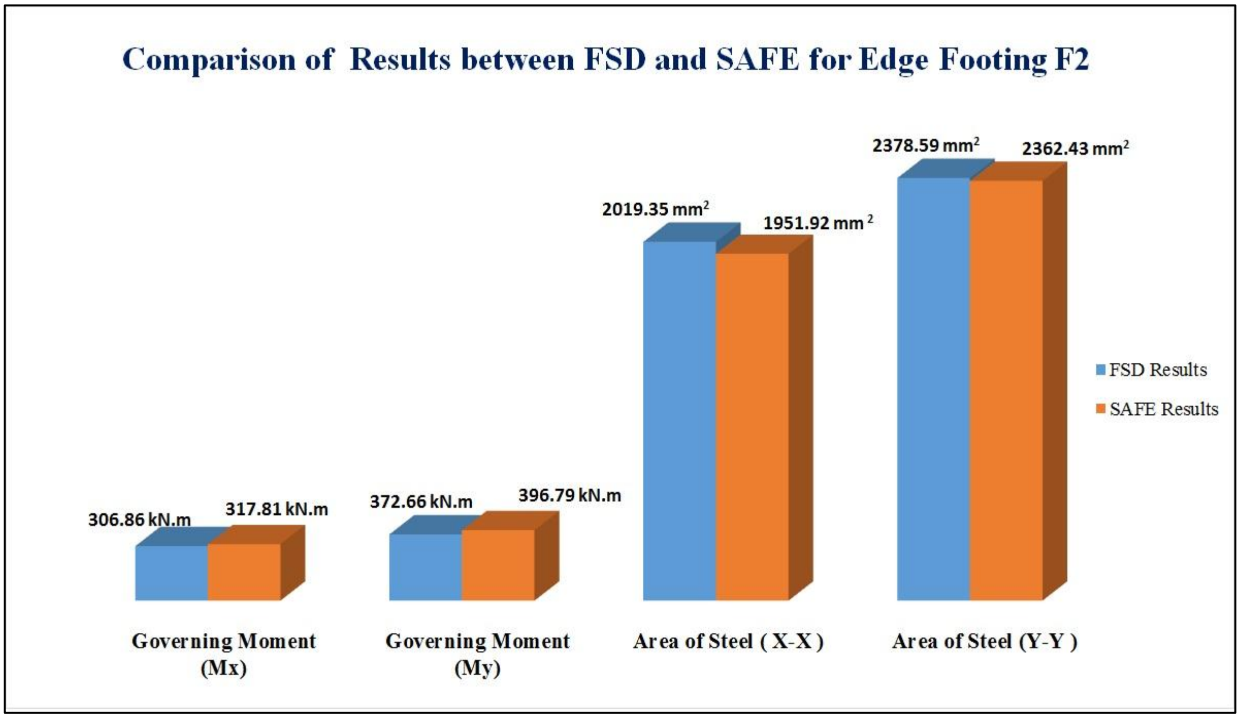

Figure 4.2: Comparison of Bending Moment and Flexural design F2

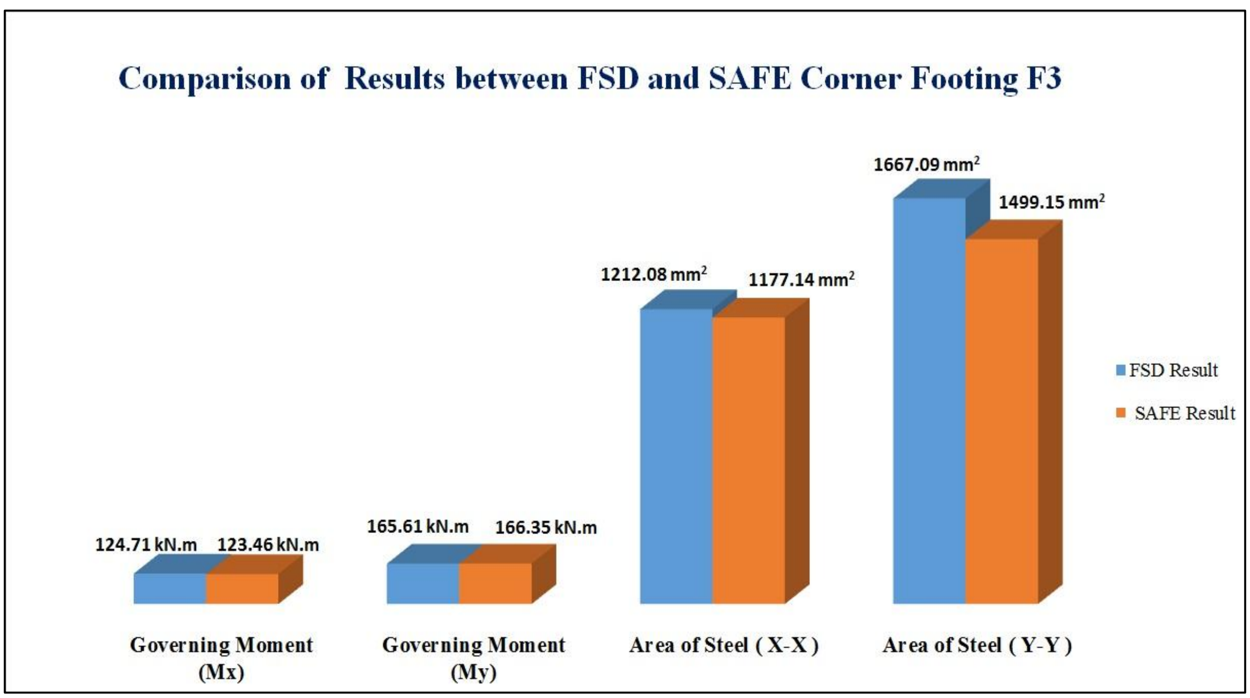

Figure 4.3: **Comparison of Bending Moment and Flexural design F3**

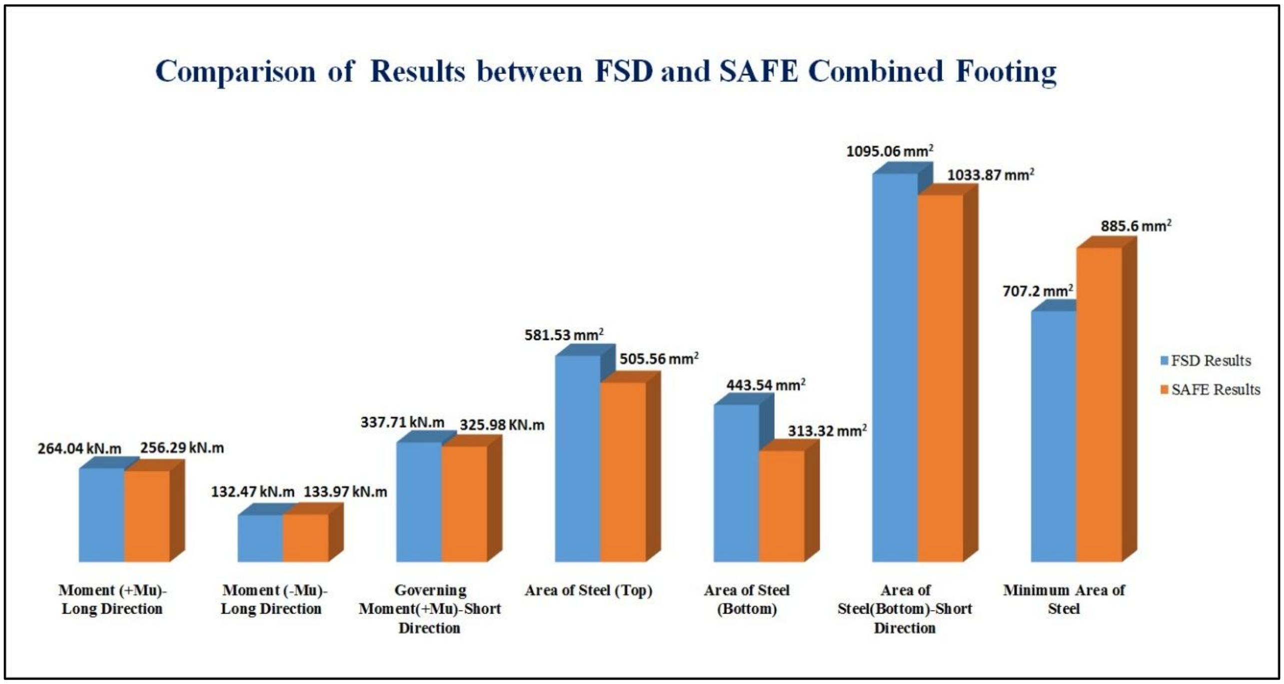

Figure 4.4: **Comparison of Bending Moment and Flexural Design Combined Footing**

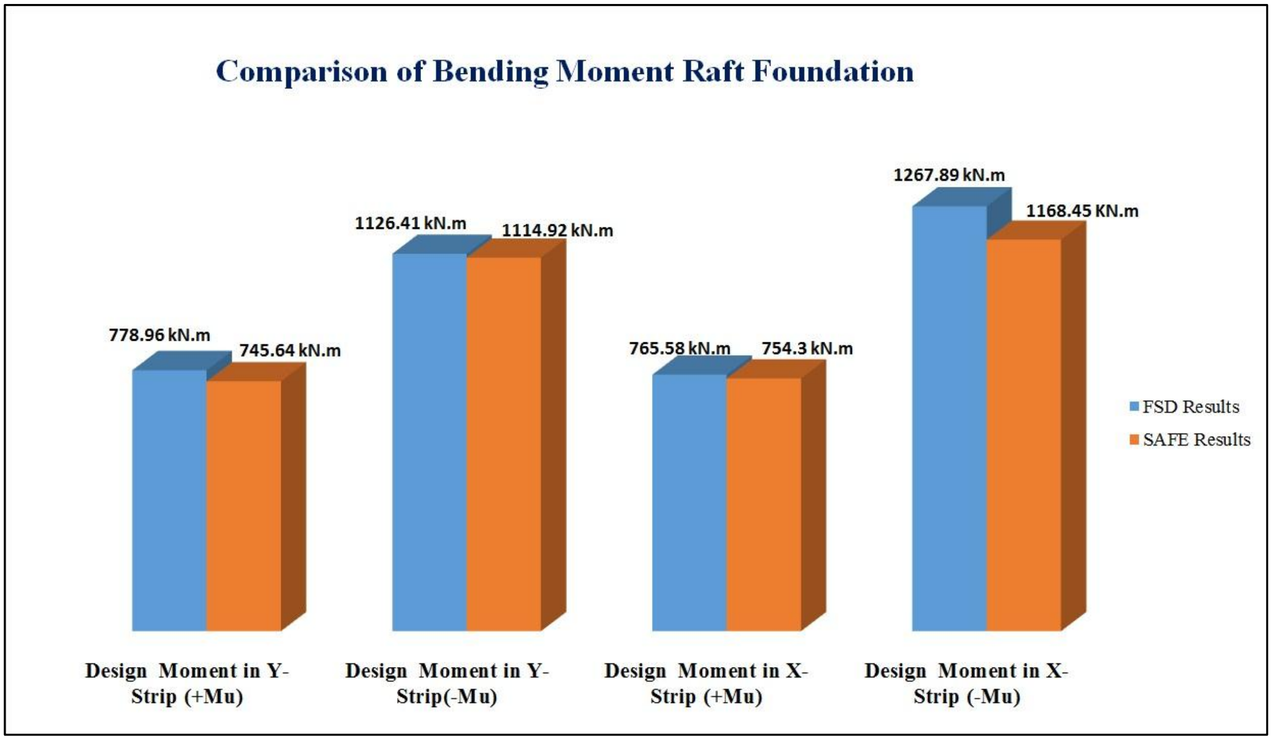

Figure 4.5: Comparison of Bending Moment Raft Foundation

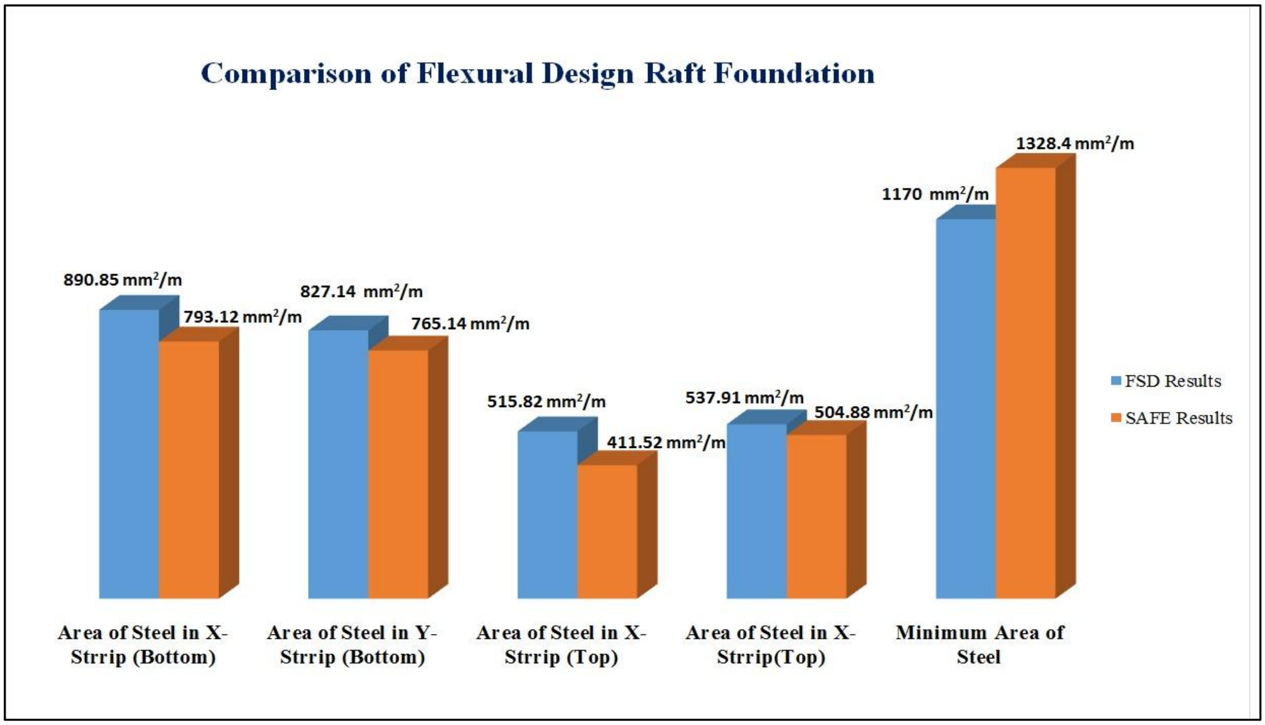

Figure 4.6: Comparison of Flexural Design Raft Foundation

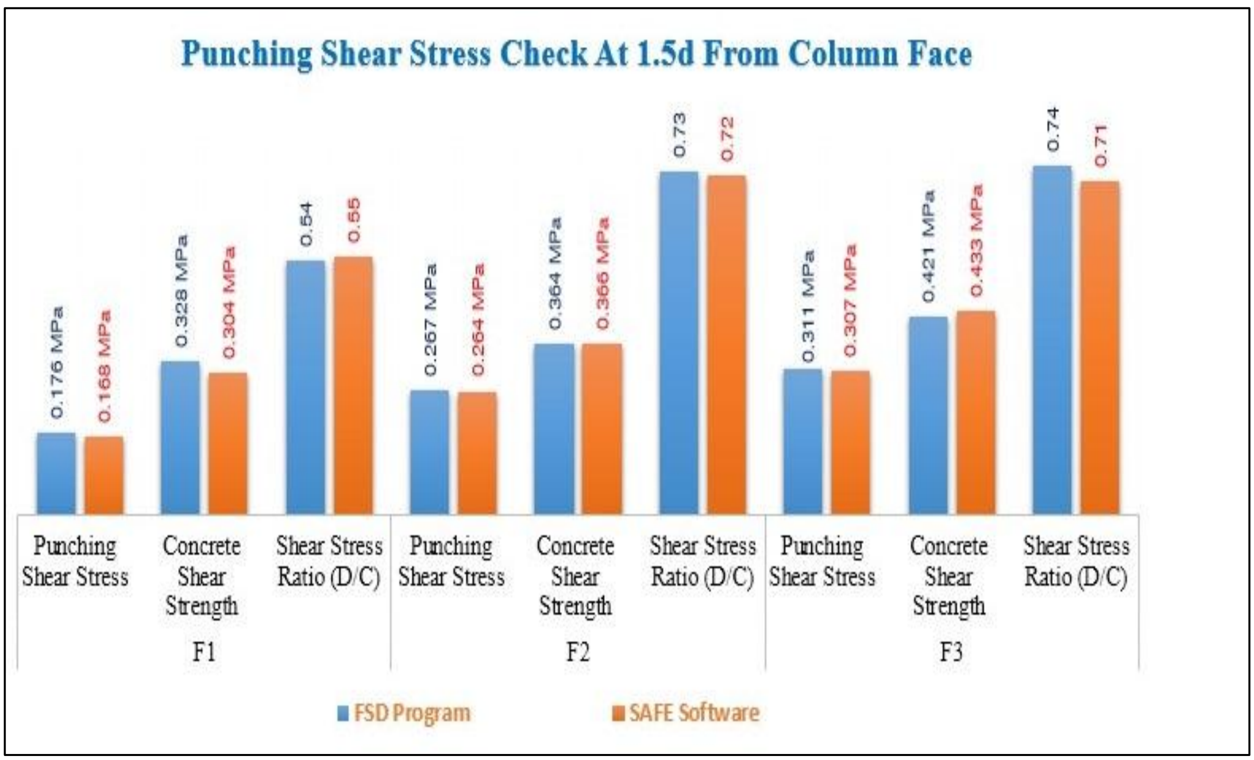

Figure 4.7: Comparison of Punching Shear Stress for Isolated Footings

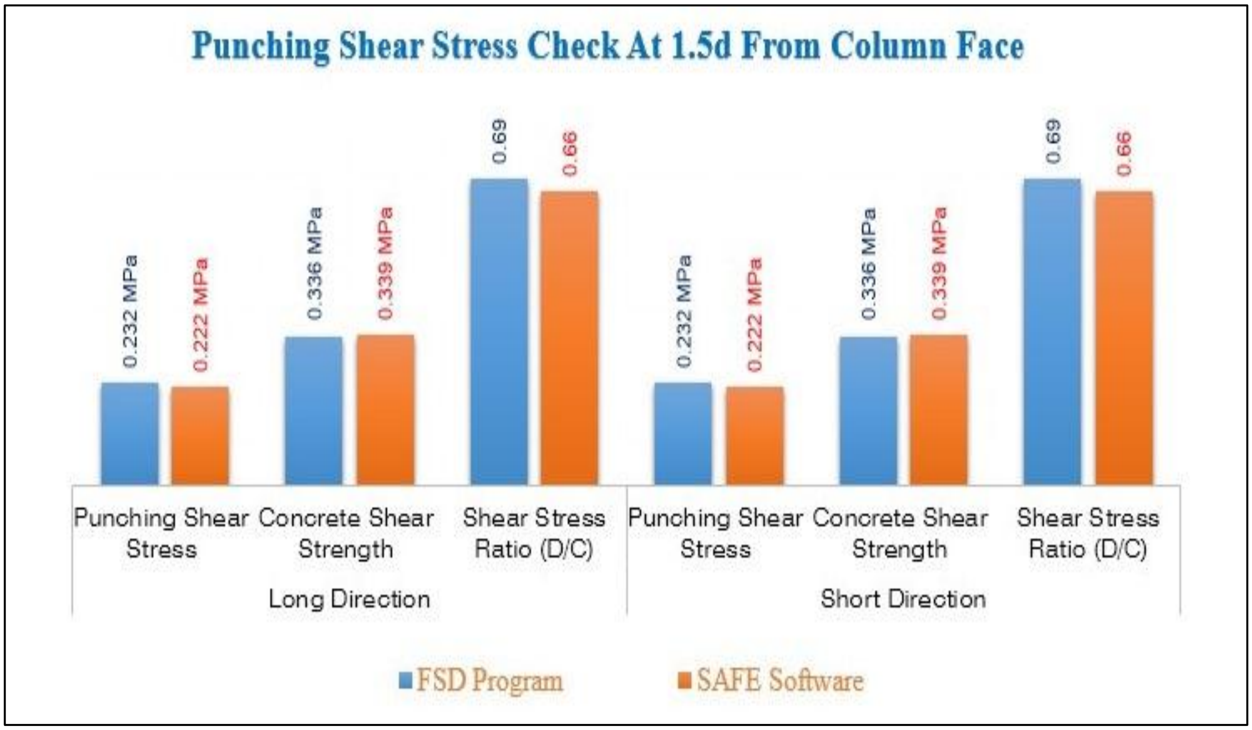

Figure 4.8: Comparison of Punching Shear Stress for Combined Footings

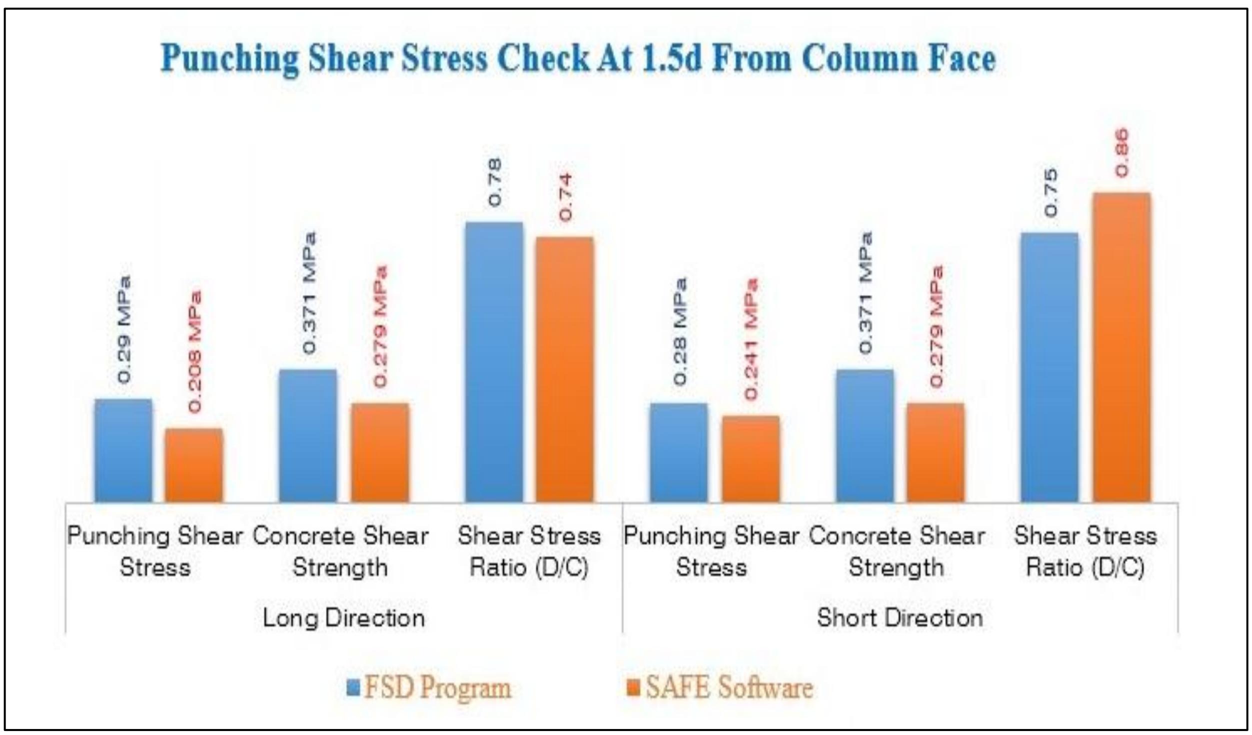

Figure 4.9: Comparison of Punching Shear Stress for Raft Footing

4.3 Comparison of Results

Comparison of design results between **FSD** and **SAFE** software for isolated footing was presented in Tables A.43-A.45. And Comparison results between **FSD** and **SAFE** for combined footing and raft footing was presented in Tables A.45-A.49. The differences of design results between **FSD** and **STAAD-Foundation V8i** verification Manual for isolated footing was presented in Tables A.50-A.52. Comparison of result between **FSD** Program and **STAAD-Foundation V8i** verification Manual for Combined

4.4 Discussion of Results

The overall summary of the thesis is given and could attract the attention of readers. The author is giving a complete clear picture for design types of footing by using traditional methods, which use in manual design and design by using finite element computer software.

By comparison of the results between the **FSD** program and the **SAFE**, it is clear that when designing the Footings using traditional methods Finite Element Method, the results are quite suitable. It was noticed that, the great convergence of the design values, especially when analyzing the isolated and combined footings. Comparison of results in the raft foundation using the conventional method in balancing column loads with soil pressure to make the loads at the same point as the soil pressure ratio when dividing the Raft into design strips is not significant.

Also from comparison of results, it was noticed that the **SAFE** gives for the area of steel values less than that obtained from the **FSD** program, but from the verification of results it was not considered to be suitable and economical.

It was also noticed that the **FSD** program when examining the shear stress in the isolated footings and comparing the ultimate shear stress ($\boldsymbol{\nu_u}$) divided by design concrete shear strength ($\boldsymbol{\nu_c}$) obtained from the **FSD** program with **SAFE** gave different values. The **FSD** program gave a larger percentage of reinforcement steel than the **SAFE** program.

Chapter Five

Conclusion and Recommendations

5.1 Summary of Thesis

The objectives of the research conducted was first create of programme **(FSD)** that work with ETABS and second to use this programme (**FSD**) to design and easy understand difference between design footing by traditional method and finite element method.

The first task required in-depth of investigation in to **ETABS** API functions to automatic analyze models of building and get ultimate base reactions for design footing. The next step was to complete programming in **Excel VBA** to design and use direct link with **AutoCAD** software to make the structural detailing for footing design output.

5.2 Conclusion

Using the oriented programming **VBA** language to write the programs is very easy and useful, based on the findings of this report, the following conclusions were made:

- There is no large different between Analysis and design footing by finite element software and the traditional method (manual design) for isolated and combined footing as has shown in this study.
- The use of programming languages such as **VBA** has several benefits to assist civil engineers in design the foundations systems of buildings.
- **FSD** programme may have practical uses for the design of footing.
- Structural engineers could find many applications and software when using **FSD** programme to analyze and design footing.

5.3 Recommendations

Researcher recommends the following suggestions for the future study and research using programming language in structural engineering especially when use **Excel VBA**.

- Preforming independent study of using other **ETABS** API functions to reduce time of analysis and design structural elements of building models.
- Use of the flexible method with conventional method to analyze mat foundation for better results.
- Comparison of programming results of regular method with more finite element software to Optimization the results.
- Develop the programming of **FSD** by using other codes of practice or use more than one code when programming applications.
- Develop of FSD programme user interface by reduction the numbers of user form which used in design programme.

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Richard Shepherd. Excel VBA Programming. Copyright 2004 McGraw-Hill Companies, United States of America

Appendix A:

Analysis and Design Results

Table A.1: ETABS Column Reaction (Serviceability)

Type of footing	Column Reaction (SLS)				
	F_z	F_x	F_y	M_x	M_y
Middle F1	1908.87	9.22	-13.55	0	0
Edge F2	1024.19	-20.02	-30.03	0	0
Corner F3	578.85	18.53	-20.11	0	0

Table A.2: ETABS Column Reaction (Ultimate)

Type of footing	Column Reaction (Ultimate)				
	F_{zu}	F_{ux}	F_{uy}	M_{ux}	M_{uy}
Middle F1	2754.66	13.43	-18.17	0	0
Edge F2	1478.67	43.31	-39.1	0	0
Corner F3	834.74	26.82	-29.09	0	0

Table A.3: Dimensions of isolated footing using FSD (Case Study One)

Footing	Size of Footing				Max Pressure SLS
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Middle F1	3.3	3.3	11	0.65	195.09
Edge F2	2.4	2.4	6	0.5	194.61
Corner F3	1.9	1.9	3.5	0.35	186.53

Table A.4: Shear and Moment of isolated footing (Case Study One)

Footing	M_{ux} kNm	M_{uy} kNm	P_{ux} At column face kPa	P_{uy} At column face kPa	v_{ux} At d from column kN	v_{uy} At d from column kN
Middle F1	906.62	1059.55	269.09	268.94	625.25	764.77
Edge F2	372.66	306.86	250.32	250.75	362.75	454.8
Corner F3	124.71	165.61	269.13	269.07	212.37	278.47

Table A.5: Reinforcement of isolated footing FSD (Case Study One)

Footing	A_{sx} mm^2	A_{sy} mm^2	Provided As_x mm^2	Provided As_y mm^2	A_{sx} min mm^2	A_{sy} min mm^2
Middle F1	3671.65	4290.98	4021.24	4624.42	3233.71	3233.71
Edge F2	2339.78	2807.44	2412.73	2814.87	1592.17	1592.17
Corner F3	1212.08	1667.09	1357.2	1809.6	851.23	851.23

Table A.6: Shear Stress of isolated footing FSD (Case Study One)

Footing	Shear Stress (MPa)		Punching Shear (MPa)			
	One Way Shear		At Column		At 1.5 d	
	v_x	v_y	v_{ux}	v_{uy}	v_{ux}	v_{uy}
Middle F1	0.288	0.337	2.68	2.68	0.175	0.175
Edge F2	0.330	0.406	2.27	2.27	0.267	0.267
Corner F3	0.377	0.497	1.89	1.89	0.311	0.311

Table A.7: Punching Shear Stress Check (Failed) FSD (Case Study One)

Footing	Shear Strength (MPa)		Punching Shear Stress (MPa)			
	Concrete		Shear Stress (v)		Shear Ratio [$\frac{v_u}{v_c}$]	
	$0.8\sqrt{f_{cu}}$	v_C	v_{ux}	v_{uy}	X	Y
Middle F1	4	0.471	0.396	0.396	1.4	1.4
Edge F2	4	0.391	0.683	0.683	1.75	1.75
Corner F3	4	0.453	0.379	0.379	0.87	0.87

Table A.8: ETABS Columns Reaction (Serviceability)

Unique Name of ETABS Columns	Columns Reaction (SLS)				
	F_z	F_x	F_y	M_x	M_y
EC8	880.69	25.43	6.92	0	0
MC6	953.08	9.22	-5.40	0	0

Table A. 9: ETABS Columns Reaction (Ultimate)

Unique Name of ETABS Columns	Columns Reaction (ULS)				
	F_{zu}	F_{ux}	F_{uy}	M_{ux}	M_{uy}
EC8	1268.86	36.91	10.04	0	0
MC6	1373.53	13.43	-7.83	0	0

Table A.10: FSD Shear and Moment of combined footing (Case Study One)

Direction	$-M_u$ kNm	$+M_u$ kNm	At column face P_u kPa	At d from column v_u kN
Long	-132.47	+264.04	249.73	514.05
Short	-	404.41	249.73	110.05

Table A. 11: FSD Dimensions of combined footing (Case Study One)

Footing	Size of Footing				Max. Pressure SLS
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Combined	4.2	2.52	10.59	0.5	185.81

Table A. 12: FSD Flexural Reinforcement combined footing (Case Study One)

Direction	$A_{sBottom}$ mm^2/m	A_{sTop} mm^2/m	As_{Bott} Provided mm^2/m	As_{Top} Provided mm^2/m	$A_s min$ mm^2/m
Long	443.54	581.53	797.85	797.85	707.20
Short	1095.06	-	1310.04	-	707.20

Table A. 13: FSD Maximum Shear and Moment in Raft strips

Direction	$-M_u$ kNm	$+M_u$ kNm	Shear Force v_u kN
X-direction	-1115.26	+695.50	1410.93
Y-direction	-1267.89	+822.63	1488.20

Table A. 14: FSD Dimensions of Raft Footing

Footing	Size of Footing				Max Pressure SLS
	Max Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Raft (mat)	20.6	15.6	297.51	0.9	99.12

Table A. 15: FSD Flexural Reinforcement of Raft

Direction	$A_{sBottom}$ mm^2/m	A_{sTop} mm^2/m	As_{Bott} Provided mm^2/m	As_{Top} Provided mm^2/m	$A_s min$ mm^2/m
X-direction	827.14	515.82	1256.64	1256.64	1170.00
y-direction	860.23	578.00	1256.64	1256.64	1170.00

Table A. 16 : Dimensions of isolated footing SAFE (Case Study One)

Footing	Size of Footing				Max Pressure At corners (SLS)
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Middle F1	3.3	3.3	11	0.75	192.11
Edge F2	2.4	2.4	6	0.50	198.9
Corner F3	1.9	1.9	3.5	0.35	177.38

Table A. 17: SAFE Shear and Bending Moment of isolated footing (Case Study One)

Footing	M_{ux} kNm	M_{uy} kNm	At column face P_{ux} kPa	At column face P_{uy} kPa	At d from column v_{ux} kN	At d from column v_{uy} kN
Middle F1	903.40	1053.84	281.92	281.93	875.86	912.53
Edge F2	317.81	397.11	272.64	271.85	394.99	421.3
Corner F3	123.46	166.35	247.11	246.36	197.11	232.37

Table A. 18 :SAFE Flexural Reinforcement of isolated footing

Footing	A_s mm^2	A_{sy} mm^2	As_x Provided mm^2	As_y Provided mm^2	A_{sx}min mm^2	A_{sy}min mm^2
Middle F1	3438.38	4105.79	3438.38	4105.79	3653.1	3653.1
Edge F2	1951.92	2362.43	1459.53	1459.53	1771.2	1771.2
Corner F3	1177.14	1499.15	1177.14	1459.53	981.5	981.5

Table A. 19: SAFE Punching Shear Stress Check for Isolated Footing (Failed) (Case Study One)

Footing	Shear Strength (MPa)		Punching Shear Stress (MPa)			
	Concrete		Shear Stress		Shear Ratio [$\frac{v_u}{v_c}$]	
	$0.8\sqrt{f_{cu}}$	v_C	v_{ux}	v_{uy}	X	Y
Middle F1	4	0.464	4.259	4.259	1.06	1.06
Edge F2	4	0.467	0.575	0.575	1.23	1.23
Corner F3	4	0.656	0.932	0.932	1.42	1.42

Table A. 20 : SAFE Punching Shear Stress Check for Isolated Footing (Failed) (Case Study One)

Footing	Shear Strength (MPa)		Punching Shear Stress (MPa)			
	Concrete				Shear Ratio [$\frac{v_u}{v_c}$]	
	$0.8\sqrt{f_{cu}}$	v_C	v_{ux}	v_{uy}	X	Y
Middle F1	4	0.304	0.168	0.168	0.55	0.55
Edge F2	4	0.366	0.264	0.264	0.72	0.72
Corner F3	4	0.432	0.307	0.307	0.71	0.71

Table A. 21 : SAFE Dimensions of combined footing (Case Study One)

Footing	Size of Footing				Max Pressure SLS
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Combined	4.2	2.52	10.59	0.6	189.44

Table A. 22: SAFE Shear and Moment of combined footing (Case Study One)

Direction	$-M_u$ kNm	$+M_u$kNm	At column face P_u kPa	At d from column v_u kN
Long	112.96	254.66	276.46	475.73
Short	-	373.74	275.86	-

Table A. 23 : SAFE Flexural and Reinforcement of combined footing (Case Study One)

Direction	$A_{sBottom}$ mm^2/m	A_{sTop} mm^2/m	As_{Bott} Provided mm^2/m	As_{Top} Provided mm^2/m	$A_s min$ mm^2/m
Long	313.32	505.56	885.6	885.6	885.6
Short	1033.87	-	1033.87	-	885.6

Table A.24 : SAFE Raft Dimensions (Case Study One)

Footing	**Size of Footing**				**Max Pressure SLS**
	Max Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Raft (mat)	20.6	15.6	297.51	0.9	95.85

Table A.25 : SAFE Maximum Shear and Moment in Raft Strips (Case Study One)

Direction	$-\mathbf{M_u}$ **kNm**	$+\mathbf{M_u}$ **kNm**	**Shear Force (v_u) kN**
X-direction	-1121.98	+591.27	1196.63
Y-direction	-1168.45	+754.30	1289.90

Table A.26 : SAFE Flexural Reinforcement for Raft Footing (Case Study One)

Direction	$A_{sBottom}$ mm^2/m	A_{sTop} mm^2/m	As_{Bott} **Provided** mm^2/m	As_{Top} **Provided** mm^2/m	A_s**min** mm^2/m
X-direction	880.26	577.72	1256.64	1256.64	1170.00
Y-direction	899.87	618.49	1256.64	1256.64	1170.00

Table A.27 : FSD Footing Dimensions (Case Study Tow)

Footing	**Size of Footing**				**Max Pressure SLS**
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
F	2.5	2.5	6.25	0.5	188.5

Table A.28 : FSD Design Shear and Moment (Case Study Tow)

Footing	M_{ux} kNm	M_{uy} kNm	At column face P_{ux} kPa	At column face P_{uy} kPa	At d from column v_{ux} kN	At d from column v_{uy} kN
F	352.8	352.8	256	256	396.80	396.80

Table A.29 : FSD Design Flexural Reinforcement (Case Study Tow)

Footing	A_{sx}	A_{sy}	As_x Provided	As_y Provided	A_{sx} min	A_{sy} min
F	1976.31	1976.31	1976.31	1976.31	1625	1625

Table A.30 : FSD Design Shear Stress (Case Study Tow)

Footing	Shear Stress (MPa)		Punching Shear (MPa)			
	One Way Shear		At Column		At 1.5 d	
	v_x	v_y	v_{ux}	v_{uy}	v_{ux}	v_{uy}
F	0.369	0.369	2.32	2.32	0.299	0.299

Table A.31: FSD Design Punching Shear Check for Concrete Shear Strength (Case Study Tow)

Footing	Shear Strength (MPa)		Punching Shear Stress (MPa)			
	Concrete		Shear Stress		Shear Ratio [$\frac{v_u}{v_c}$]	
	$0.8\sqrt{f_{cu}}$	v_C	v_{ux}	v_{uy}	X	Y
F	4.73	0.402	0.299	0.299	0.74	0.74

Table A.32: FSD Design Shear and Bending Moment For Combined Footing (Case Study Tow)

Direction	$-M_u$ kNm	$+M_u$ kNm	At column face P_u kPa	At d from column v_u kN	At 1.5d from column v_u kN
Long	101.15	175	186.67	225.68	3.24
Short	-	168.00	186.67	252	-

Table A.33 : FSD Design Footing dimensions (Case Study Tow)

Footing	Size of Footing				Max Pressure SLS
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Combined	5	1.5	7.50	0.6	148.33

Table A.34 : FSD Design Flexural Reinforcement for Combined Footing (Case Study Tow)

Direction	$A_{sBottom}$ mm^2	A_{sTop} mm^2	As_{Bott} Provided (mm^2)	As_{Top} Provided (mm^2)	$A_s$min mm^2
Long	457.83	792.10	1206.37	1206.37	1170.00
Short	760.41	-	4021.24	-	3900.00

Table A.35 : STAAD- Foundation Verification Manual Shear and Moment for Isolated Footing (Case Study Tow)

Footing	M_{ux} kNm	M_{uy} kNm	At column face P_{ux} kPa	At column face P_{uy} kPa	At d from columnv_{ux} kN	At d from columnv_{uy} kN
F	352.8	352.8	256	256	396.8	396.8

Table A. 36 : STAAD- Foundation Verification Manual Footing Dimensions for Isolated Footing (Case Study Tow)

Footing	Size of Footing				Max Pressure SLS
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
F	2.5	2.5	5.89	0.5	-

Table A.37: STAAD- Foundation Verification Manual Flexural Reinforcement for Isolated Footing (Case Study Tow)

Footing	A_{sx}	A_{sy}	As_x Provided	As_y Provided	A_{sx} min	A_{sy} min
F	1976.31	1976.31	1976.31	1976.31	1625	1625

Table A.38: STAAD- Foundation Verification Manual Shear Stress for Isolated Footing (Case Study Tow)

Footing	Shear Stress (MPa)		Punching Shear (MPa)			
	One Way Shear		At Column		At 1.5 d	
	v_x	v_y	v_{ux}	v_{uy}	v_{ux}	v_{uy}
F	0.369	0.369	-	-	0.3	0.3

Table A.39 : STAAD- Foundation Verification Manual Punching Shear Check for Concrete Shear Strength for Isolated Footing (Case Study Tow)

Footing	Shear Strength (MPa)		Punching Shear Stress (MPa)			
	Concrete				Shear Ratio [$\frac{v_u}{v_c}$]	
	$0.8\sqrt{f_{cu}}$	v_C	v_{ux}	v_{uy}	X	Y
F	4.73	0.402	0.3	0.3	-	-

Table A.40 : STAAD- Foundation Verification Manual Shear and Moment for Combined Footing (Case Study Tow)

Direction	$-M_u$ kNm	$+M_u$ kNm	At column face P_u kPa	At d from column v_u kN	At 1.5d from column v_u kN
Long	140.04	174.99	186.667	225.68	3.24
Short	-	168.13	186.667	-	-

Table A.41 : STAAD-Foundation Verification Manual Footing Dimensions for Combined Footing (Case Study Tow)

Footing	Size of Footing				Max Pressure SLS
	Length (L) m	Width (B) m	Area (A) m^2	Thickness (H) m	(P) kPa
Combined	5	1.5	7.50	0.6	147.82

Table A.42 : STAAD-Foundation Verification Manual Flexural Reinforcement for Combined Footing (Case Study Tow)

Direction	$A_{sBottom}$ mm^2	A_{sTop} mm^2	As_{Bott} Provided mm^2	As_{Top} Provided mm^2	$A_s min$ mm^2
Long	637	792	1170	1170	1170
Short	761	-	1170	-	1170

Table A. 43 : Comparison of Results between FSD and SAFE for Middle Foundation F1 (Case Study One)

Value of	FSD Result	SAFE Result	Difference%
Soil Pressure (SLS)	195.09	192.11	1.55
Effective Depth(X-X)	684	684	None
Effective Depth(Y-Y)	684	684	None
Governing Moment(M_x)	906.62	904.16	0.27
Governing Moment(M_y)	1059.55	1054.70	0.46
Area of Steel(Along X-X)	3671.65	3438.38	6.78
Area of Steel(Along Y-Y)	4290.98	4105.79	4.51
Punching Shear (Two-way)	0.175	0.168	4.17

Table A. 44: Comparison of Results between FSD and SAFE for Edge Footing F2 (Case Study One)

Value of	FSD Results	SAFE Results	Difference %
Soil Pressure (SLS)	194.61	198.9	2.16
Effective Depth (X-X)	434	434	None
Effective Depth (Y-Y)	434	434	None
Governing Moment (Mx)	306.86	317.81	2.9
Governing Moment (My)	372.66	396.79	6.16
Area of Steel (Along X-X)	2019.35	1951.92	3.45
Area of Steel(Along Y-Y)	2378.59	2362.43	0.68
Punching Shear (Two-way)	0.267	0.265	0.75

Table A. 45 : Comparison of Results between FSD and SAFE for Corner Foundation F3 (Case Study One)

Value of	FSD Result	SAFE Result	Difference %
Soil Pressure (SLS)	186.53	177.38	5
Effective Depth (X-X)	343	343	None
Effective Depth (Y-Y)	343	343	None
Governing Moment (Mx)	124.71	123.46	1
Governing Moment (My)	165.61	166.35	0.44
Area of Steel (Along X-X)	1212.08	1177.14	2.96
Area of Steel(Along Y-Y)	1667.09	1499.15	11.20
Punching Shear (Two-way)	0.311	0.307	1.3

Table A. 46 : Comparison of design results between FSD and SAFE Program in Long Direction for Combined Footing (Case Study One)

Value of	FSD Result	SAFE Result	Difference %
Effective Depth	534	534	0
Maximum Pressure SLS	188.31	189.44	0.6
Governing Moment(M+u)	264.04	256.29	3.7
Governing Moment(M-u)	-132.47	-133.97	1.1
Area of Steel(Bottom)	443.54	313.32	1.5
Area of Steel(Top)	581.53	505.56	5.5
Minimum Area of Steel	707.20	885.6	20.1
Shear Stress at Column Face	249.73	276.46	9.7
Punching Shear (Two-way)	0.230	0.254	9.5

Table A. 47 : Comparison of design results between FSD and SAFE Program in Short Direction for Combined Footing (Case Study One)

Value of	FSD Result	SAFE Result	Difference%
Effective Depth	534	534	0
Maximum Pressure SLS	188.31	192.67	2.2
Governing Moment (M+u)	+337.71	+325.98	3.6
Governing Moment (M-u)	-	-	-
Area of Steel(Bottom)	1095.06	1033.87	5.7
Area of Steel (Top)	-	-	-
Minimum Area of Steel	707.2	885.6	20.1

Table A. 48 : Comparison of Design Results between FSD and SAFE Program in Long Direction for Raft footing (Case Study One)

Value of	FSD Results	SAFE Results	Difference%
Effective Depth	830.00	830.00	0
Maximum Pressure SLS	99.12	95.85	3.69
Governing Moment (M+u)	778.96	745.64	4.67
Governing Moment (M-u)	1126.41	1114.92	1.03
Area of Steel (Bottom)	827.14	765.14	8.1
Area of Steel (Top)	515.82	411.52	25.26
Minimum Area of Steel	1170.00	1328.4	13.54
Max Shear Force At Column	1423.63	1256.64	13.29
Punching Shear (Two-way)	0.28	0.26	7.69

Table A. 49: Comparison of Design Results between FSD and SAFE Short Direction for Raft Footing (Case Study One)

Value of	FSD Result	SAFE Result	Difference %
Effective Depth	830.00	830.00	0
Maximum Pressure SLS	99.12	95.85	3.69
Governing Moment (M^{+}_{u})	765.58	754.30	1.50
Governing Moment(M^{-}_{u})	1267.89	1168.45	8.51
Area of Steel(Bottom)	890.85	793.12	12.32
Area of Steel(Top)	537.91	504.88	6.54
Minimum Area of Steel	1170.00	1328.4	13.54
Max Shear Force At Column	1438.66	1289.90	11.53
Punching Shear (Two-way)	0.28	0.26	7.69

Table A. 50 : Comparison of Results between FSD and STAAD-Foundation Verification Manual for Isolated Footing (Case Study Two)

Value of	FSD Results	STAAD. foundation Result	Difference %
Effective Depth(X-X)	0.5	0.5	0
Governing Moment(M_x)	352.8	352.8	0
Governing Moment(M_y)	352.8	352.8	0
Area of Steel(Along X-X)	1976.31	1976.31	0
Area of Steel(Along Y-Y)	1976.31	1976.31	0
Shear Stress one way (X-X)	0.369	0.369	0
Shear Stress one way (Y-Y)	0.369	0.369	0
Punching Shear (Two-way)	0.299	0.3	0

Table A. 51 : Comparison of result between FSD Program and STAAD-Foundation Verification Manual Design Data in Long Direction for Combined Footing (Case Study Two)

Value of	FSD Result	STAAD-Foundation	Difference %
Effective Depth	544	544	0
Maximum Pressure SLS	148.33	147.82	0.4
Governing Moment(+M_u)	175	174.99	0
Governing Moment(-M_u)	101.15	140.04	27.8
Area of Steel(Bottom)	457.83	637	28.1
Area of Steel(Top)	792.10	792	0
Minimum Area of Steel	1170	1170	0
Shear Force At d Column Face	225.8	225.8	0
Shear Stress (One Way)	0.2766	0.276	0.2
Shear Force At 1.5d Column Face	3.24	3.24	0
Concrete Shear Strength (*vc*)	0.331	0.331	0
Punching Shear (Two-way)	0.000772	0.0077	0

APPENDIX B:

FSD Programme Output and Verification

B.1 Cases Study Output and Verification

The Appendix A are used for show FSD user Form Interface and how to use it and open ETABS model and run analysis to get base reactions. This appendix contains printed output of Design of the cases Study as represent in chapter 3.

B.2 FSD Programme START-UP AND FILE OPEN SCREENS

When **FSD** is opened, the screen shows in **Figure. B.1,** this screen is show ETABS model open desired file (Hassan.EDB) for run analysis. The ETABS load cases and load combinations will be saved in list Box as show in **Figure. B.2**, the screen in **Figure. B.3** and **Figure. B.4** show results from ETABS (Base reactions) for load Combinations serviceability limit state (SLS) and Ultimate limit state (ULS) respectively and select maximum reactions from middle, Edge, Corner Use the buttons in this tab.

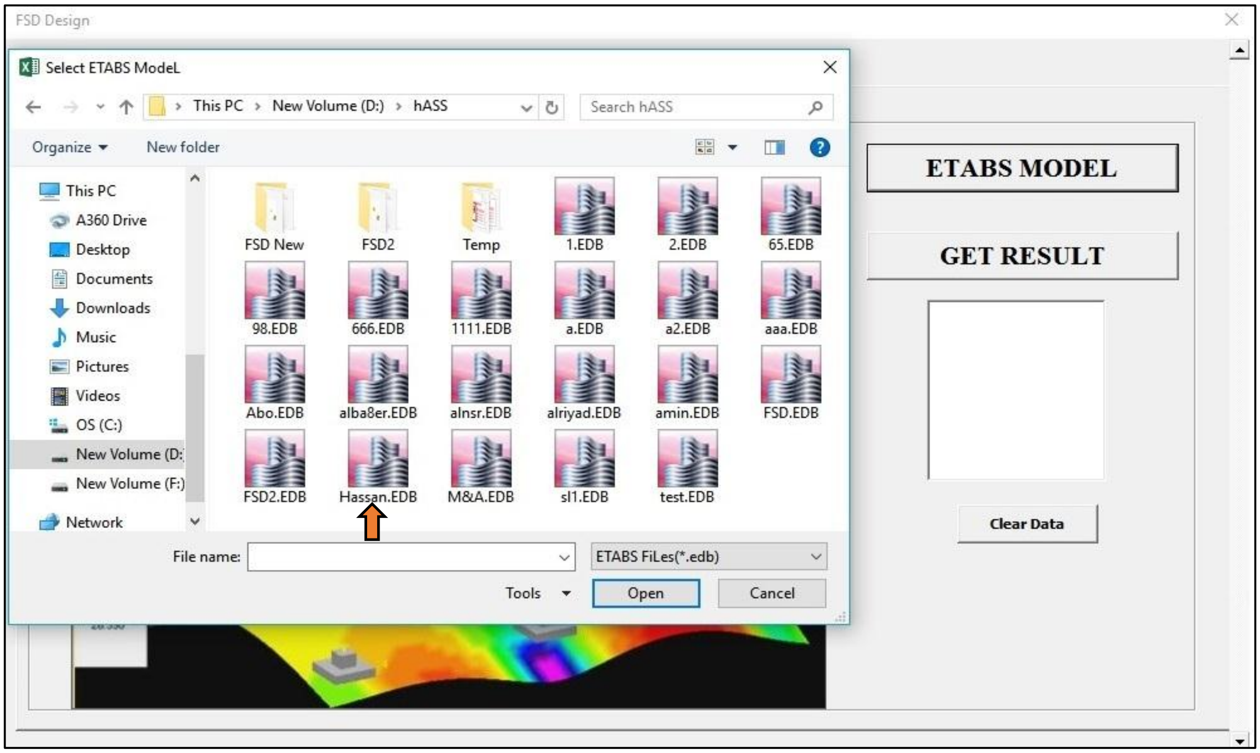


Figure B. 1 : Select ETABS Model Hassan.EDB

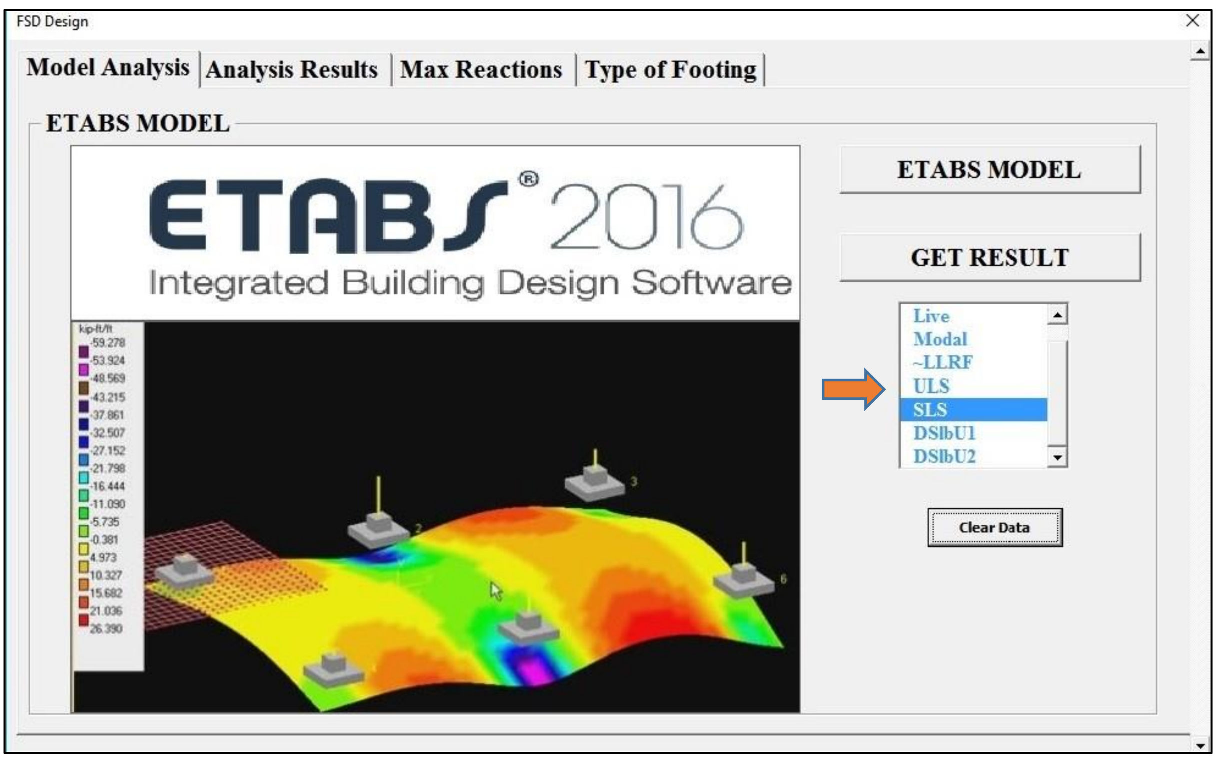


Figure B. 2Save ETASB Load Case and Load Combinations in List Box

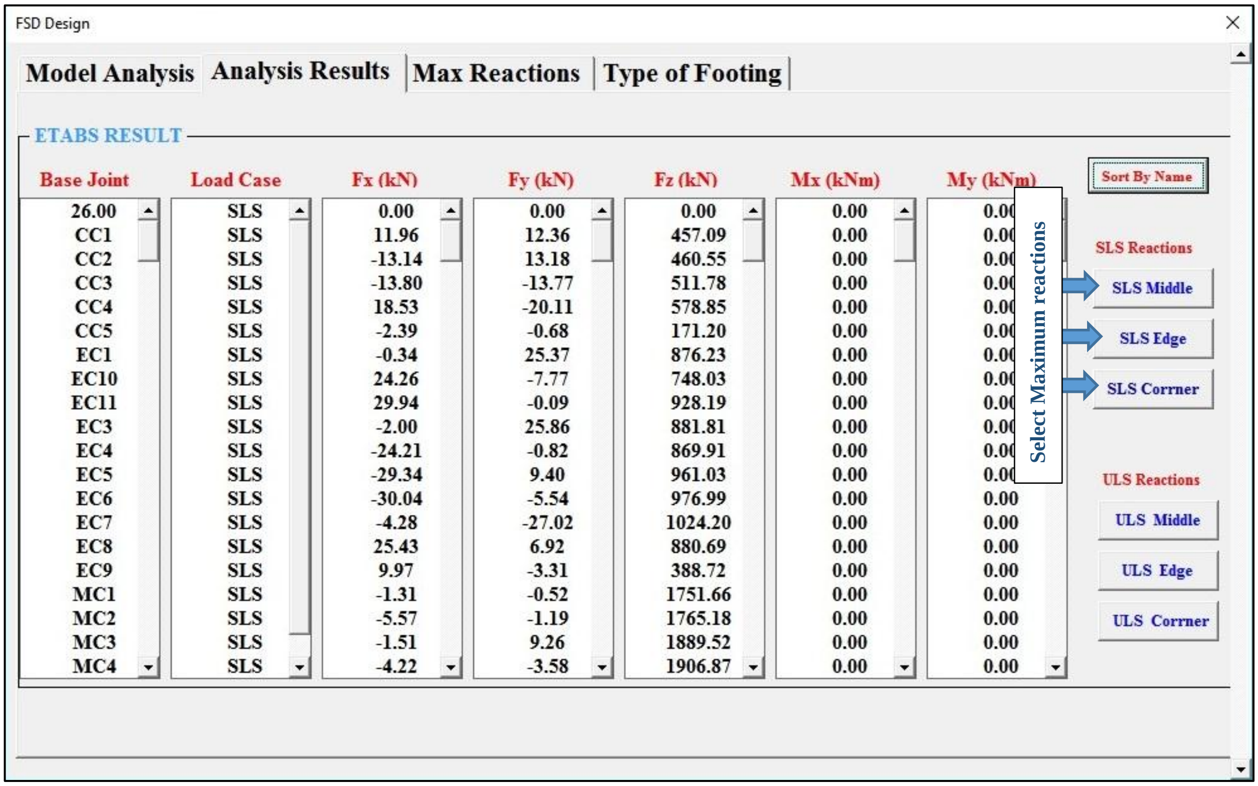


Figure B. 3ETASB Base Reactions Load Combination (SLS)

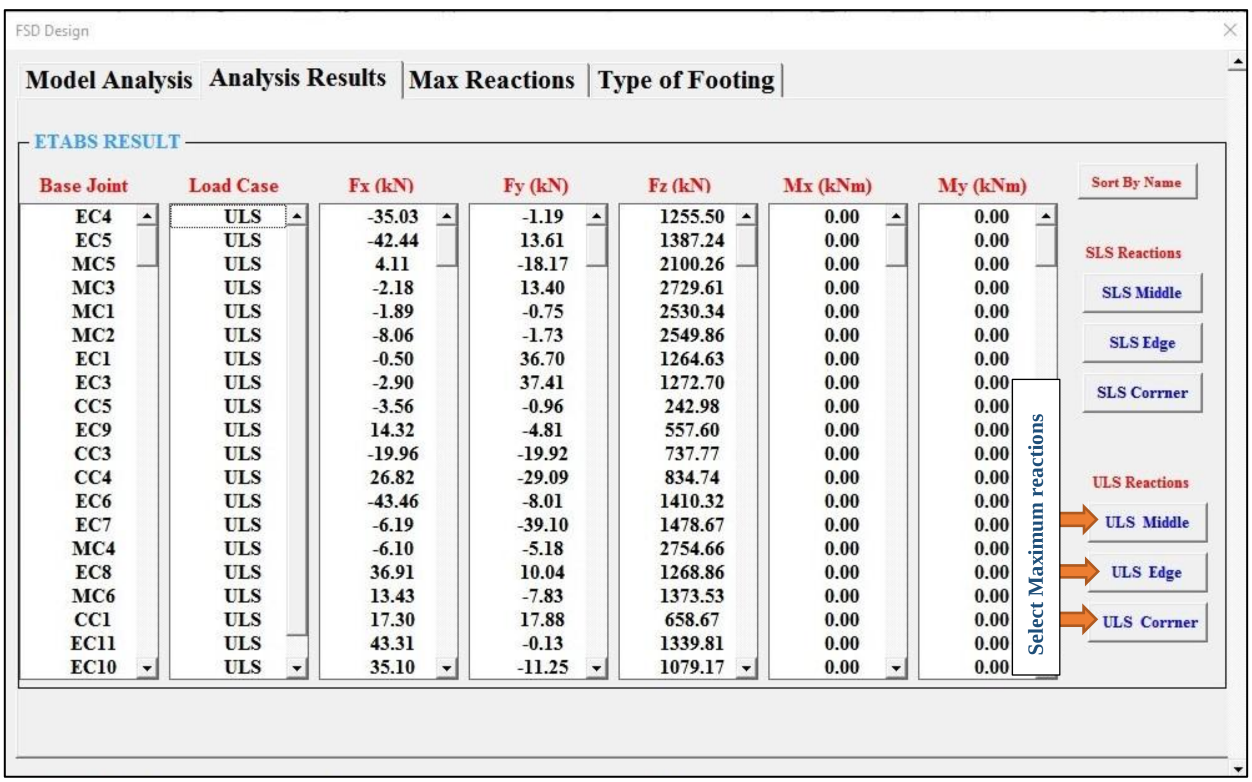


Figure B. 4 : ETASB Base Reactions Load Combination (ULS)

B.3 FSD Programme Maximum Reactions and Select Type of Footing

Selected maximum reactions in middle, Edge, Corner columns for combinations as show in The **Figure B.5,** the screen in **Figure. B.6** displayed Check the suitability of use isolated footing to maximum area under single one column and show entered Soil and materials input data.

Design input and maximum reactions and first design results for isolated footing Middle show in **Figure B.7** this screen displayed area of footing and second moment of area, pressure at corners. **Figure B.8** this screen displayed area of footing and second moment of area, pressure at corners for **Edge** footing and **Figure B.9** Show same results for corner footing.

Figure B. 5: ETASB Base Reactions Maximum Reactions Combinations Middle, Edge, Corner

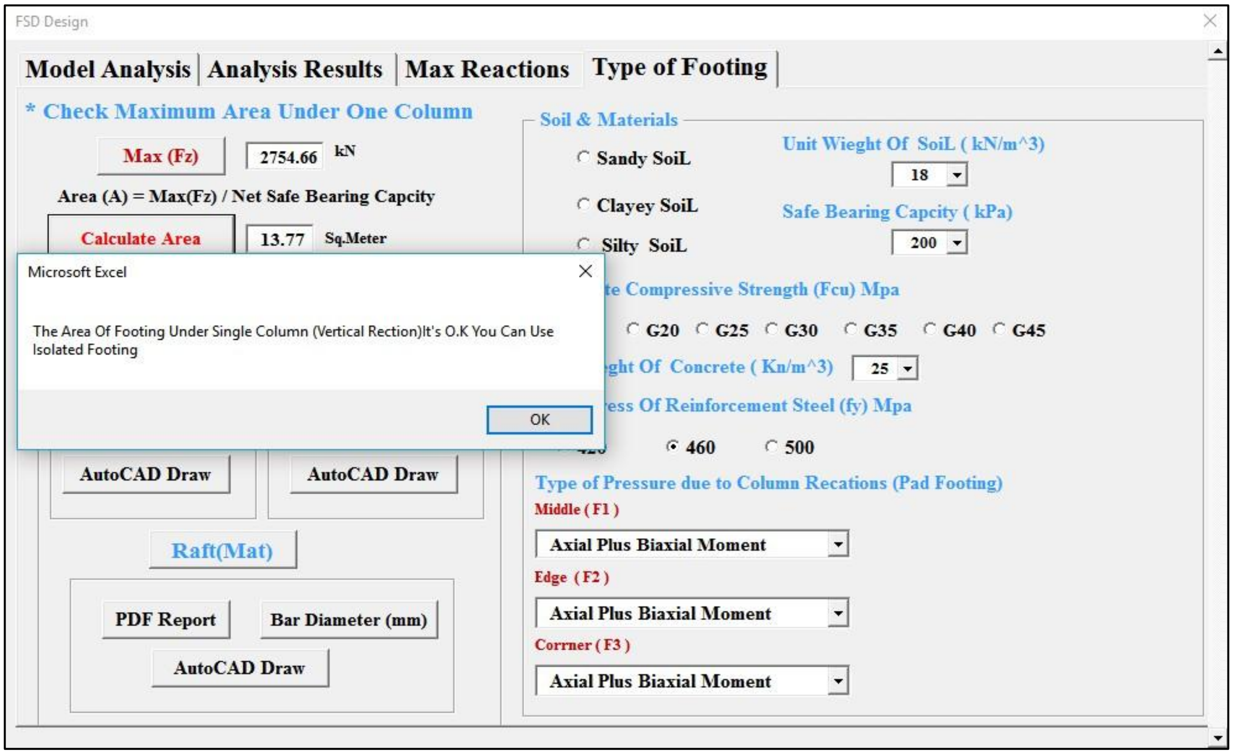


Figure B. 6 : Suitability of use isolated footing and Materials Input Entered

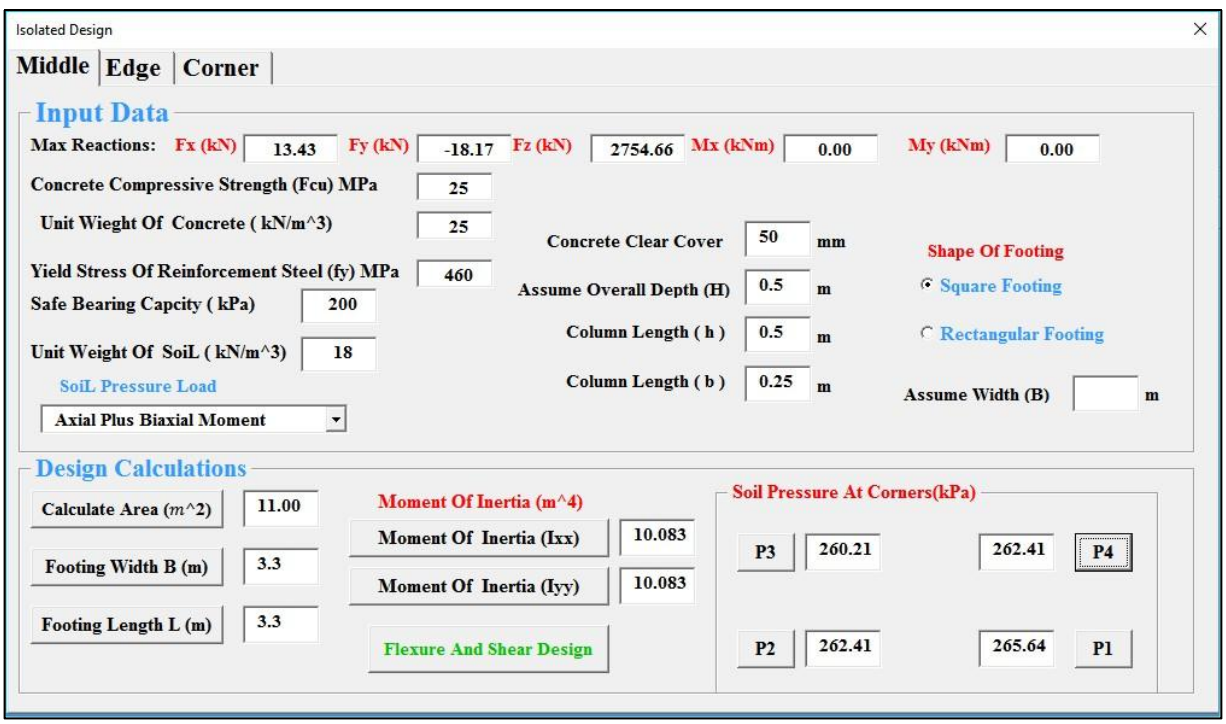


Figure B. 7Geotechnical Design Results Calculations for Middle Footing

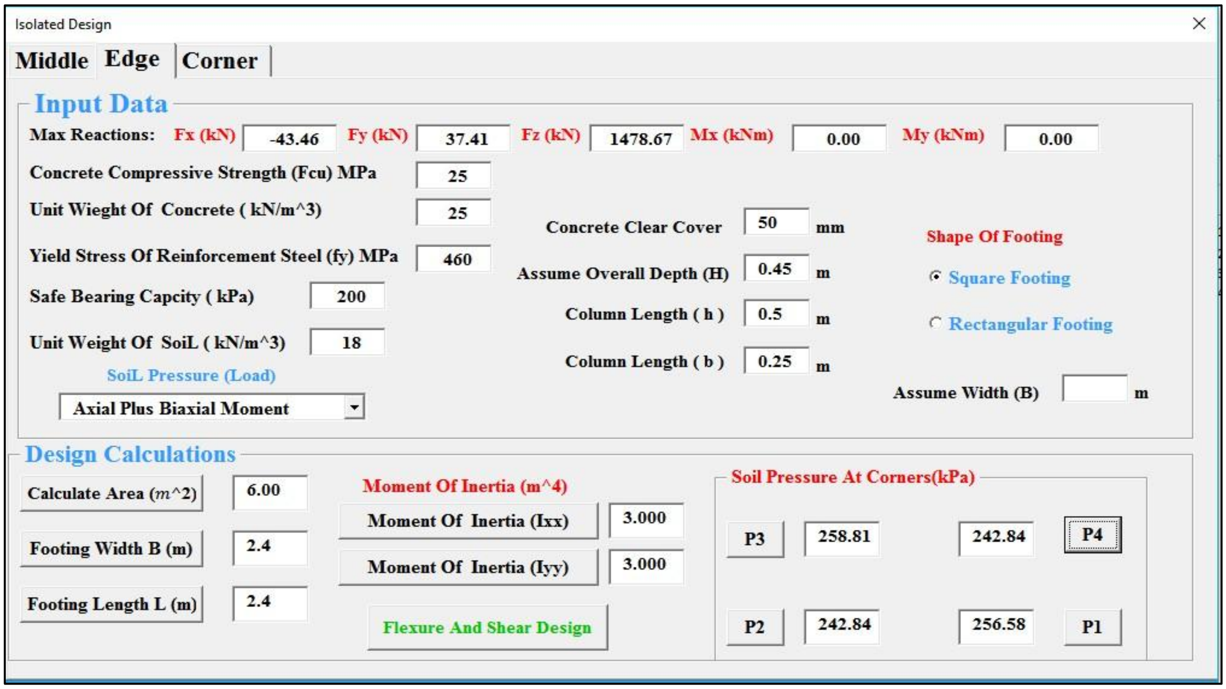


Figure B. 8 : Geotechnical Design Results Calculations for Edge Footing

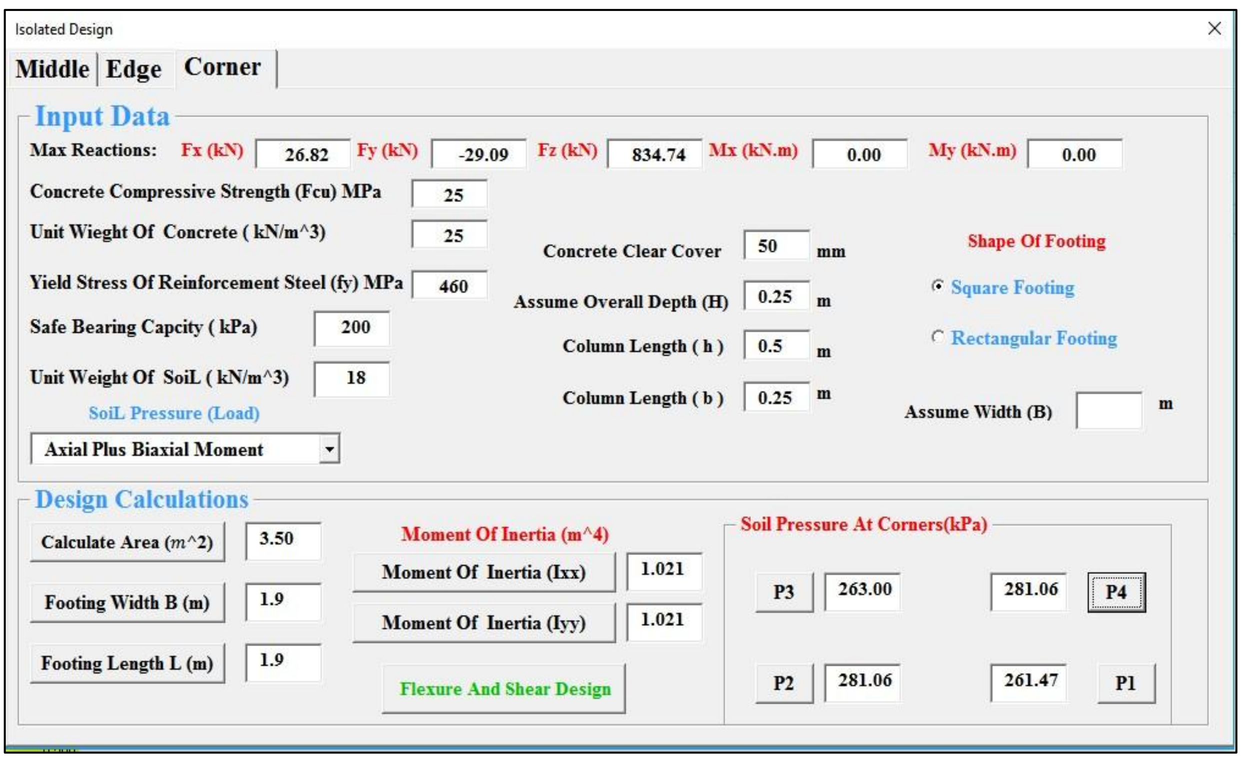


Figure B. 9Geotechnical Results Calculations for Corner Footing

B.4 FSD Programme Isolated Footing Flexure and Shear Design

For Flexure design show results of Middle footing only. **Fig B.10** this screen displayed calculated design pressure, design moment, area of steel and minimum area of steel. **Fig B.11** this screen displayed Analysis result and maximum soil Pressure and show message for check soil bearing capacity and stability of footing against sliding, Design shear stress displayed in **Fig B.12**. The design concrete shear strength and check one-way shear stress show in **Fig B.13**, the punching shear for concrete shear strength first check (failed) and massage to change Overall depth of footing show in **Fig B.14**. **Fig B.15**displayed change overall depth recalculation. **Fig B.16** show massage for error flexure calculation.

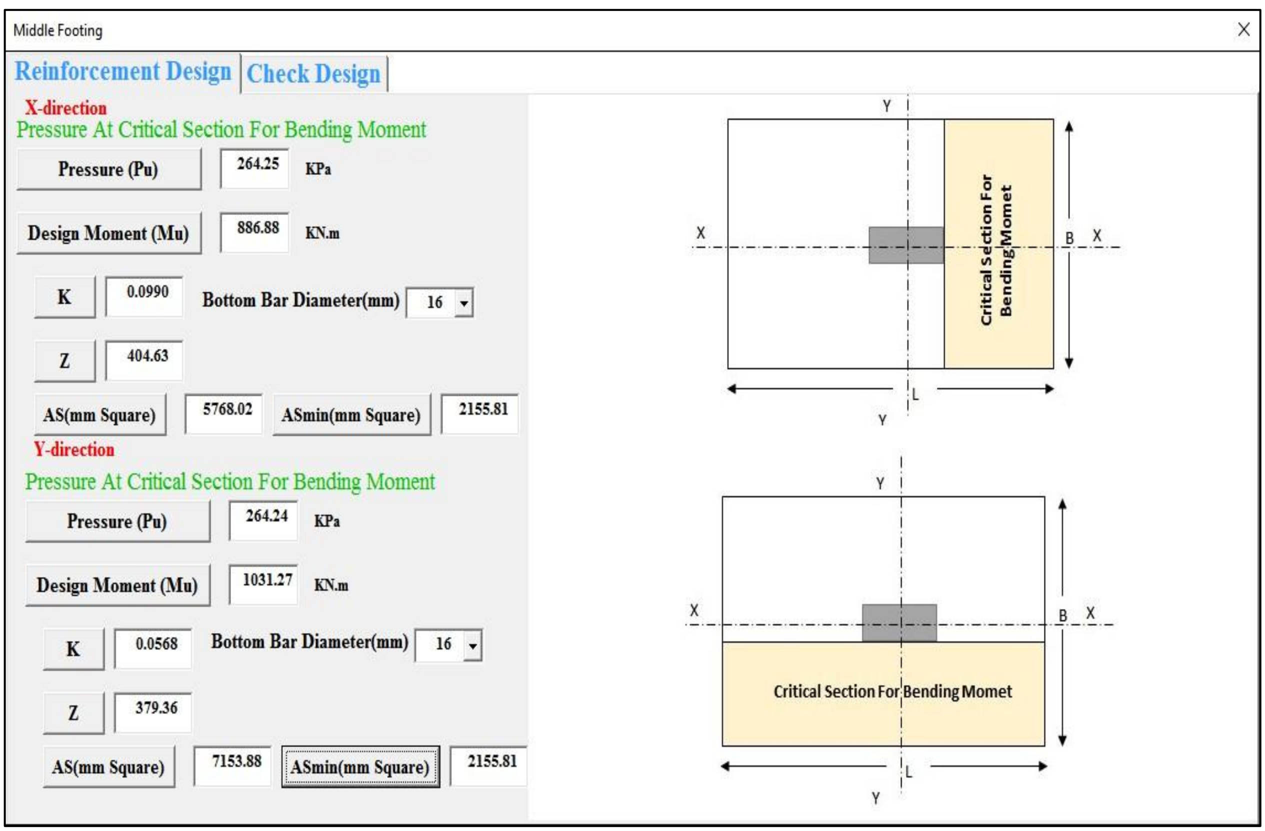


Figure B. 10: Flexure Design Results Calculations for Middle Footing

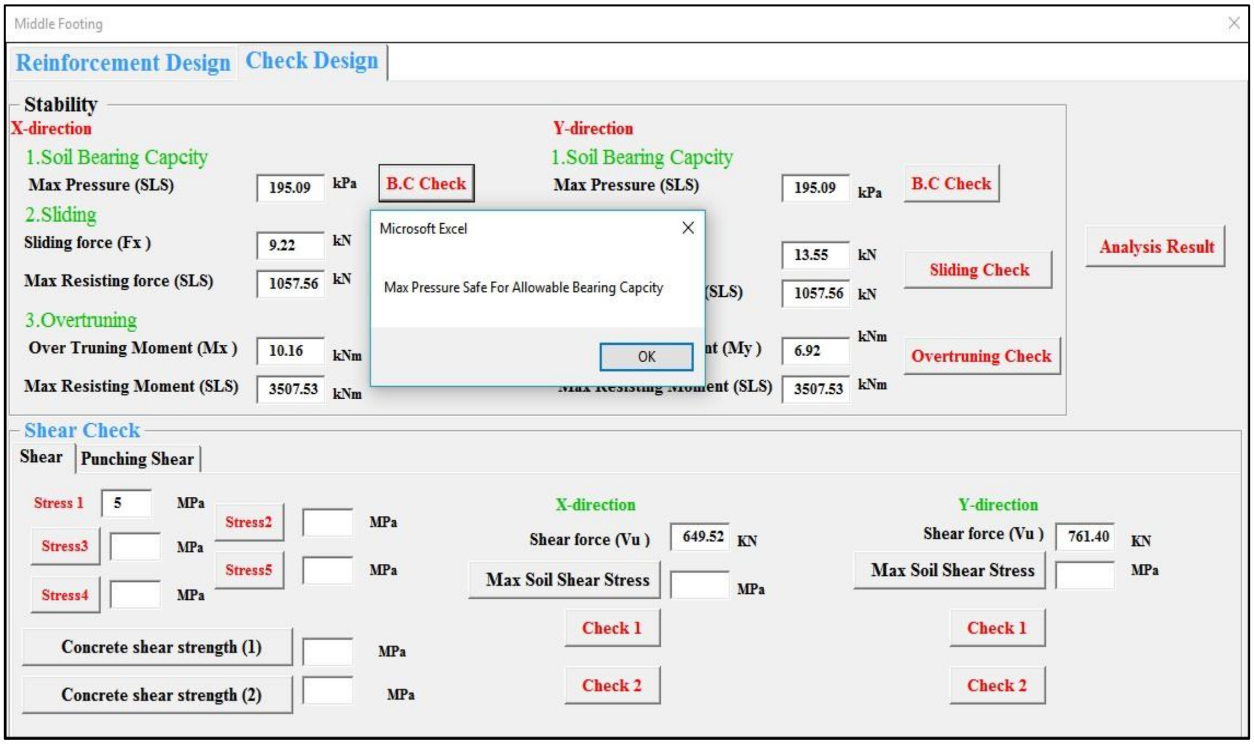


Figure B. 11: Analysis Results Calculations and Check for Soil Bearing Capacity

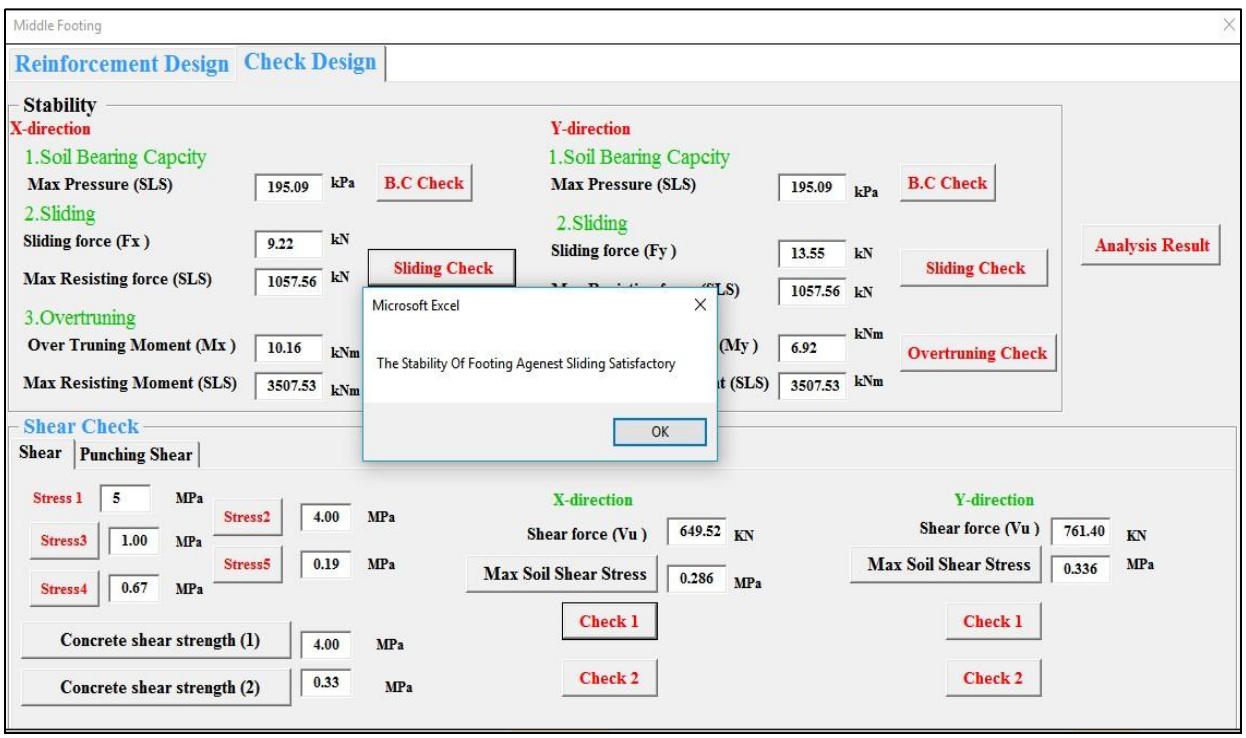


Figure B. 12: Stability of Footing against Sliding and Design shear stress

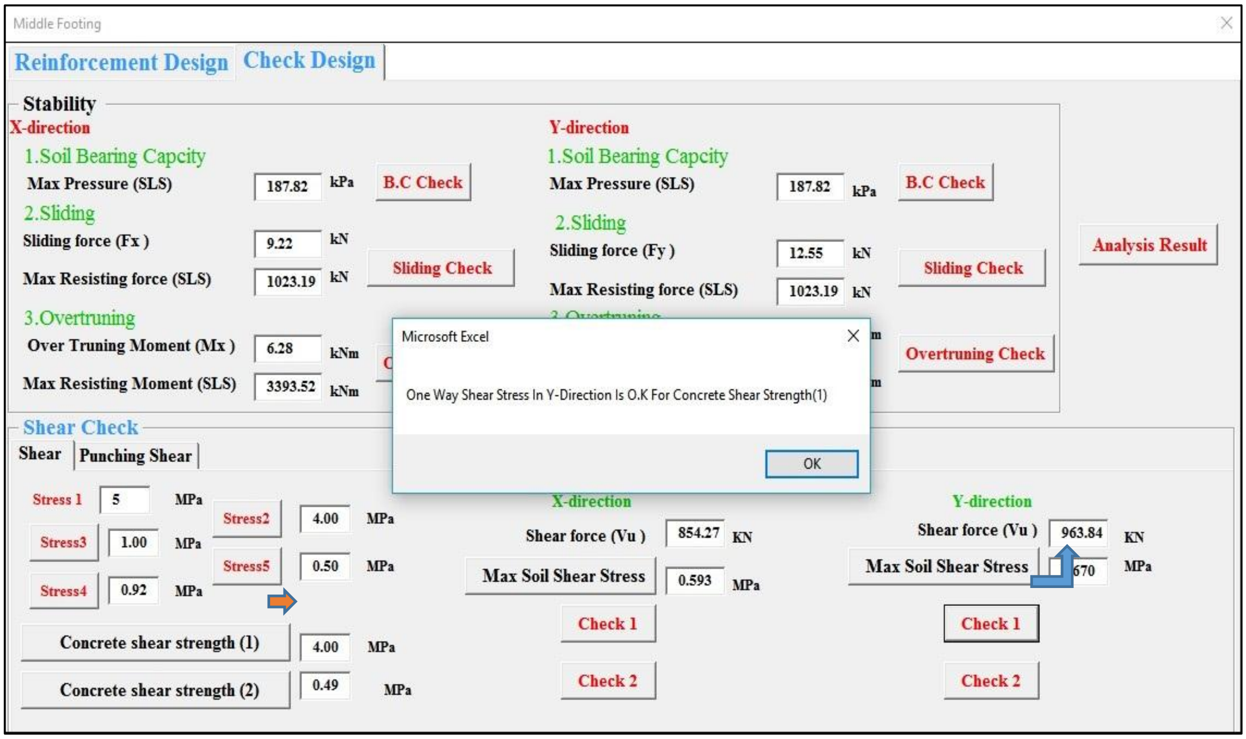


Figure B. 13: One Way Shear Stress Check for Maximum Concrete Shear Strength

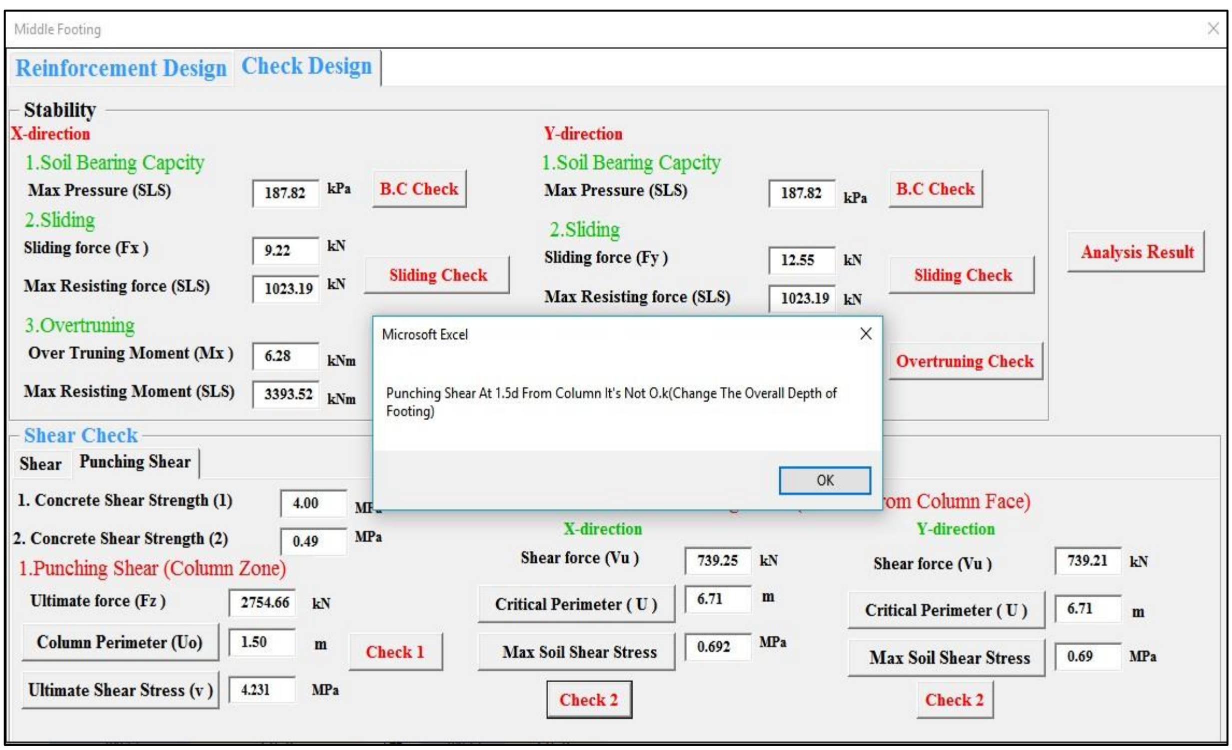


Figure B. 14 : Failed Punching Shear Check for Design Concrete Shear Strength

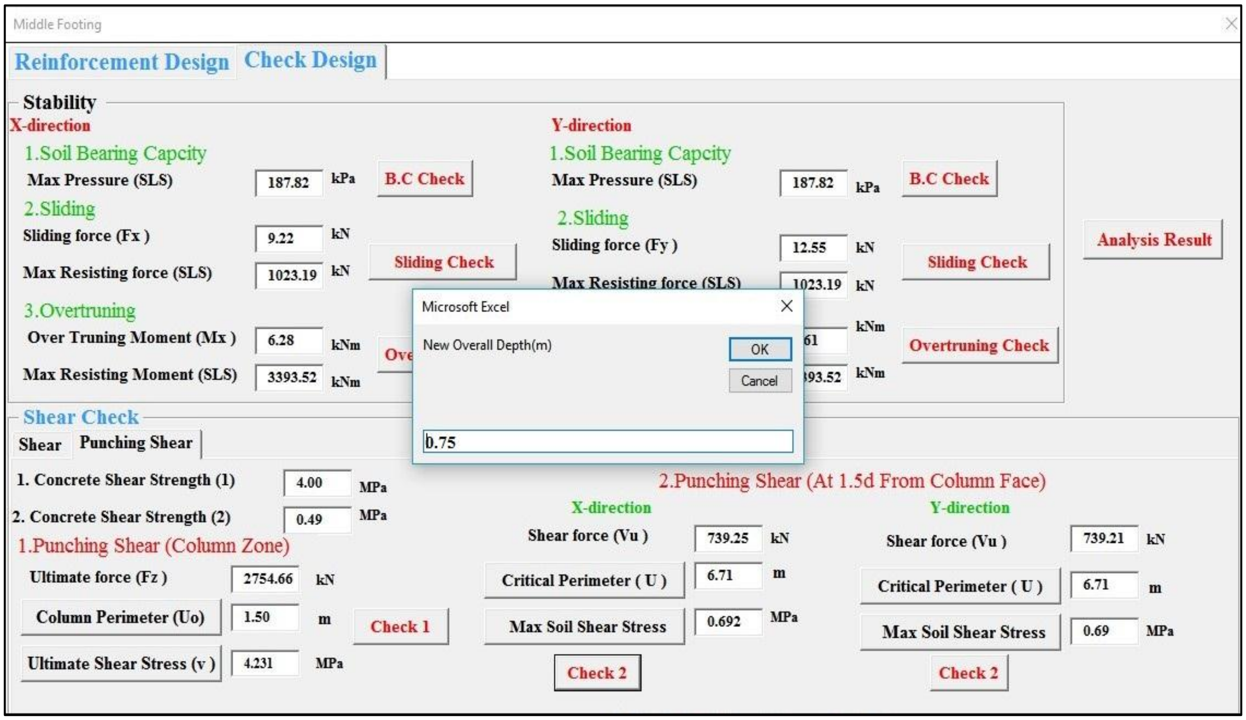


Figure B. 15 :Change Overall Depth

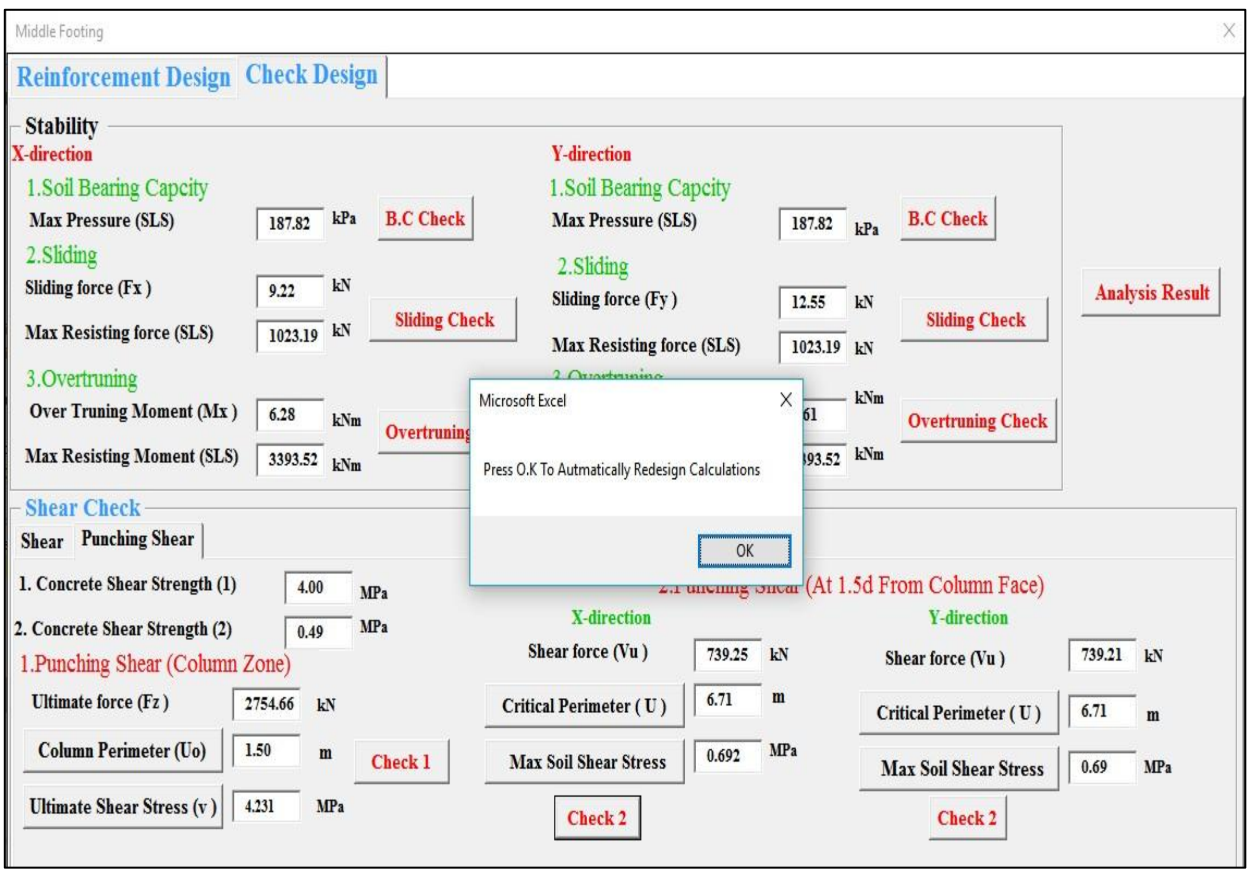


Figure B.16: Massage of Redesign Calculations

B.5 FSD Programme Combined Footing Analysis Output

Entered unique name of columns and design input data, get ETABS reaction for that Unique name show in The **Fig B.17.**

The Geotechnical and footing dimensions, Shear force and bending moment in footing First design results for isolated footing show in **Fig B.18** this screen displayed area of footing and location of summation of columns load, design pressure and maximum soil pressure in serviceability limit state (SLS)also this screen displayed shear force diagram and bending diagram in **Fig B.19**.

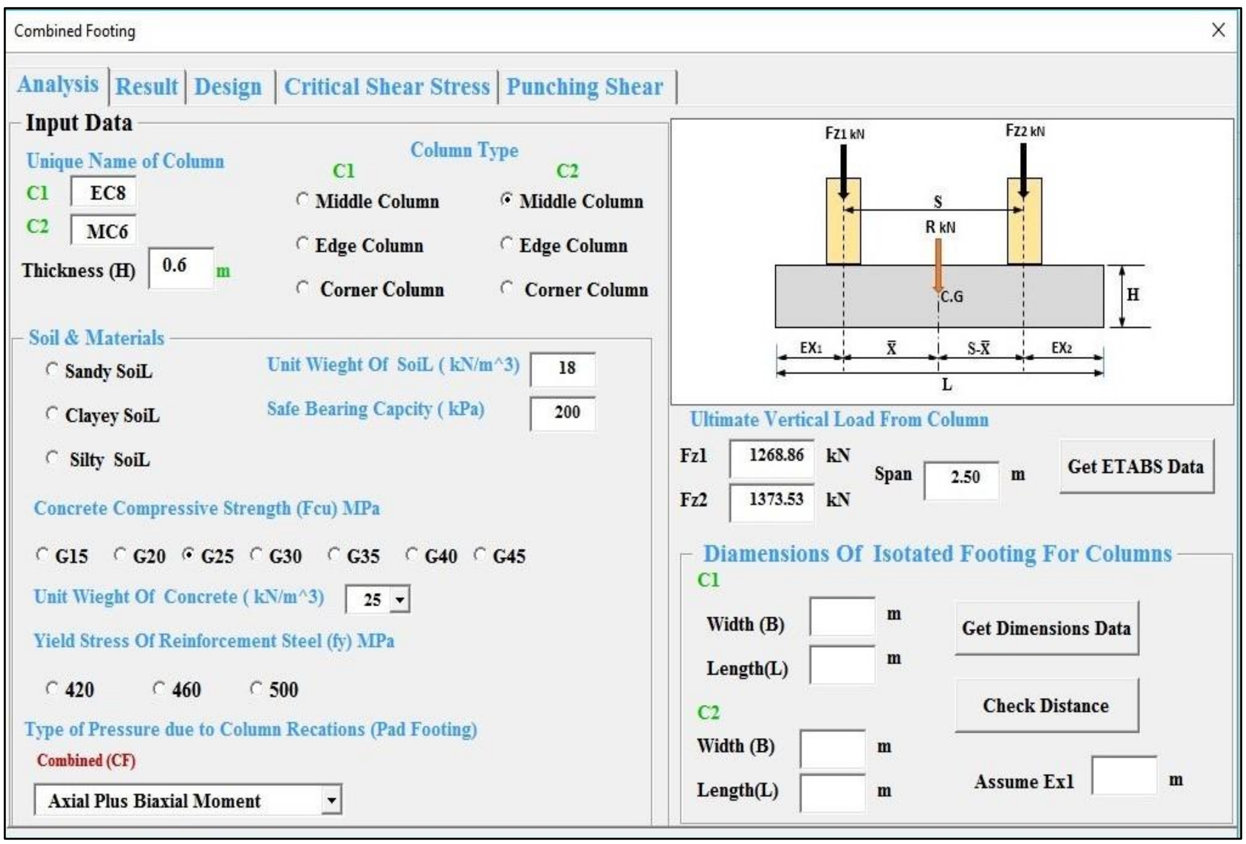


Figure B.17: Entered Unique Name of Columns and design input data and get ETABS Reactions

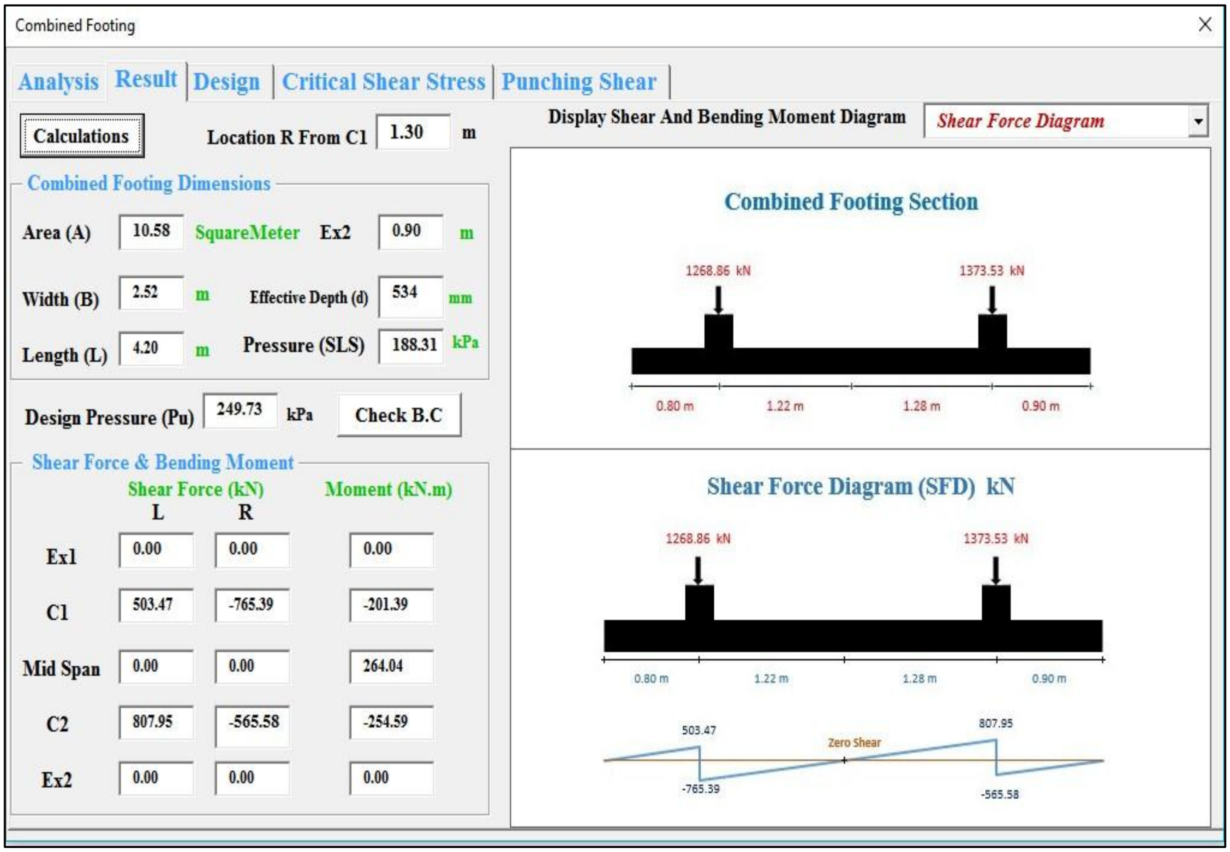


Figure B.18: Display Shear Force Diagram (S.F.D)

Figure B.19: Display Bending Moment Diagram (B.M.D)

B.6 FSD Programme Combined Footing Flexure Design and Shear Check Output

The bottom area of reinforcement steel for long direction, top area of reinforcement steel for long direction and the bottom area of reinforcement steel for short direction show in the **Figure B.20**. Check the shear stress (one-way shear) displayed in the **Figure B.21** and checks the punching shear show in **Figure B.22.**

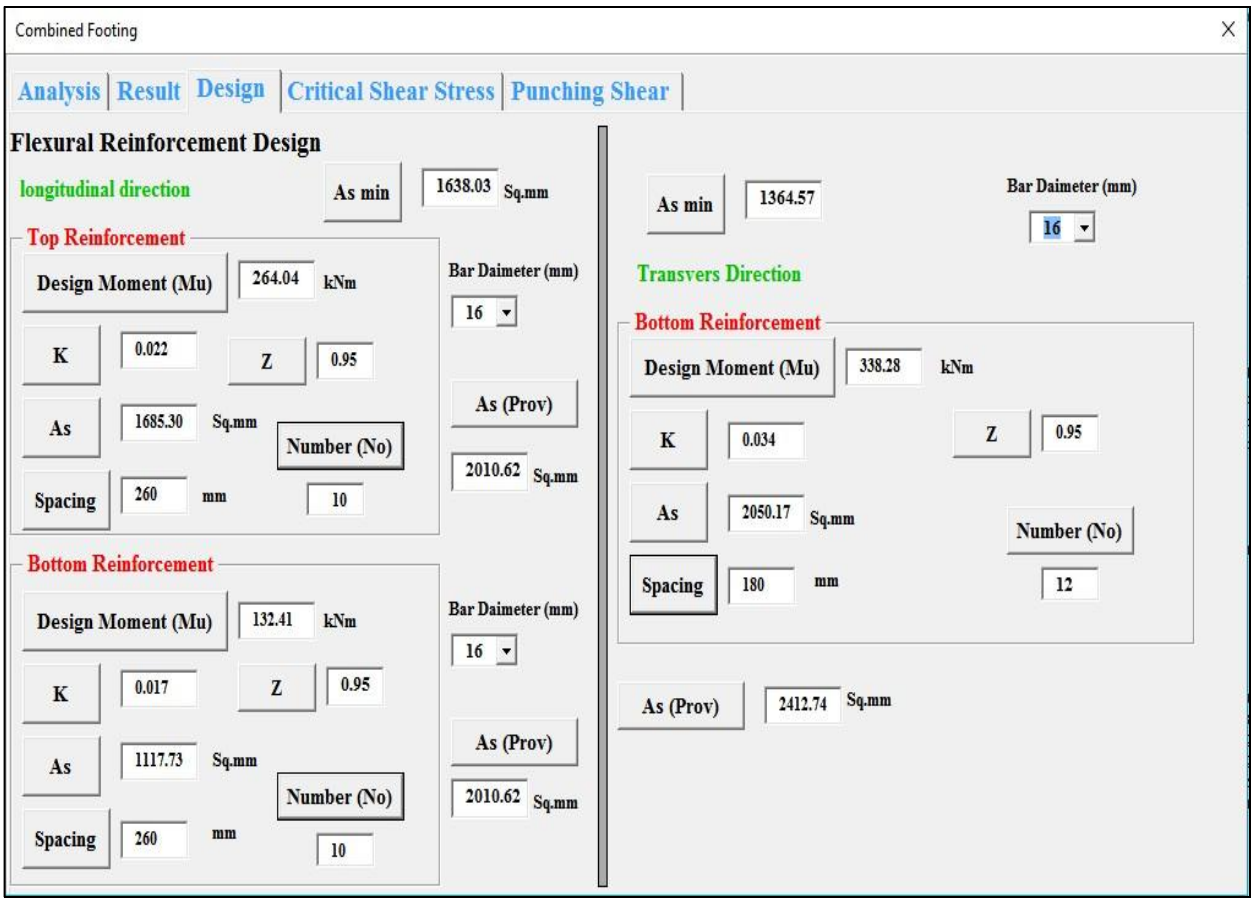


Figure B.20: Reinforcement Design in Long and Short Direction

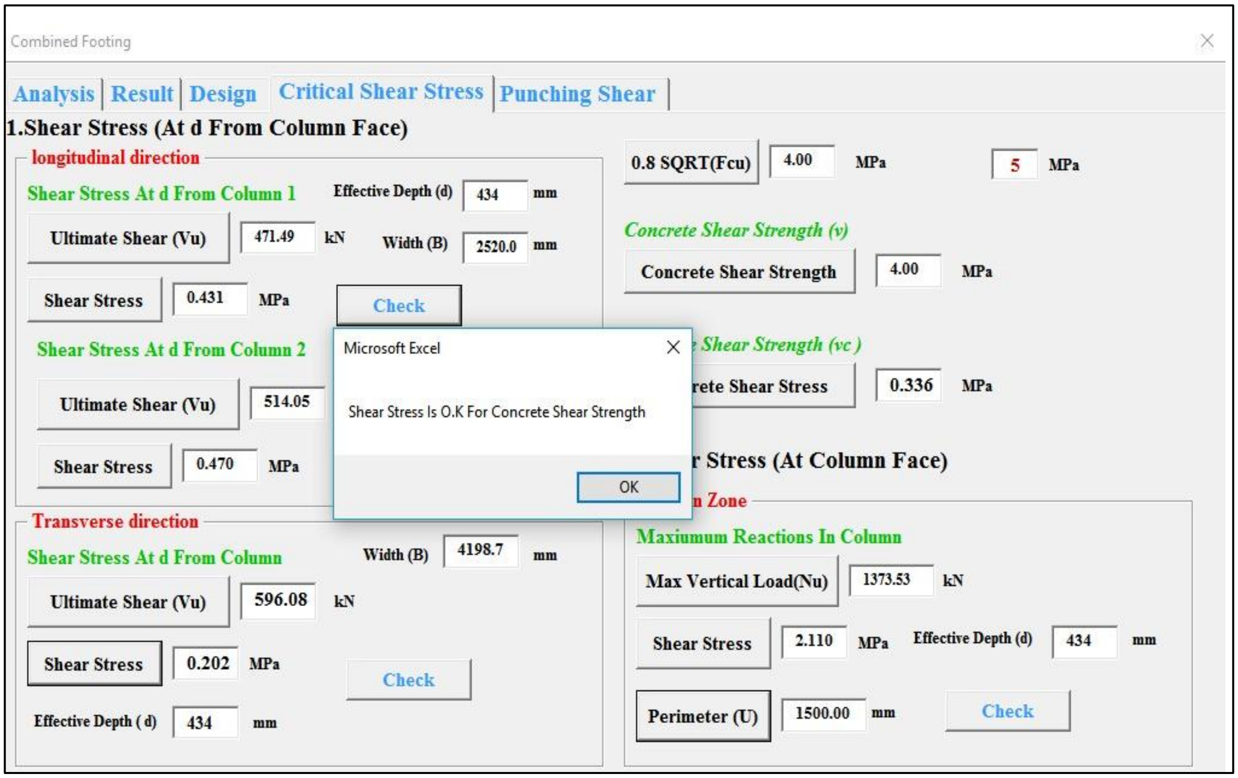


Figure B.21: Check Shear Stress (One-Way Shear)

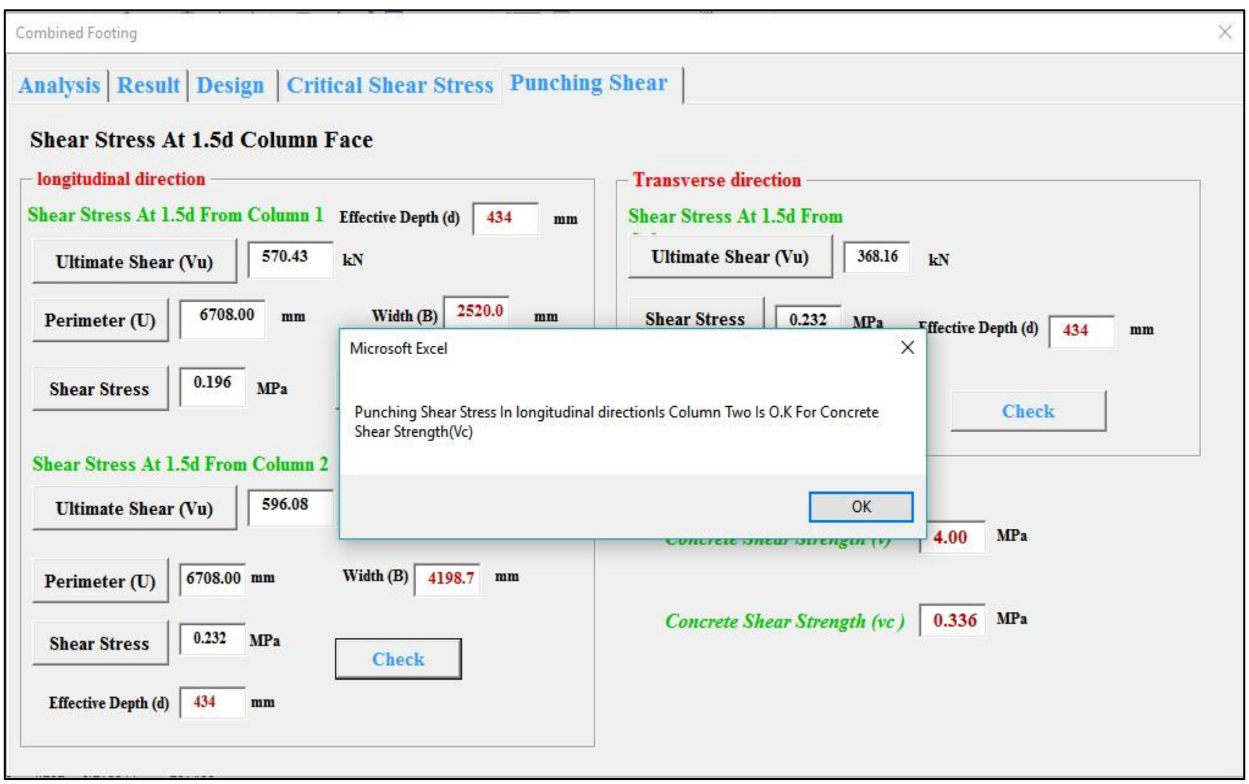


Figure B.22: Check Punching Shear in long Direction

B.7 FSD Programme Raft Footing Analysis and Design Output

Get ETABS unique name of columns and draw columns layout to select strips data, displayed calculation dimensions of Raft Footing. Raft Dimension Calculation, maximum soil pressure in serviceability limit state (SLS)**,** check soil bearing capacity Column Grid Layout, and Columns Dimension Middle, Edge and Corner show in The **Fig B.23.**

The x-strip Section and span above and below Strip selected show in **Fig B.24**, y-strip Section and span left and right Strip selected show in **Fig B.25**. **Fig B.26** Show materials entered and design input data.

Fig B.27 this screen displayed result analysis of X-Strip, Shear Force (Fu) and Bending Moment (Mu).in **Fig B.28** this screen displayed result analysis of Y-Strip, Shear Force (Fu) and Bending Moment (Mu). **Fig B.29** Show Results of design strip and critical shear stress calculations in X-Direction, **Fig B.30** Show results for design strip and critical shear stress calculations in Y-Direction, **Fig B.31** check punching shear stress in X-Direction, **Fig B.32** displayed check punching shear stress in Y-Direction, **Fig B.33** displayed shear force diagram in X-Strip, **Fig B.34** display shear force diagram in Y-Strip. **Fig B.35**displayed bending moment diagram in X-Strip, **Fig B.36** displayed bending moment diagram in Y-Strip.

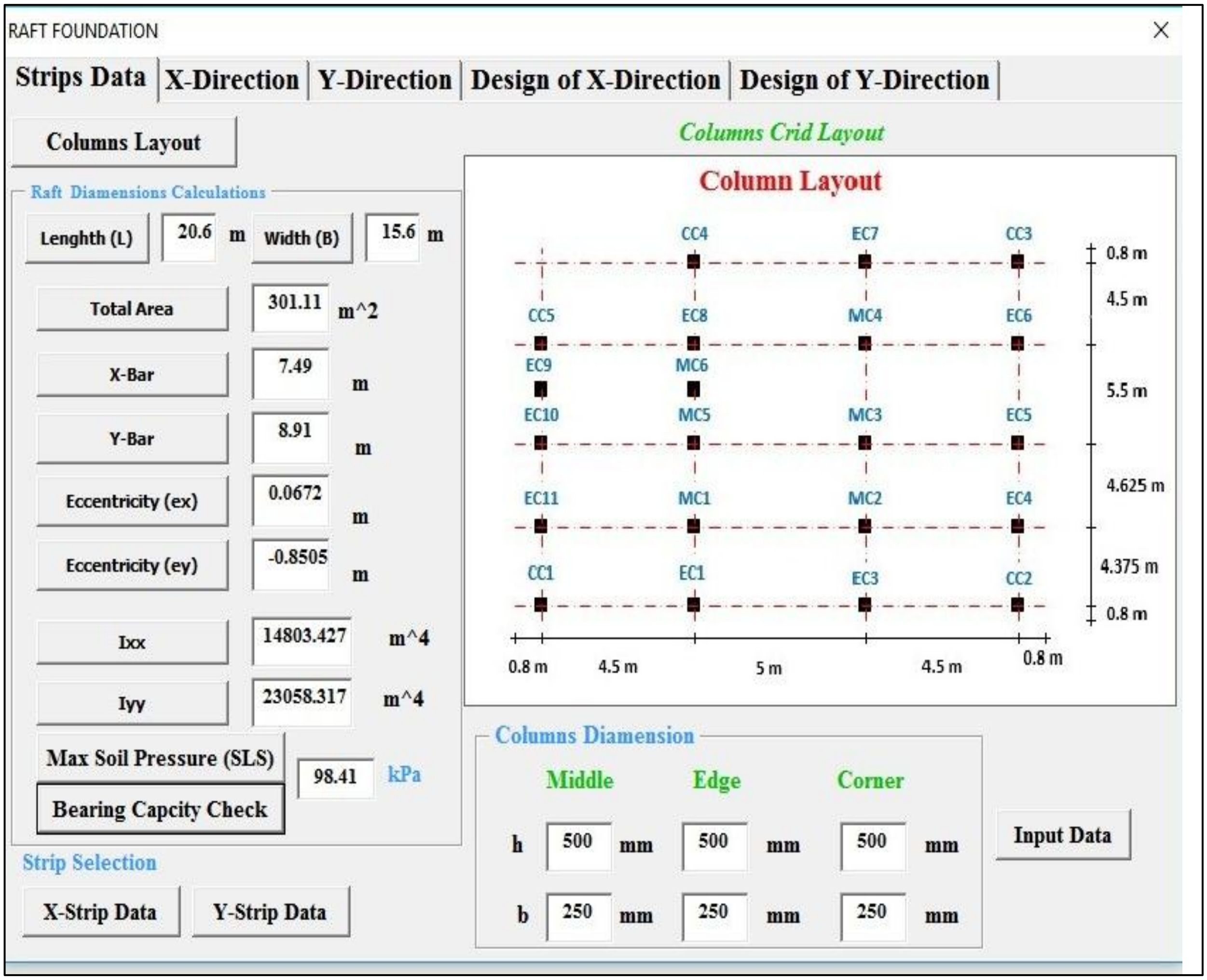


Figure B.23: Get ETABS unique name of columns and draw columns

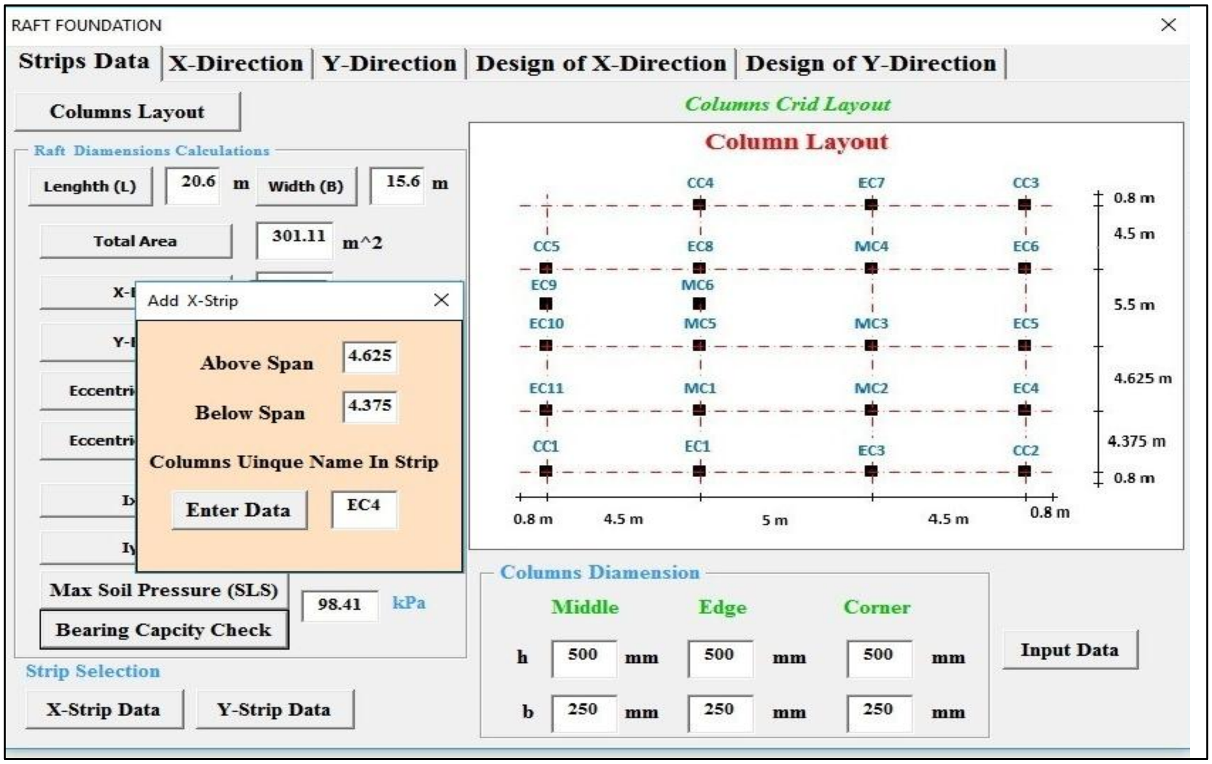


Figure B.24: Section unique Name of Columns in X-Strip

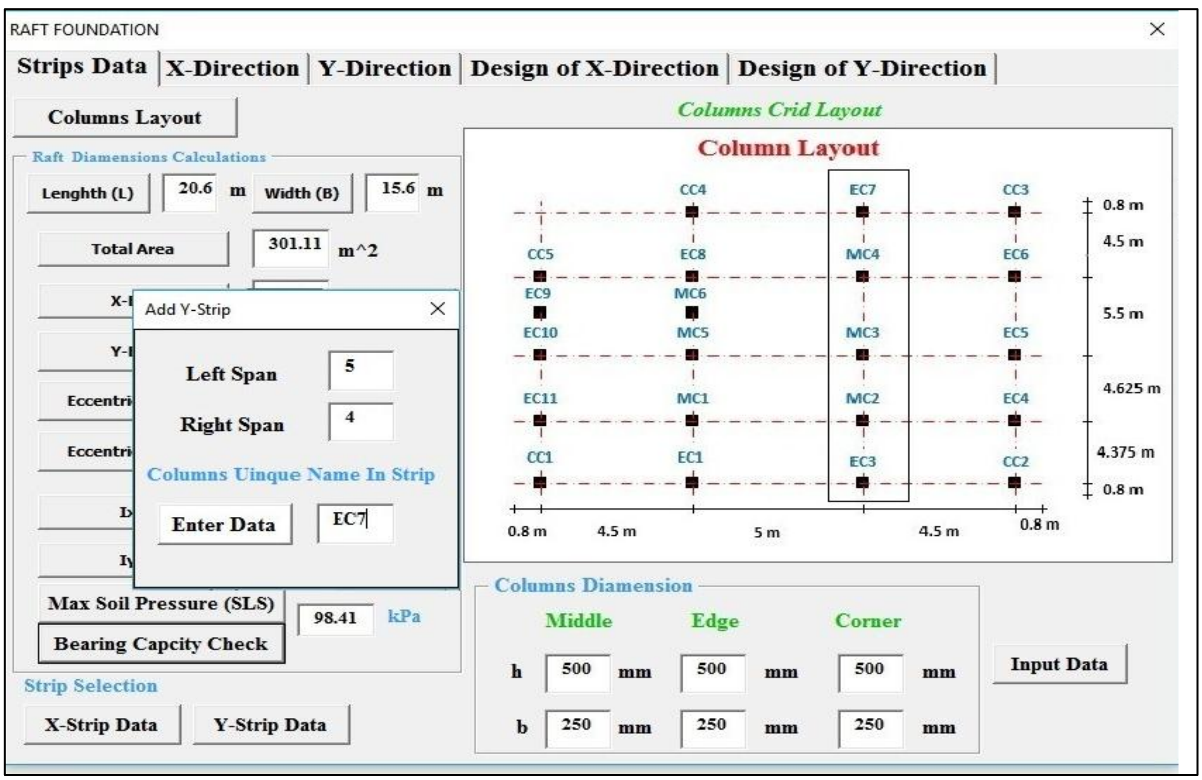


Figure B.25: Get ETABS unique name of columns in Y- Strip and draw columns

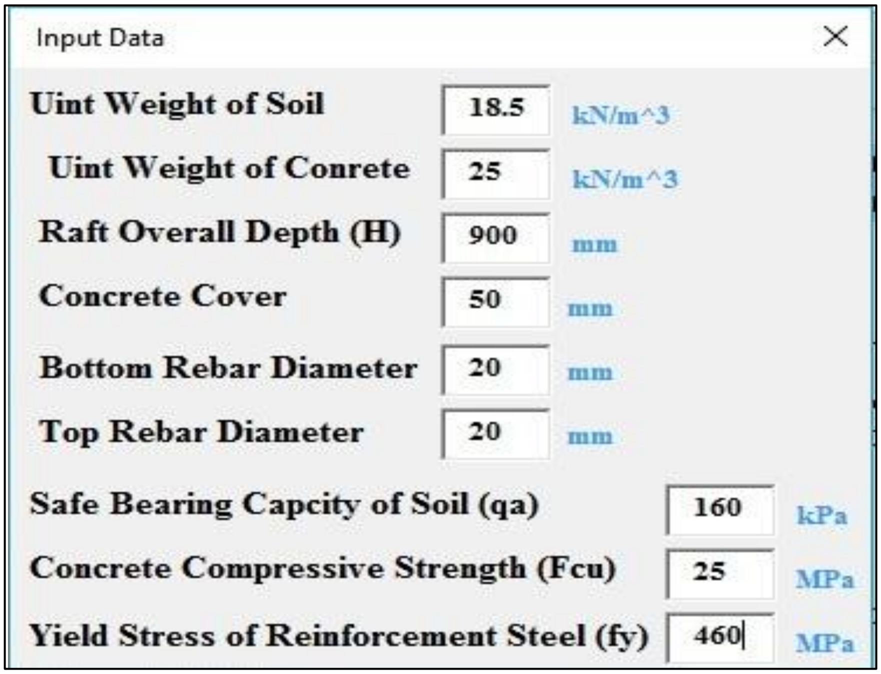


Figure B.26: materials entered and design input data

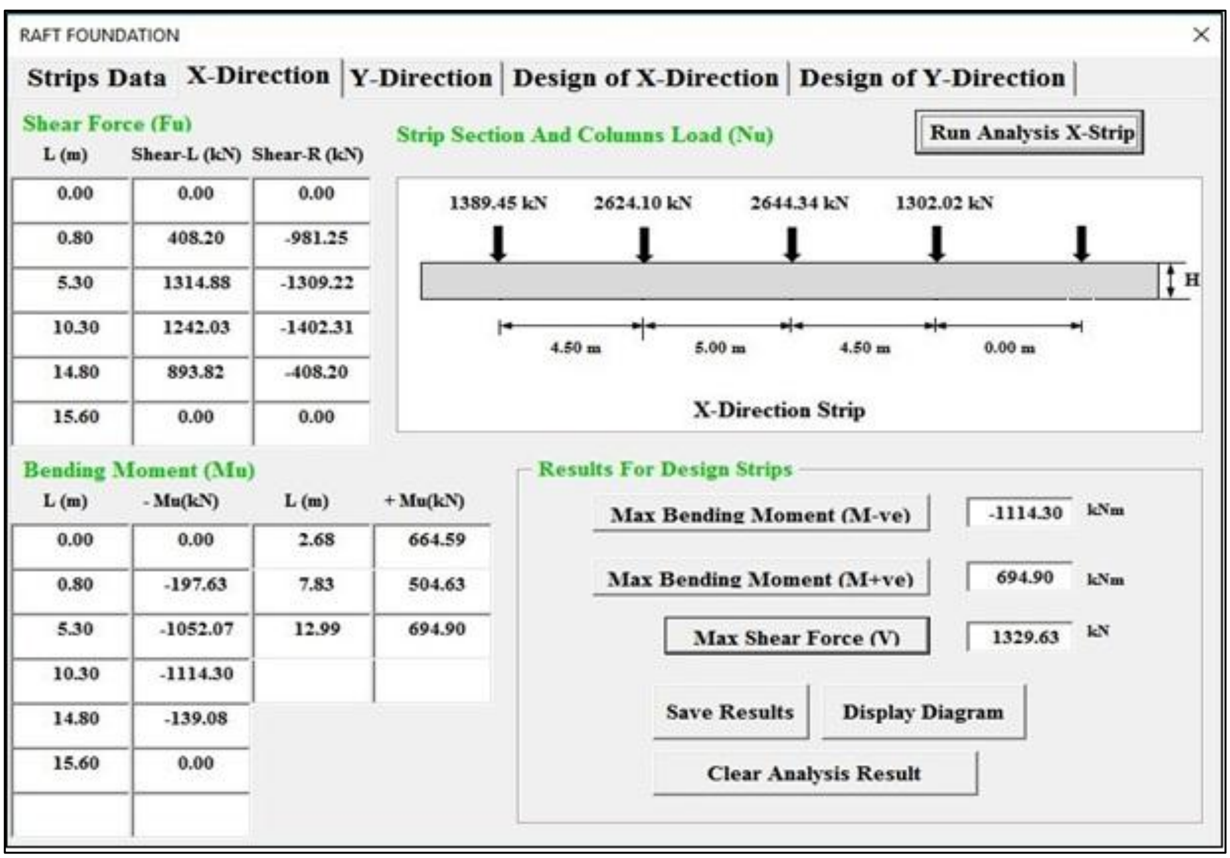


Figure B.27: Shear Force and Bending Moment Result of X-Strip

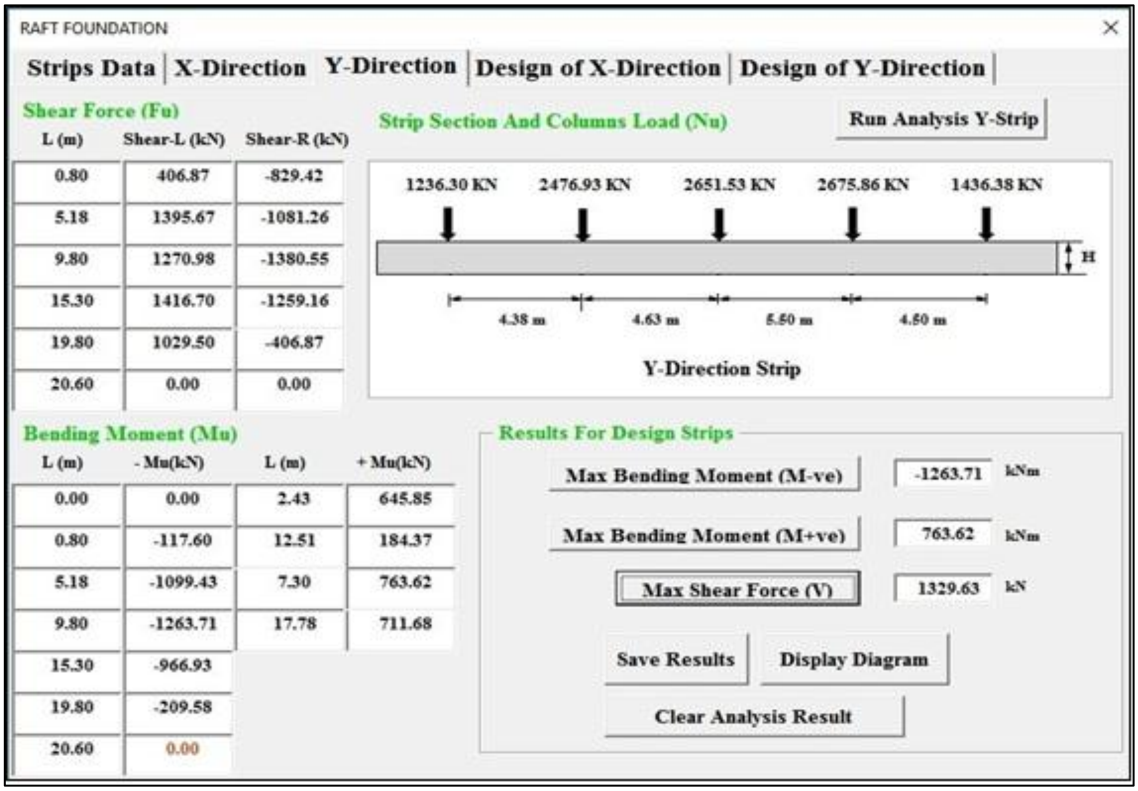


Figure B.28: Shear Force and Bending Moment Result of Y-Strip

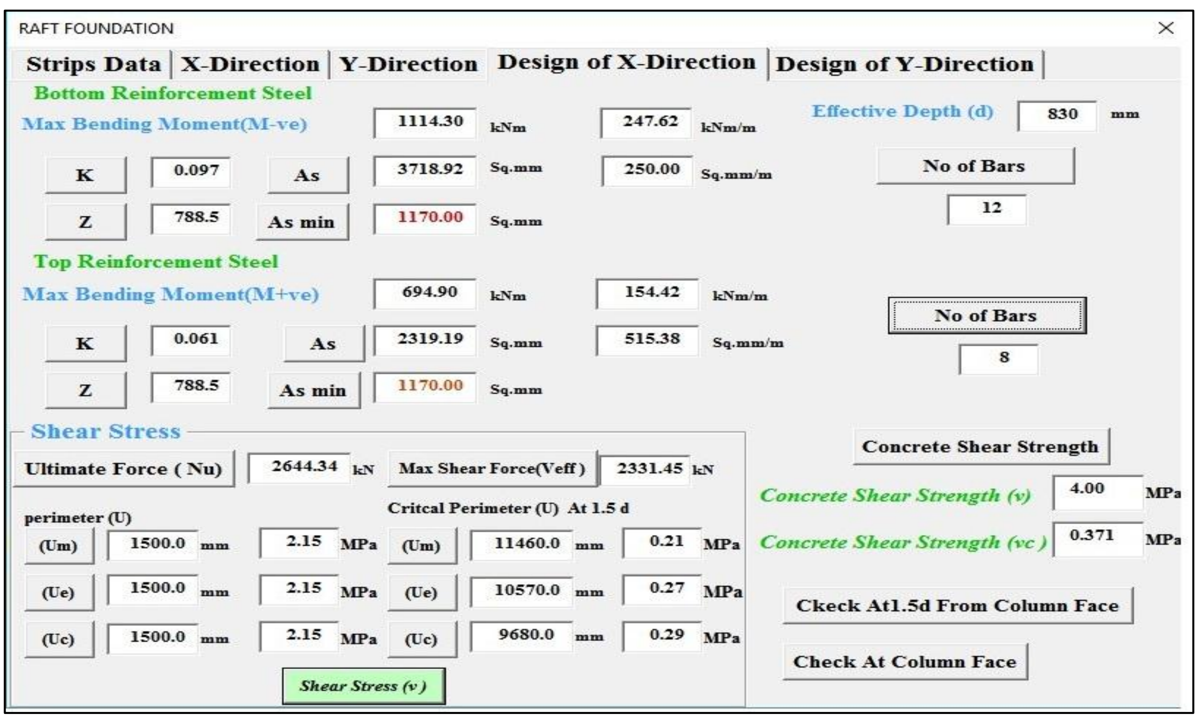


Figure B.29: Results of Design Strips and Shear Stress Calculations in X-Direction

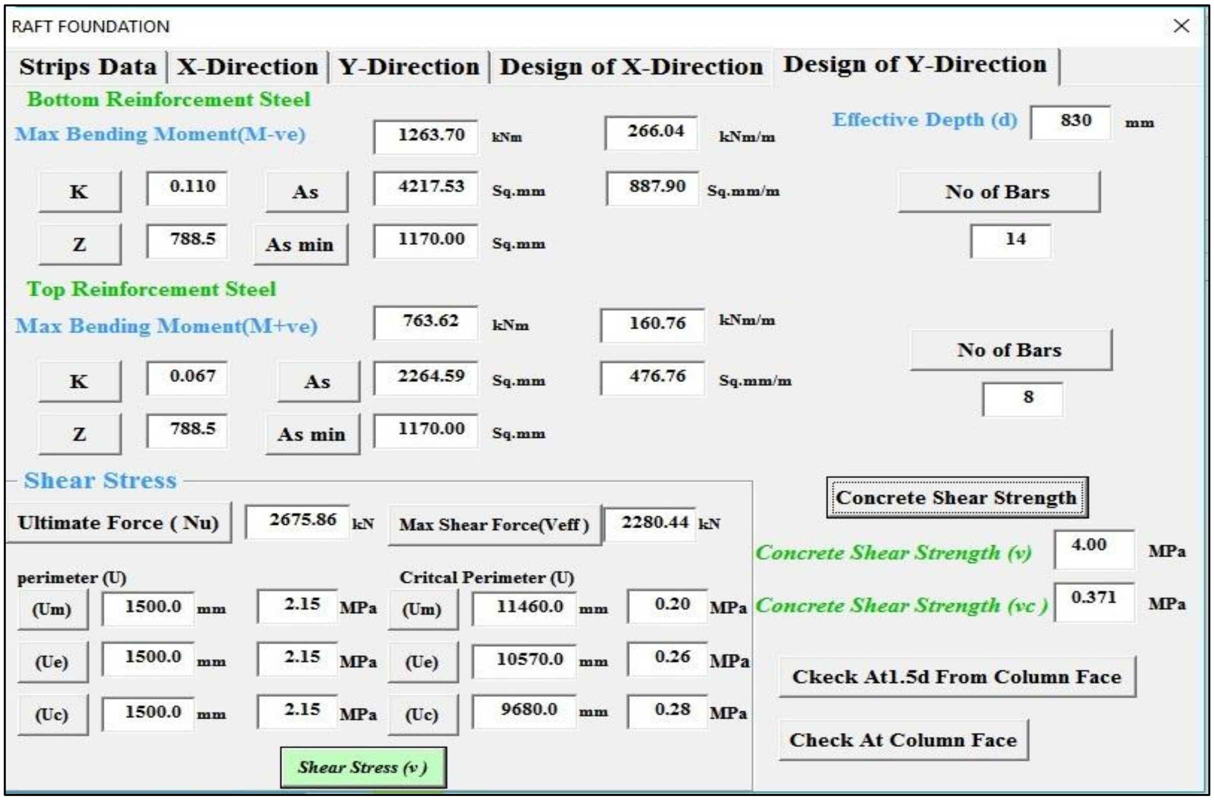


Figure B.30: Results of Design Strips and Shear Stress Calculations in Y-Direction

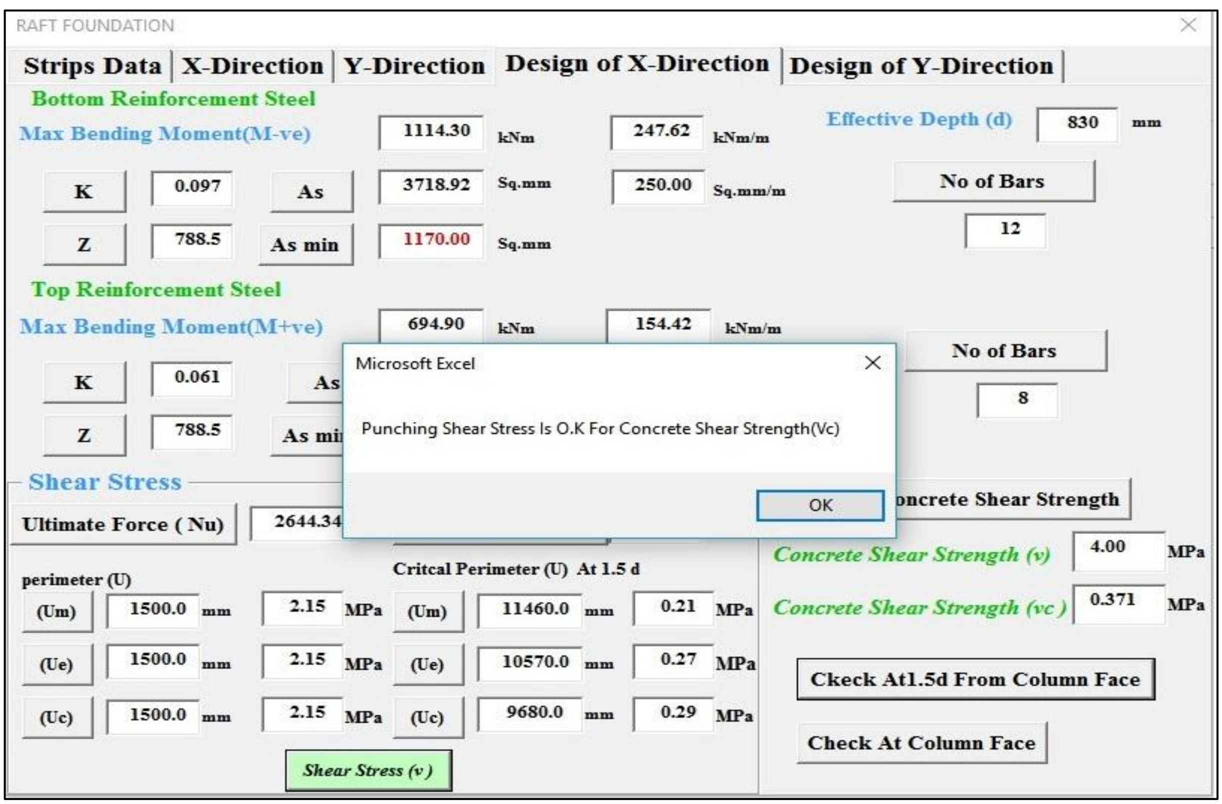


Figure B.31: Check Punching Shear Stress in X-Direction

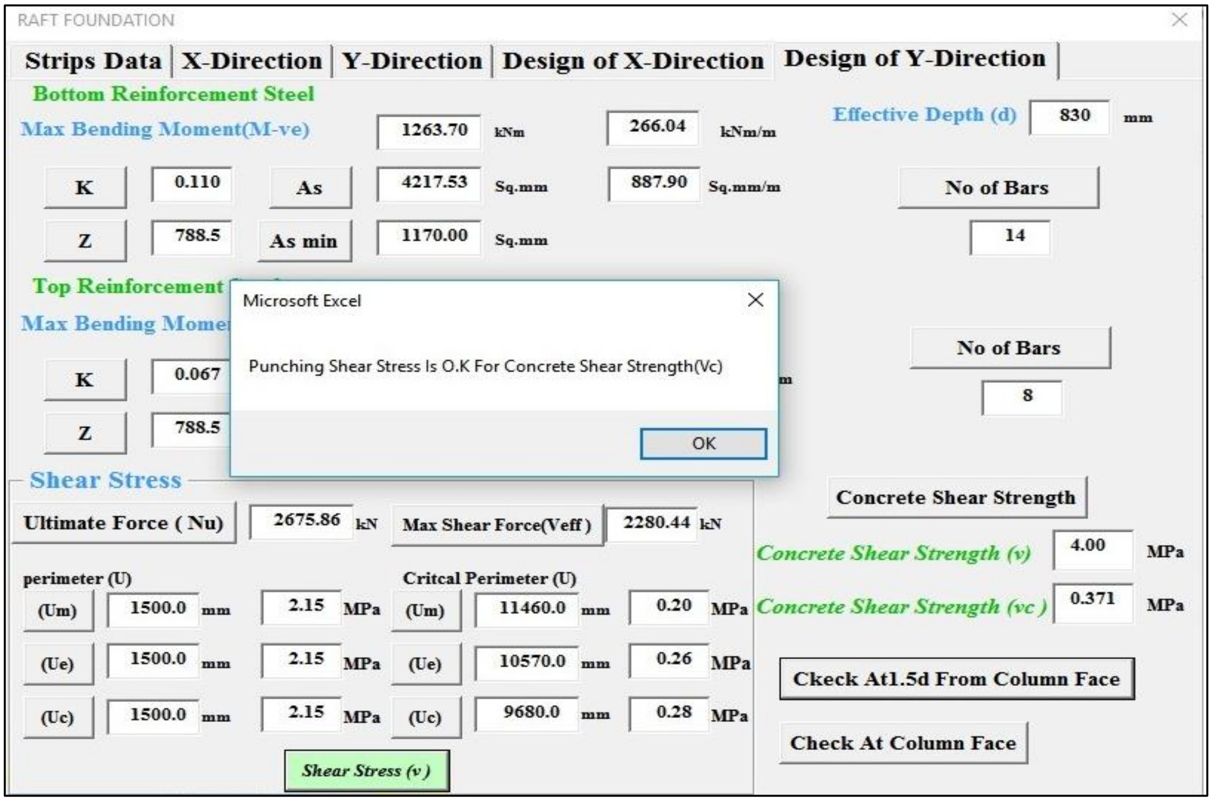


Figure B.32: Check Punching Shear Stress in Y-Direction

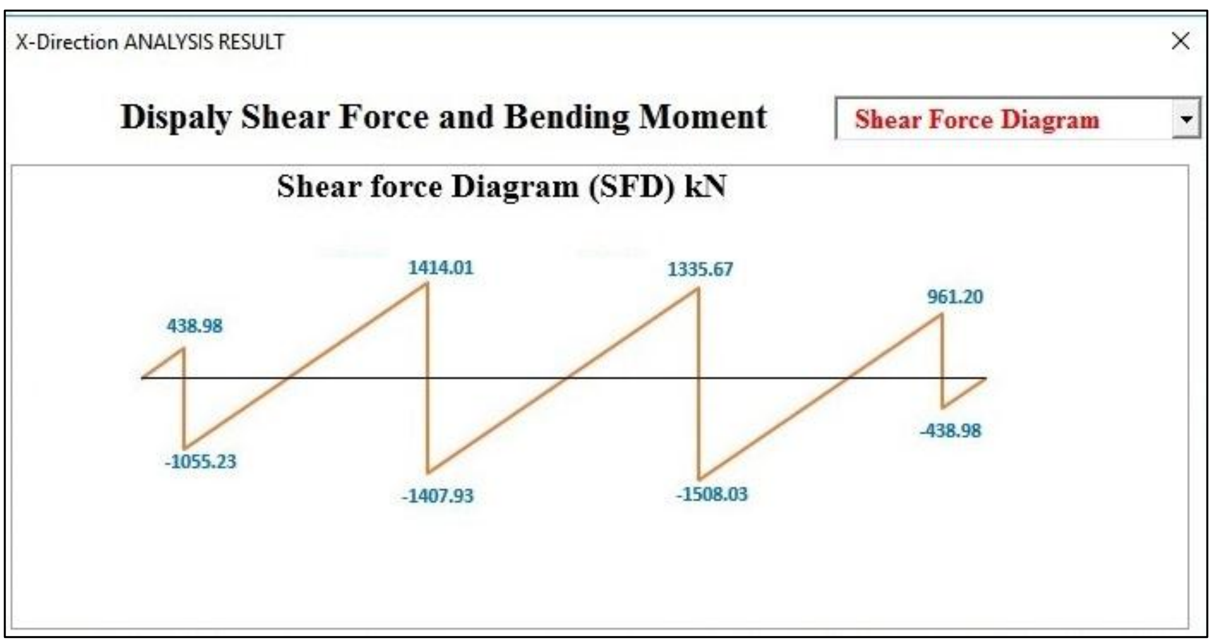


Figure B.33: Display X-Strip Shear Force Diagram

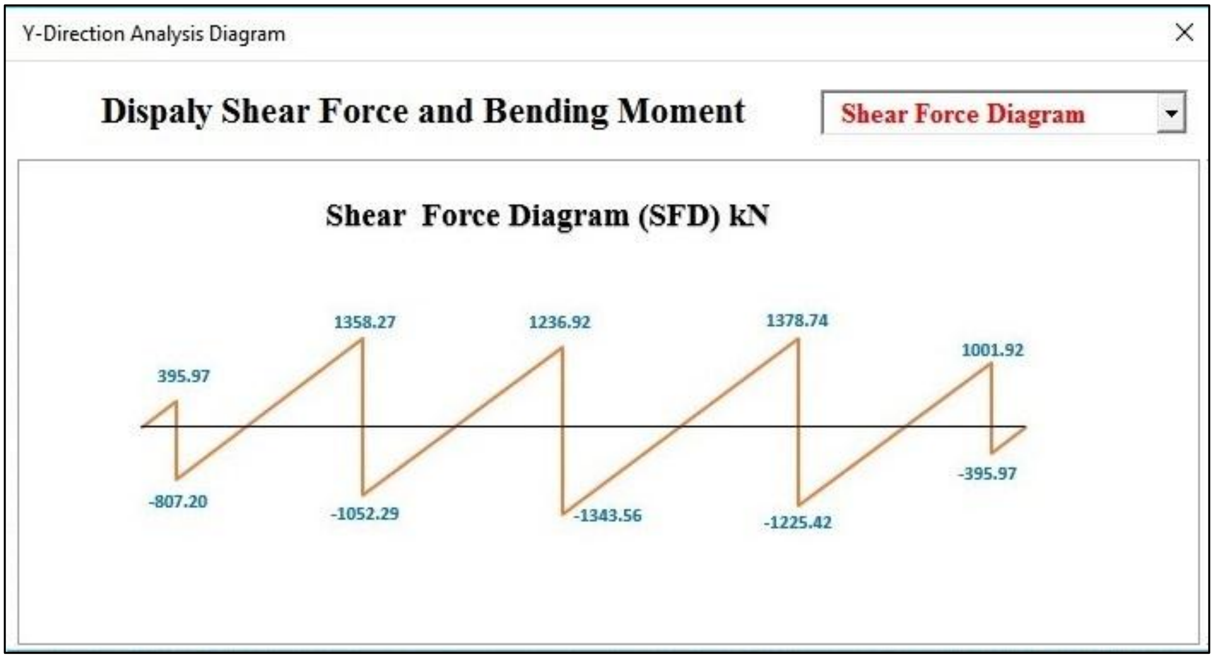


Figure B.34: Display Y-Strip Shear Force Diagram

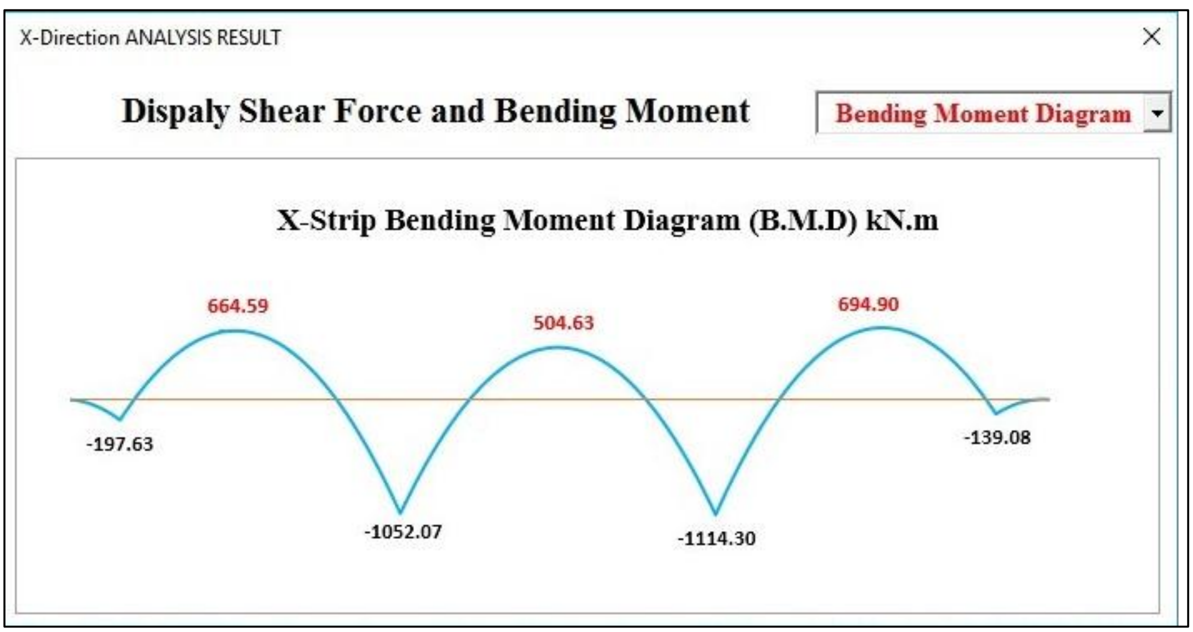


Figure B.35: Display X-Strip Bending Moment Diagram

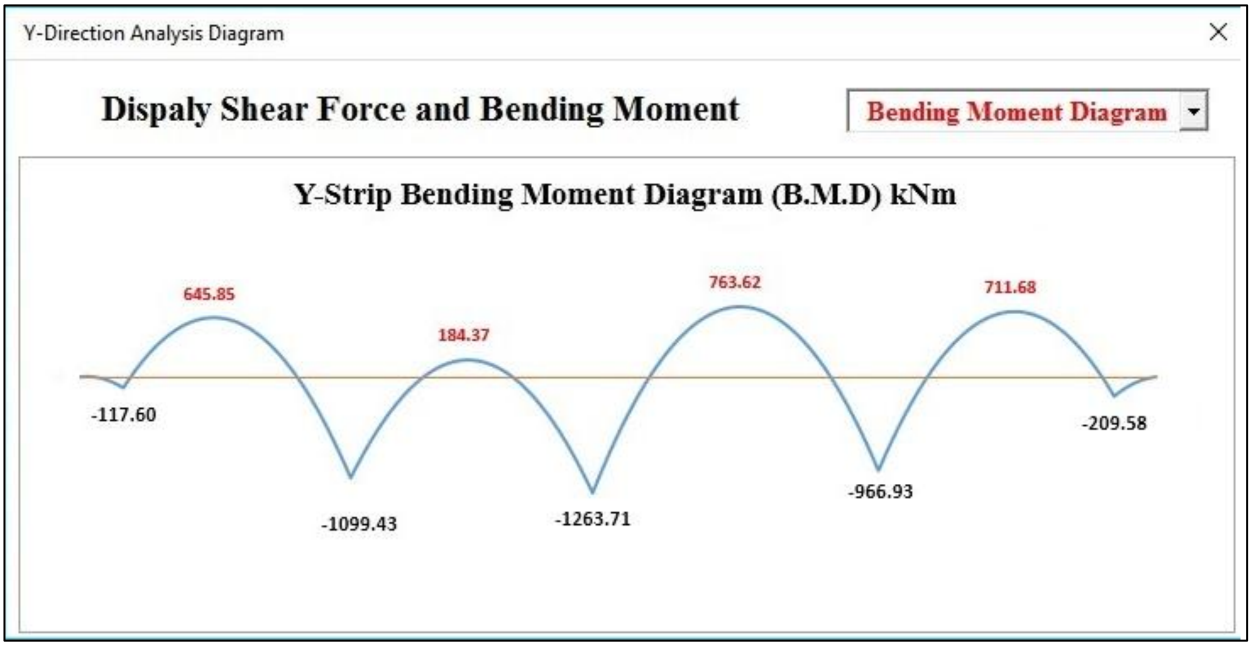


Figure B.36: Display Y-Strip Bending Moment Diagram

Appendix C:

SAFE Output and Results

C.1 SAFE Software Cases Study Output

The Appendix C are used for show result of **SAFE** Program. This appendix contains printed output of Design of the cases Study as represent in chapter 3.

C.2 SAFE Software Middle Footing Analysis and Flexure and Shear Design

For analysis and flexure design show results of Middle footing. **Figure.C.1** displayed dimension of middle footing. Maximum soil Pressure at corners in serviceability limit state (SLS) show in **Figure.C.2** and **Figure. C.3** displayed design moment (M_u) in X Direction, and design moment (M_u) in Y Direction show that in **Figure.C.4**. in **Figure.C.5** display area of steel in X Direction and area of steel in Y Direction show in **Figure.C.6**. the punching shear for concrete shear strength first check (failed) show in **Figure.C.7.** and change Overall depth of footing, The O.K punching shear check for the design concrete shear strength show in **Figure.C.8**

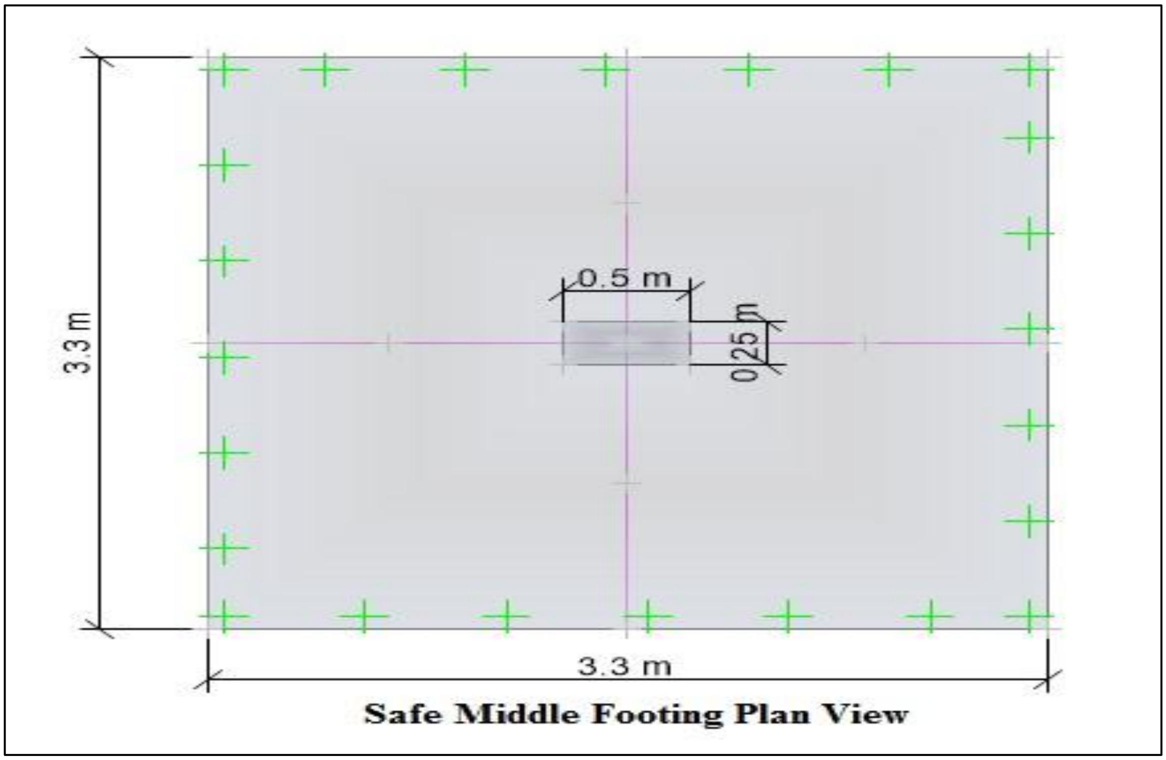


Figure C. 1: Middle Footing Plane View

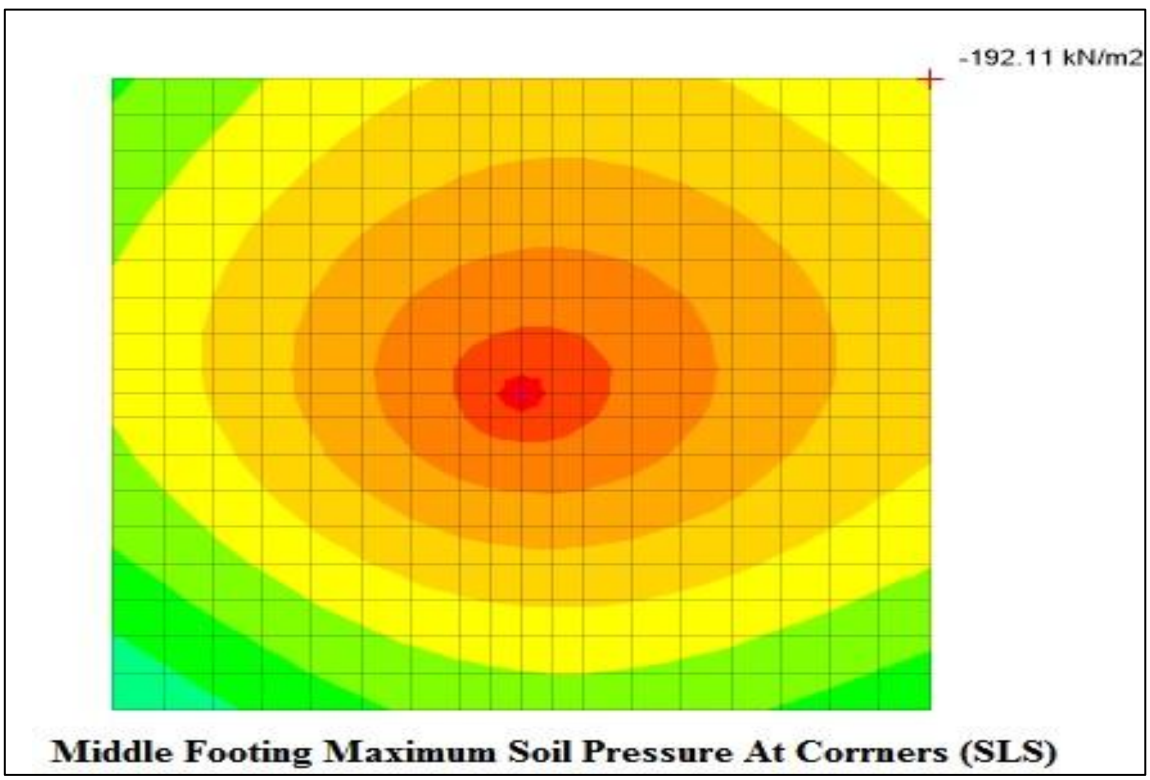


Figure C. 2：Middle Footing Maximum Soil Pressure at Corners (SLS)

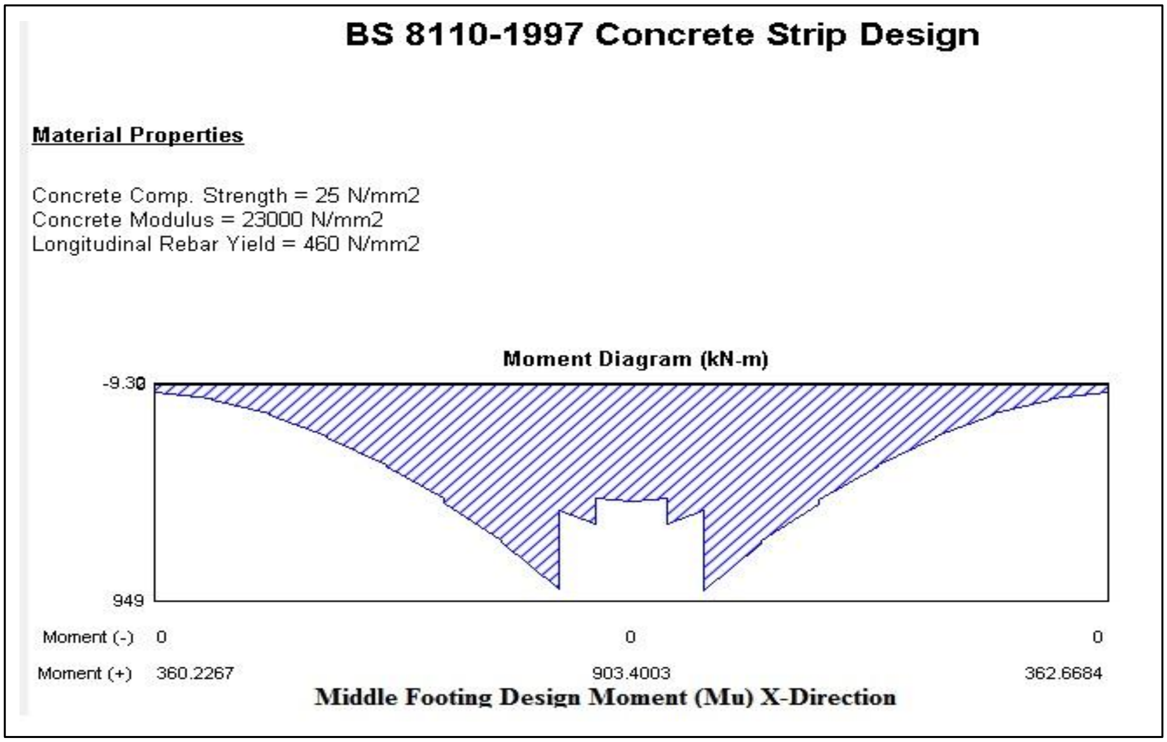


Figure C. 3: Middle Footing Design Moment (Mu) X-Direction

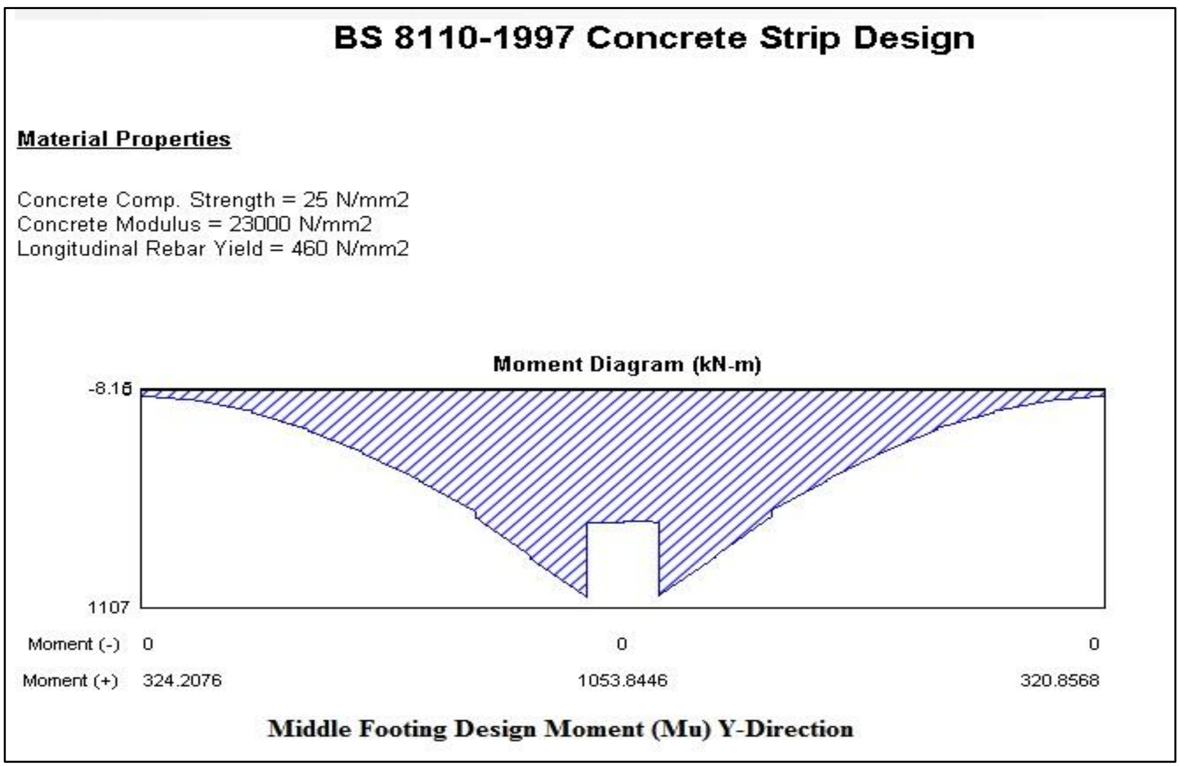


Figure C. 4: Middle Footing Design Moment Y-Direction

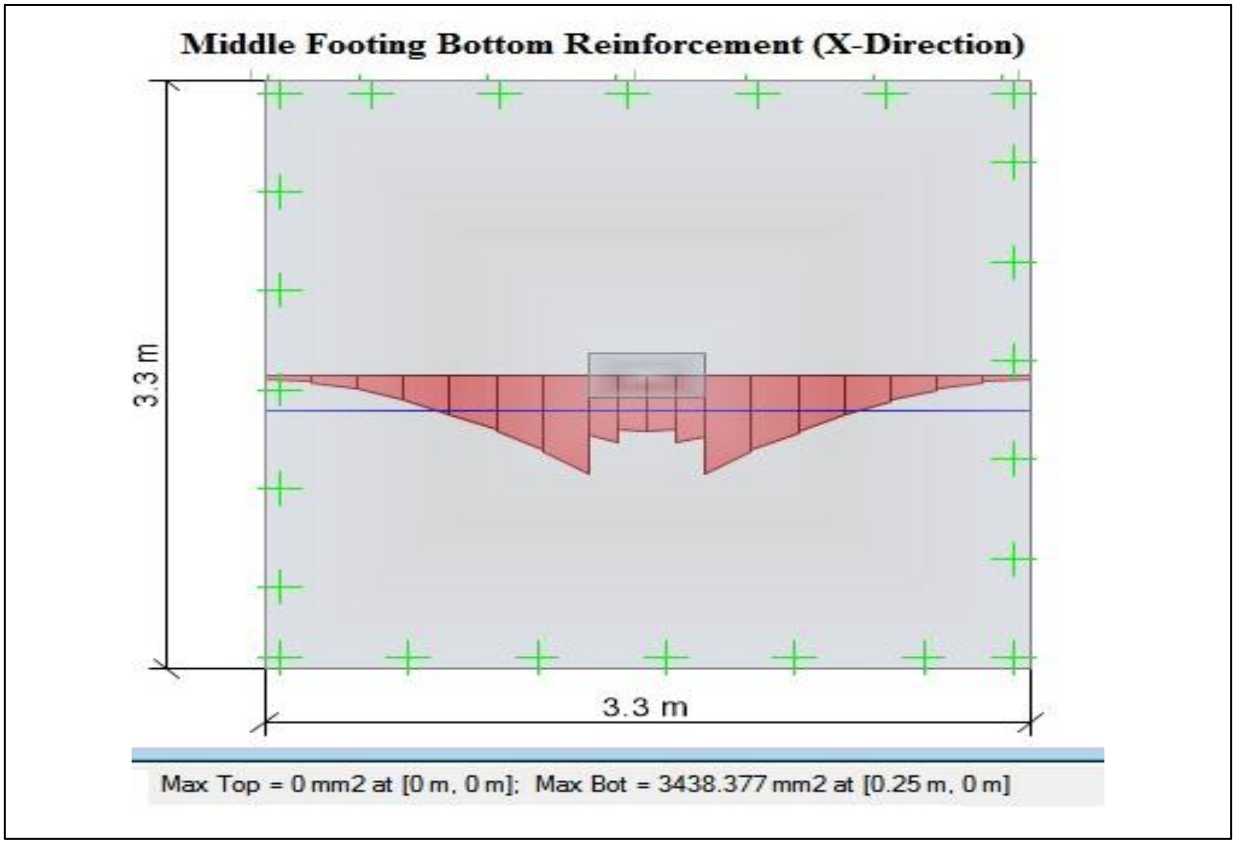


Figure C. 5: Middle Footing Bottom Reinforcement (X-Direction)

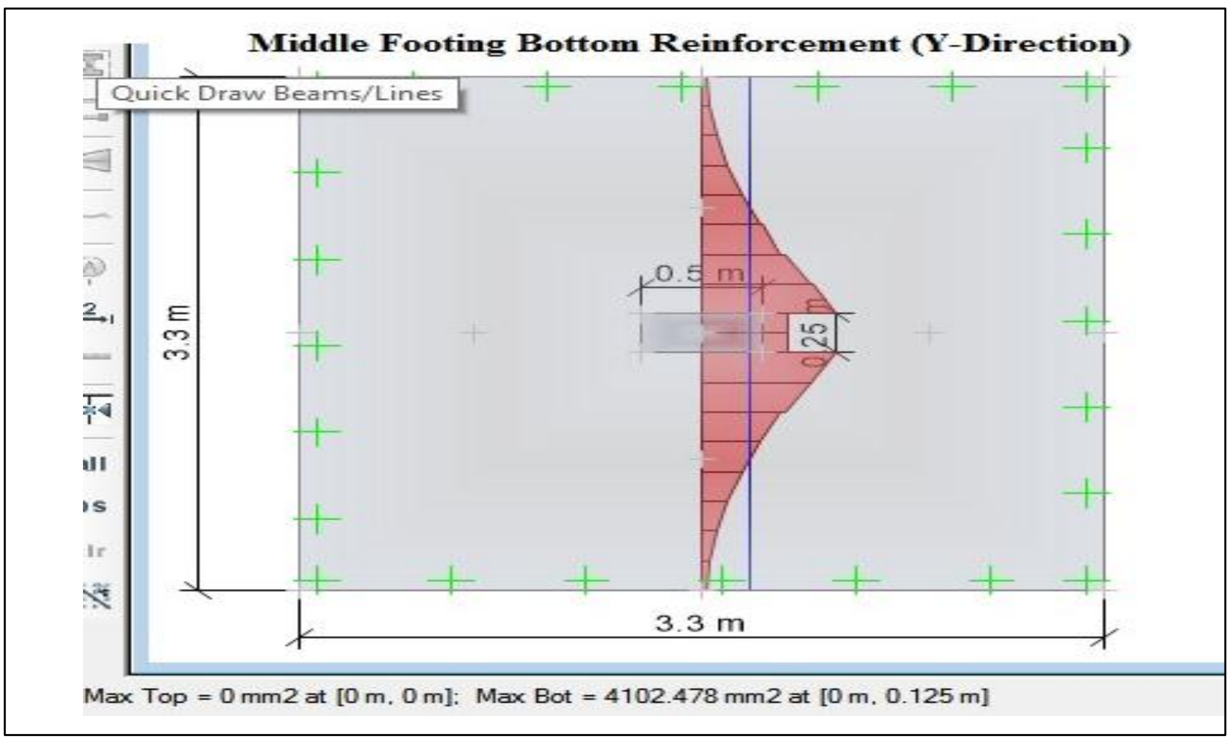


Figure C. 6: Middle Footing Bottom Reinforcement (Y-Direction)

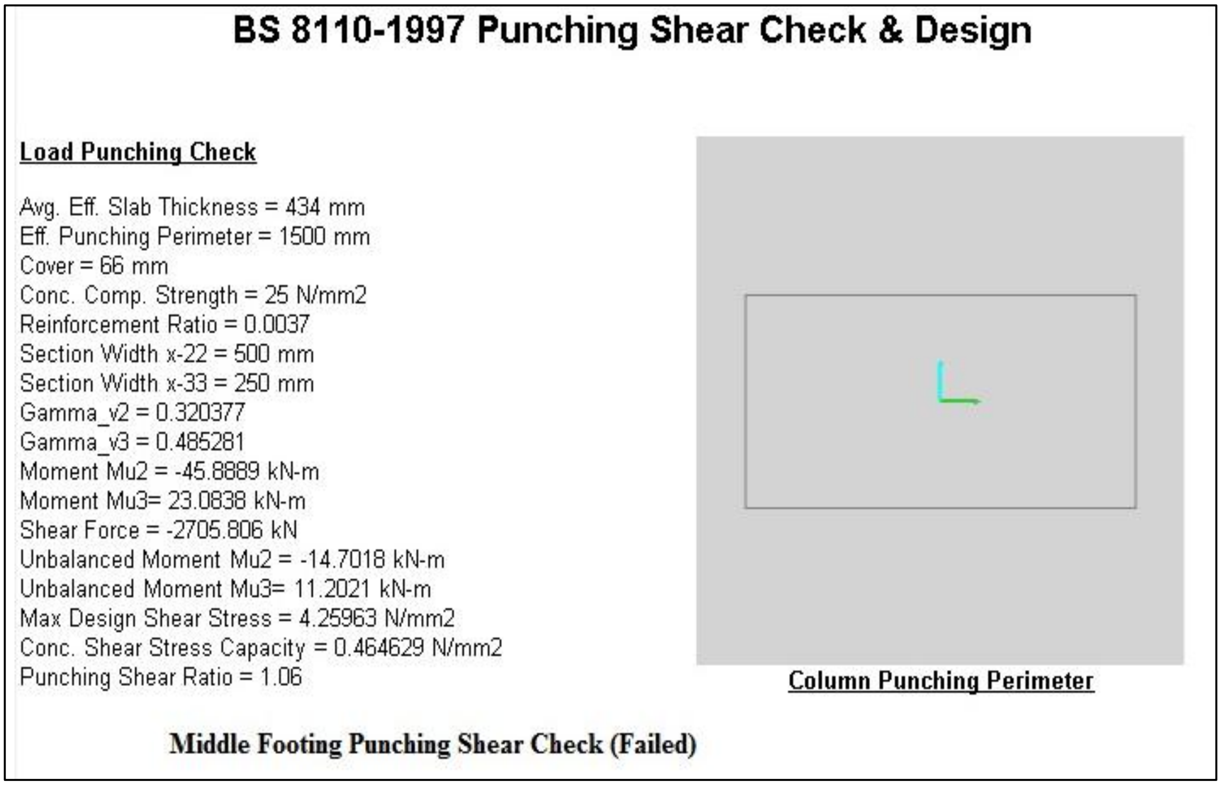


Figure C. 7: Middle Footing Punching Shear for concrete shear strength check (failed)

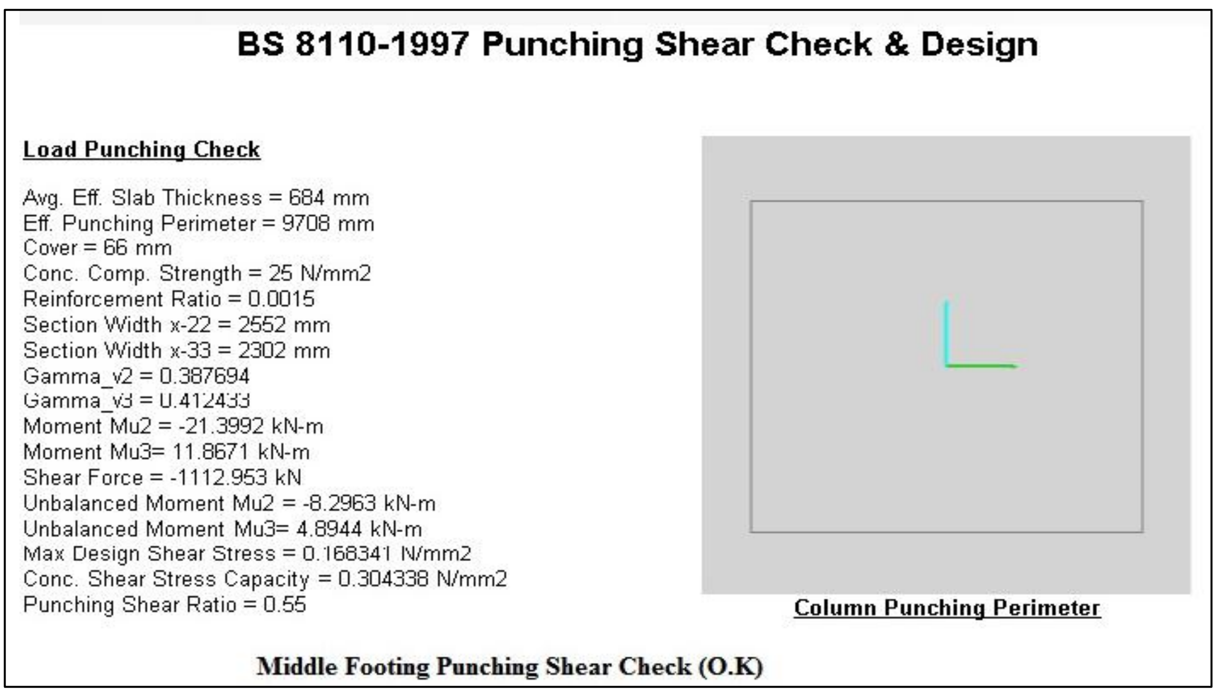


Figure C. 8: Middle Footing Punching Shear for concrete shear strength check (O.K)

C.3 SAFE Software Combined Footing Analysis and Flexure and Shear Design

For analysis and flexure design show results of combined footing. **Figure.C.9** displayed dimension of combined footing. Maximum soil Pressure at corners in serviceability limit state (SLS) show in **Figure.C.10,** and **Figure.C.11** displayed design moment (M_u) in X Direction, and design moment (M_u) in Y Direction show that in **Figure. C.12**. in **Figure. C.13** display area of steel in X Direction and area of steel in Y Direction show in **Figure.C.14**. The punching shear for concrete shear strength first check (failed) show in **Figure.C.15.** and change Overall depth of footing, The O.K punching shear check for The design concrete shear strength show in **Figure. C.16**.

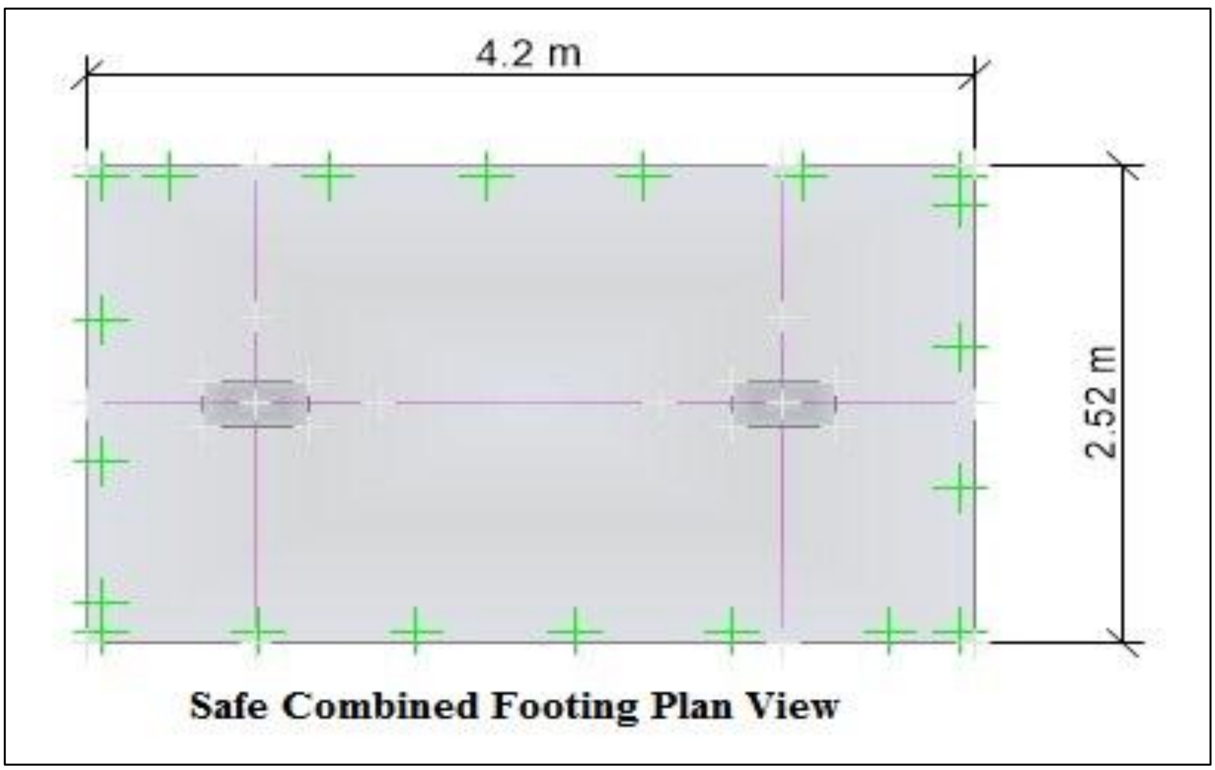


Figure C. 9: **Combined Footing Plan View**

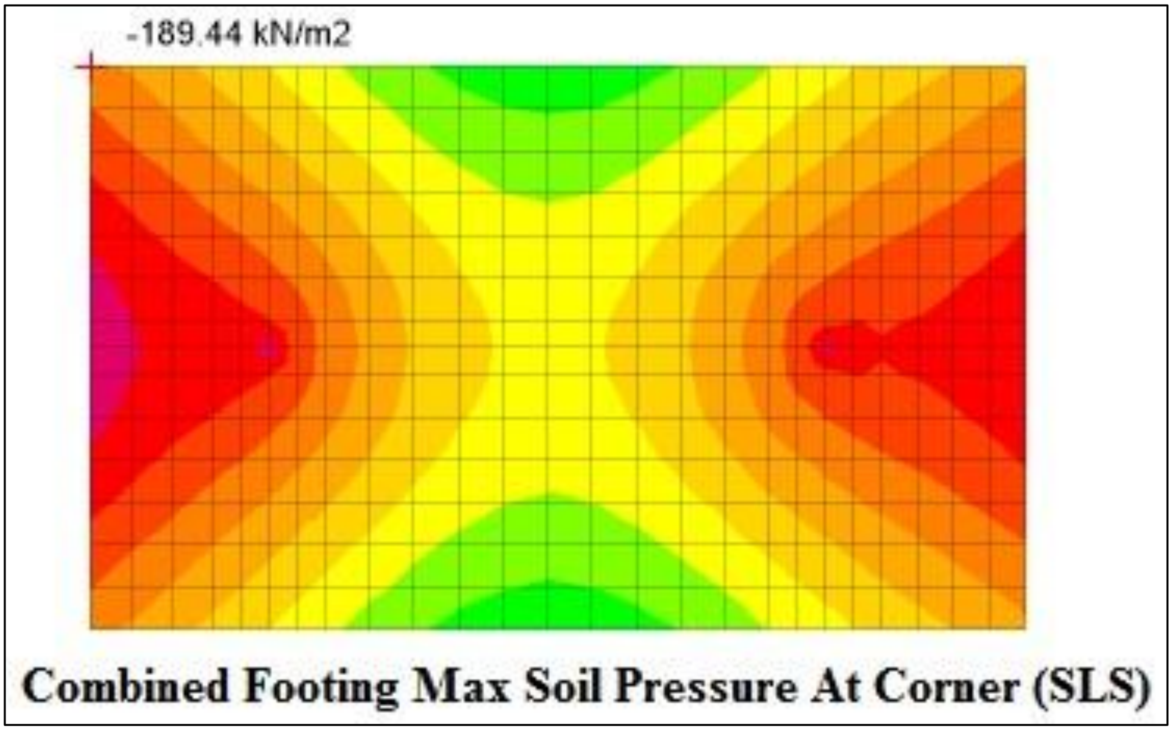


Figure C. 10 : **Combined Footing Maximum Soil Pressure at Corner (SLS)**

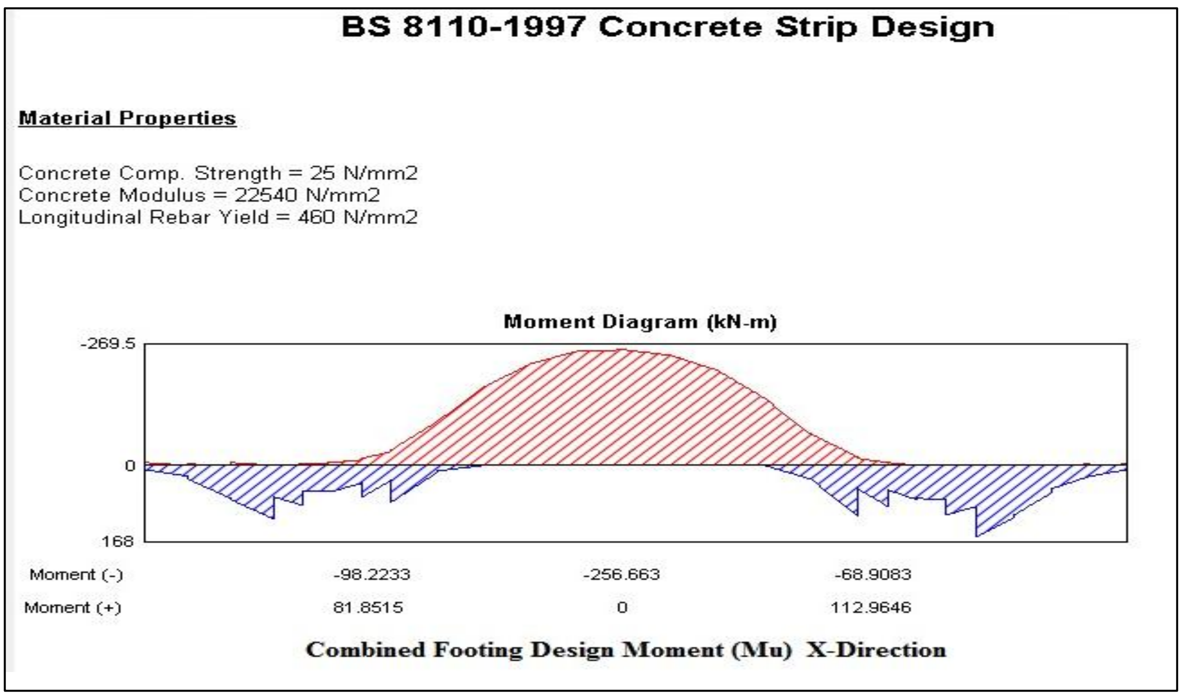


Figure C. 11 : Combined Footing Design Moment (Mu) X-Direction

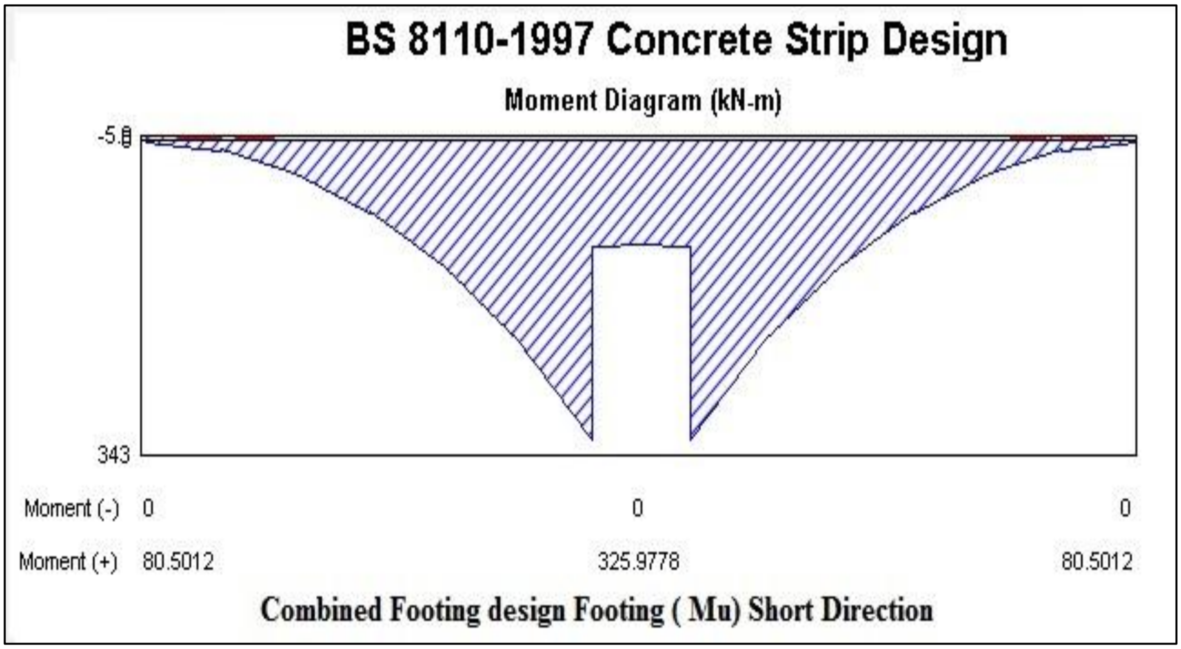


Figure C.12 : Combined Footing Design Moment (Mu) Y Direction

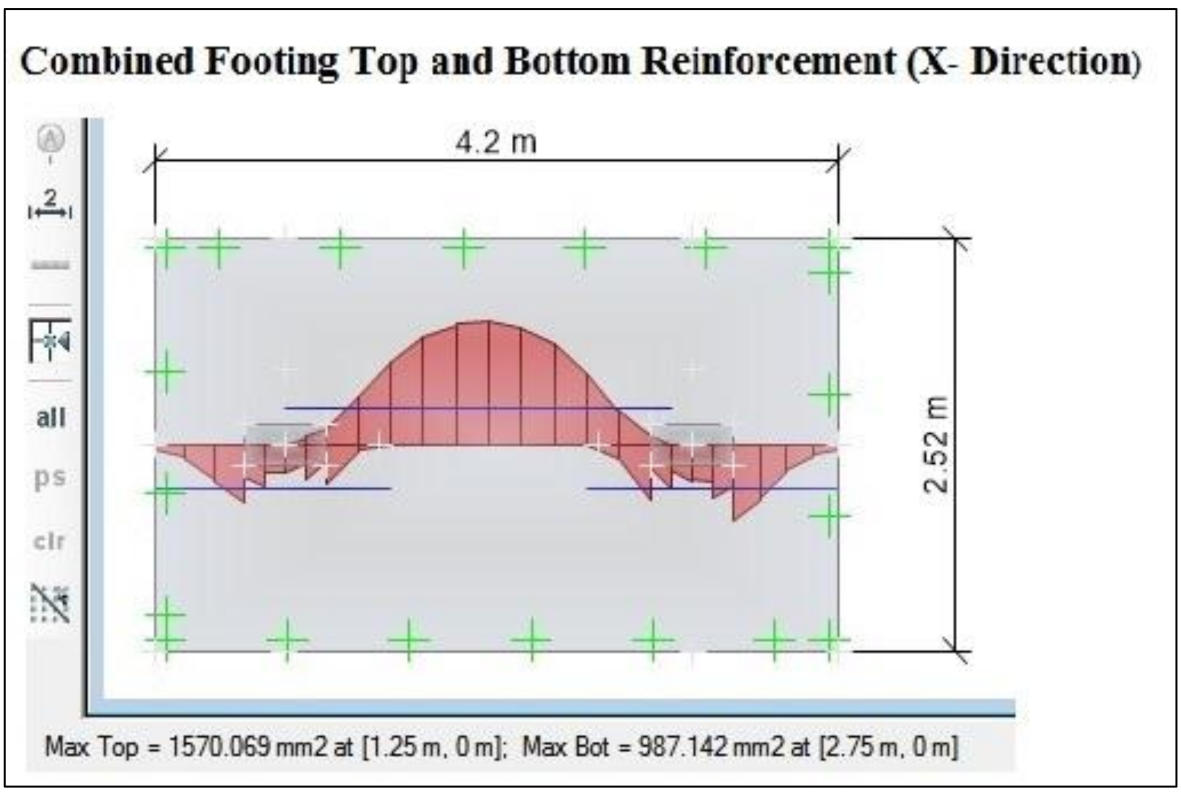


Figure C.13: Combined Footing Top and Bottom Reinforcement (X- Direction)

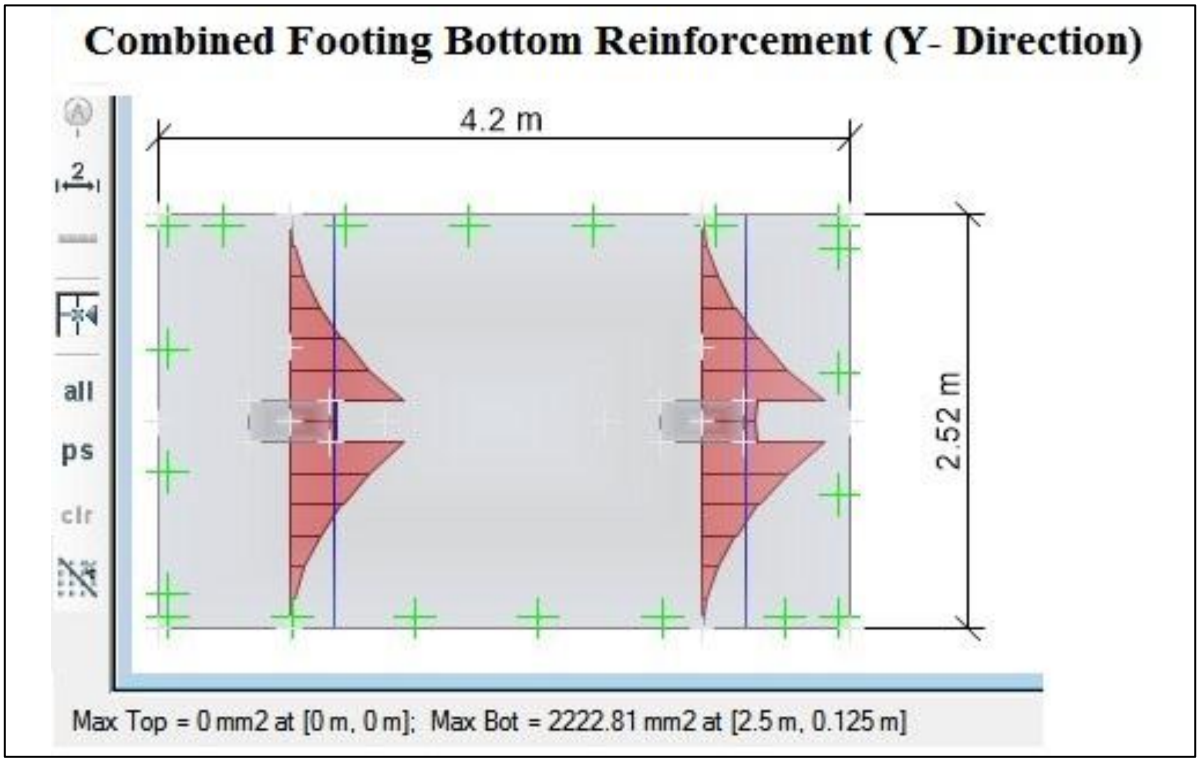


Figure C.14: Combined Footing Bottom Reinforcement (Y- Direction)

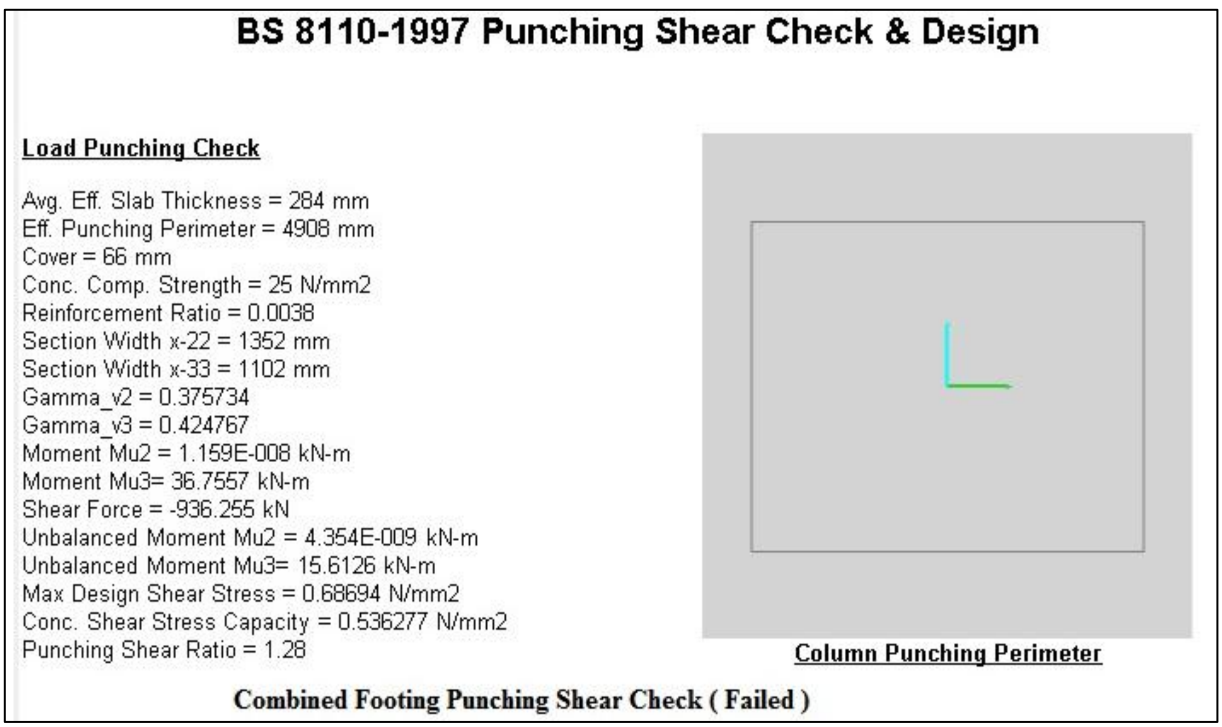


Figure C 15: Combined Footing Punching Shear for concrete shear strength check (failed)

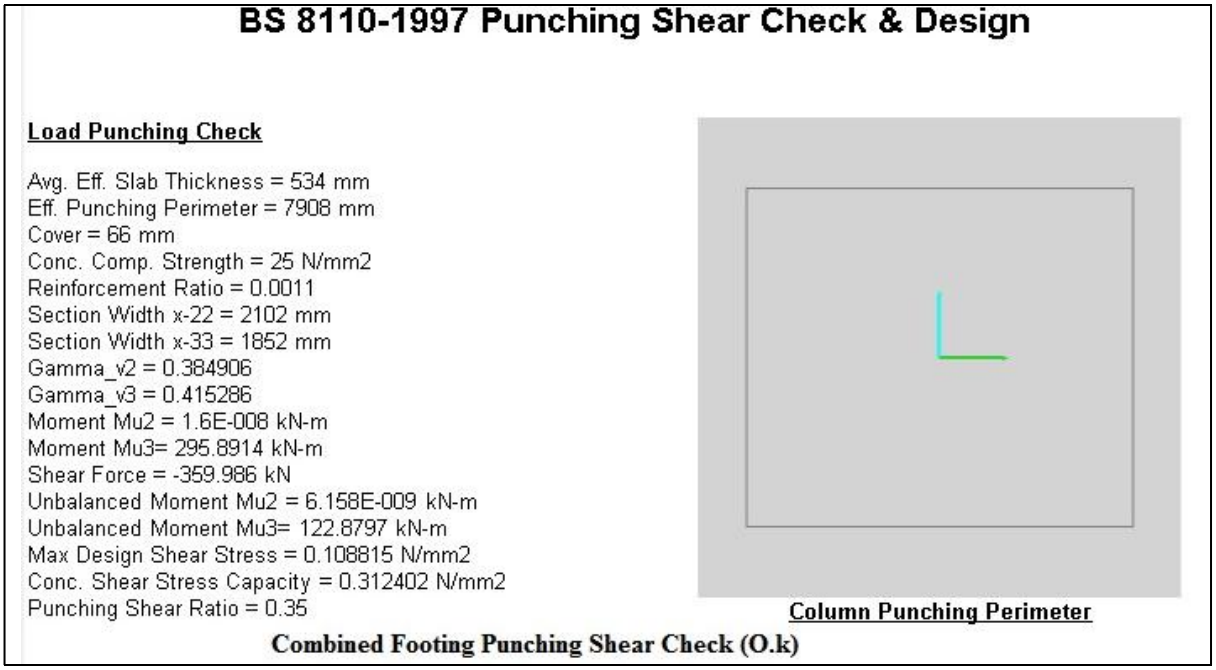


Figure C. 16:Combined Footing Punching Shear for concrete shear strength Check (O.K)

C.4 SAFE Software Raft Footing Analysis and Flexure and Shear Design

For analysis and flexure design show results of Raft footing. **Figure.C.17** displayed dimension of Raft footing. Maximum soil Pressure at corners in serviceability limit state (SLS) show in **Figure.C.18,** and **Figure. C.19** displayed design moment (M_u) in X Strip, and design moment (M_u) in Y Strip show that in **Figure.C.20**. in **Figure.C.21** display area of steel and flexural design in X Strip, and area of steel and flexural design in Y Strip show in **Figure.C.22**. The punching shear for concrete shear strength first check show in **Figure.C.23.** and change Overall depth of footing, The O.K punching shear check for The design concrete shear strength show in **Figure.C.24**.

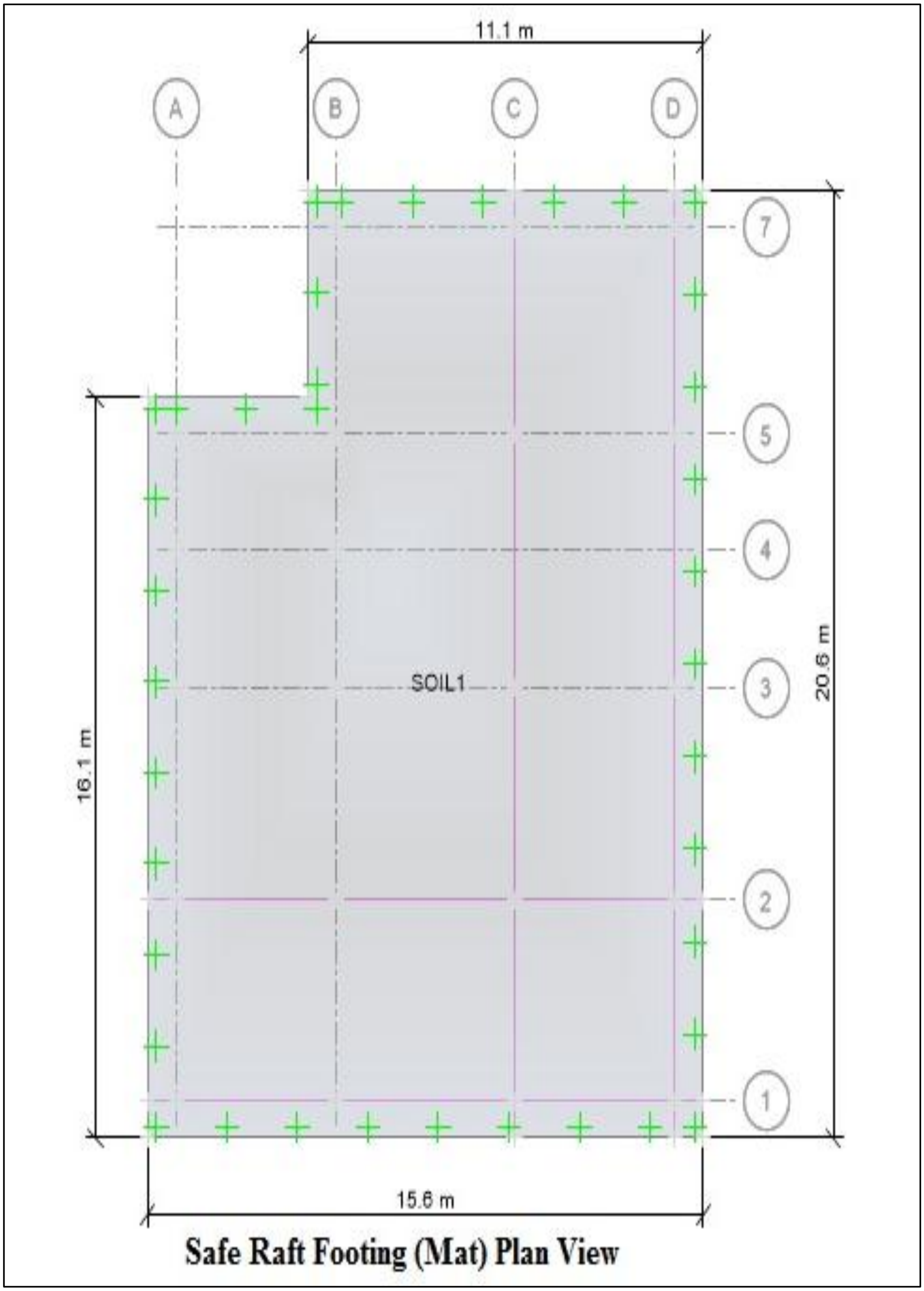


Figure C. 17 : Raft Footing Plan View

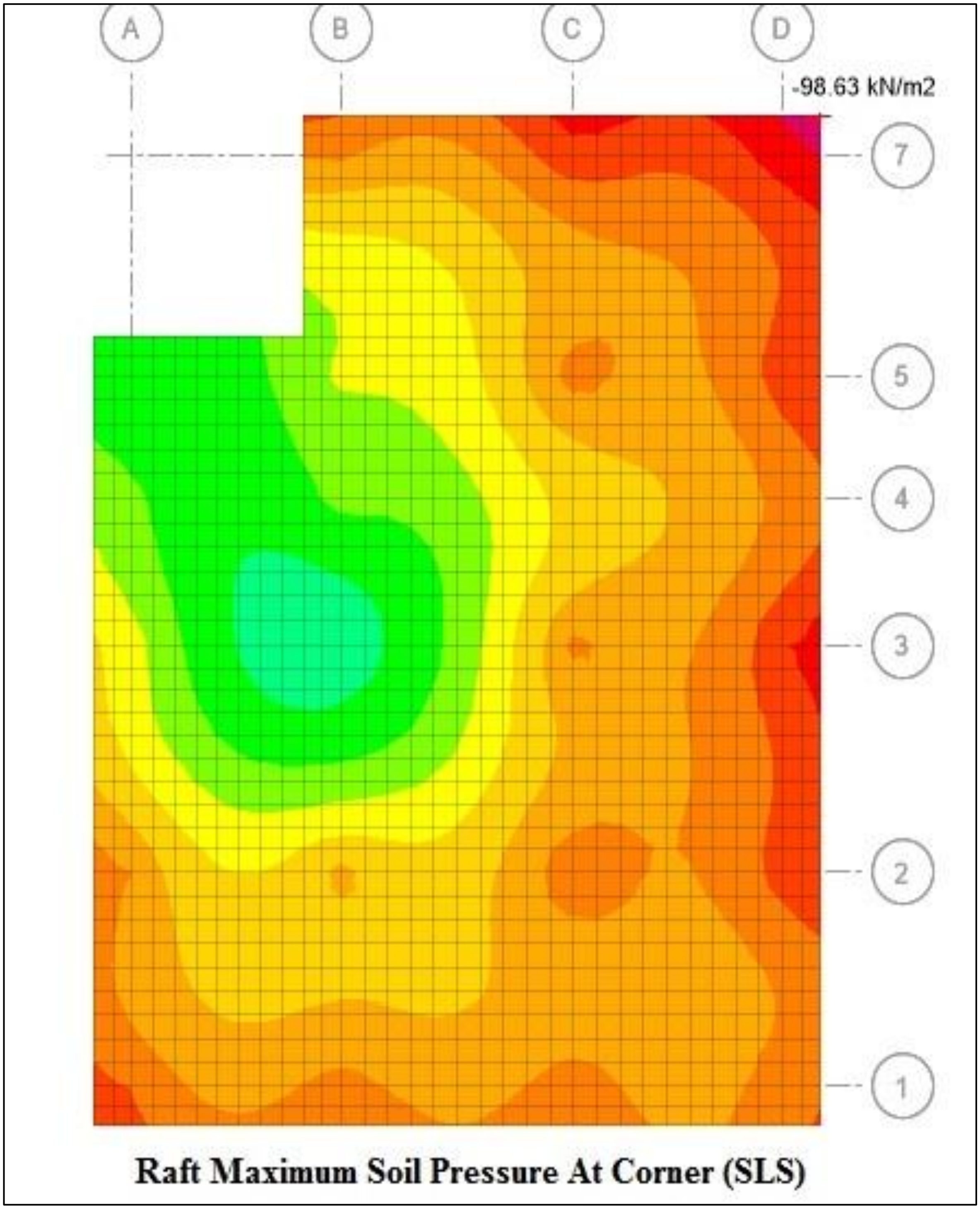


Figure C. 18: Maximum Soil Pressure at Corners in Serviceability Limit State (SLS)

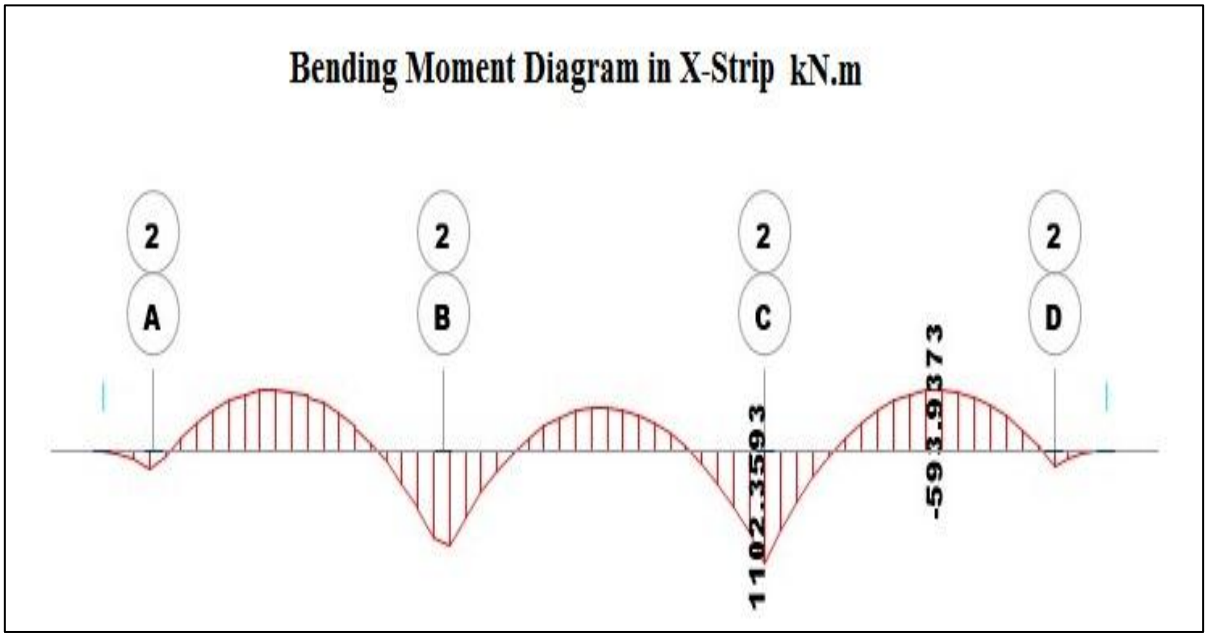


Figure C. 19: **Bending Moment Diagram in X-Strip**

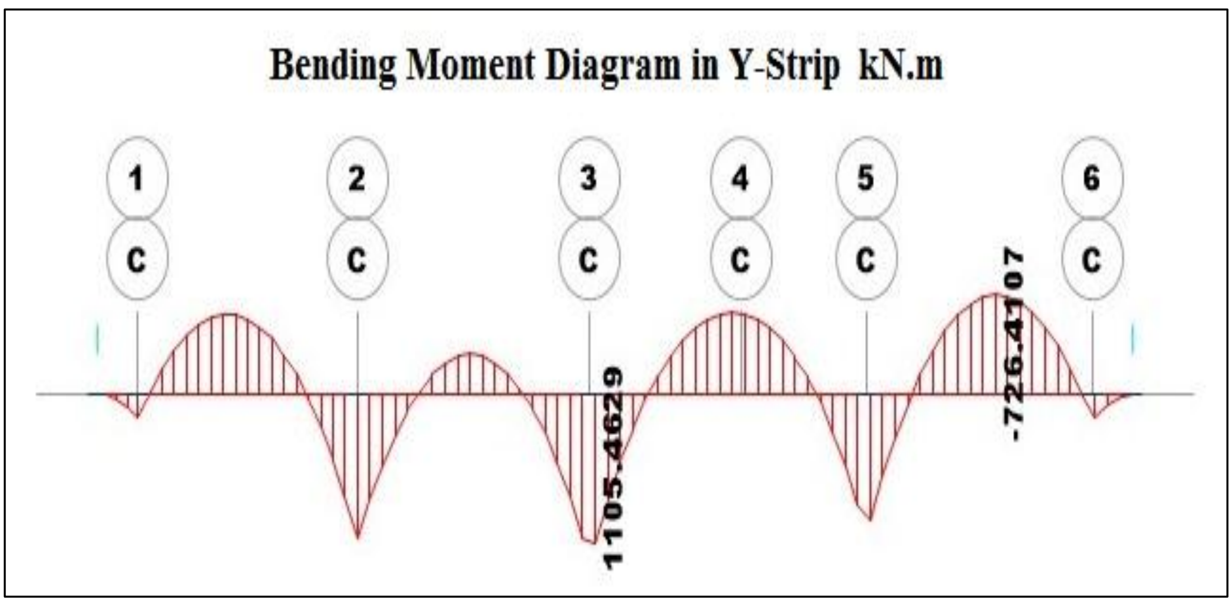


Figure C. 20: Bending Moment Diagram in Y-Strip

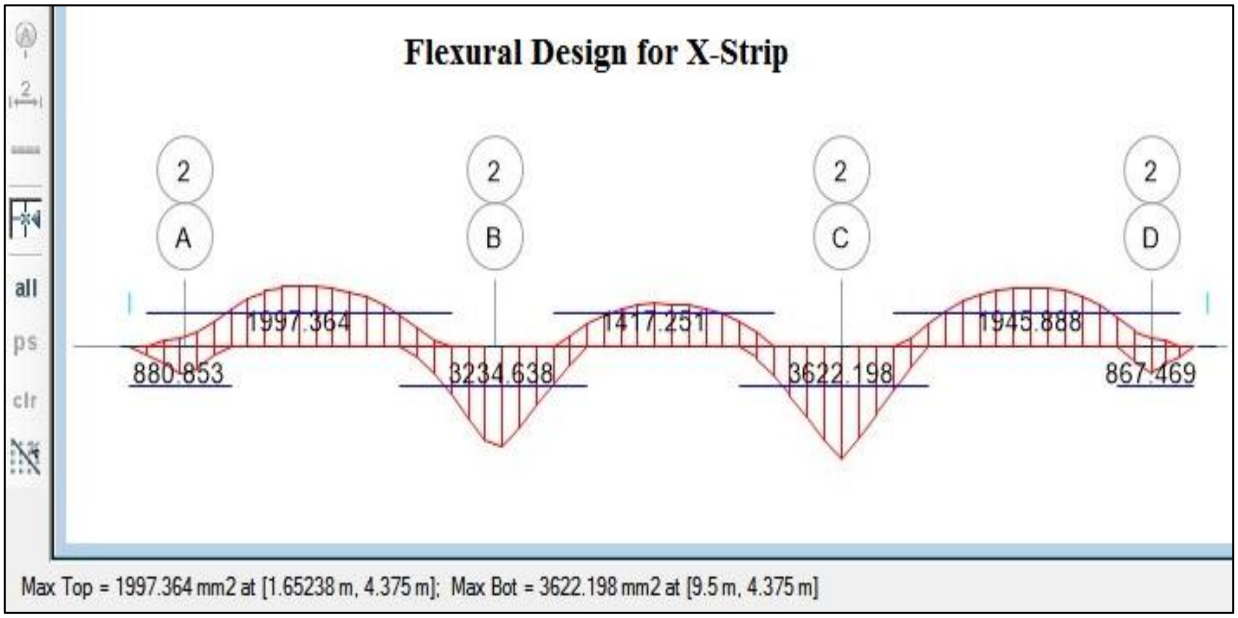


Figure C. 21: Area of Steel and Flexural Design for X-Strip

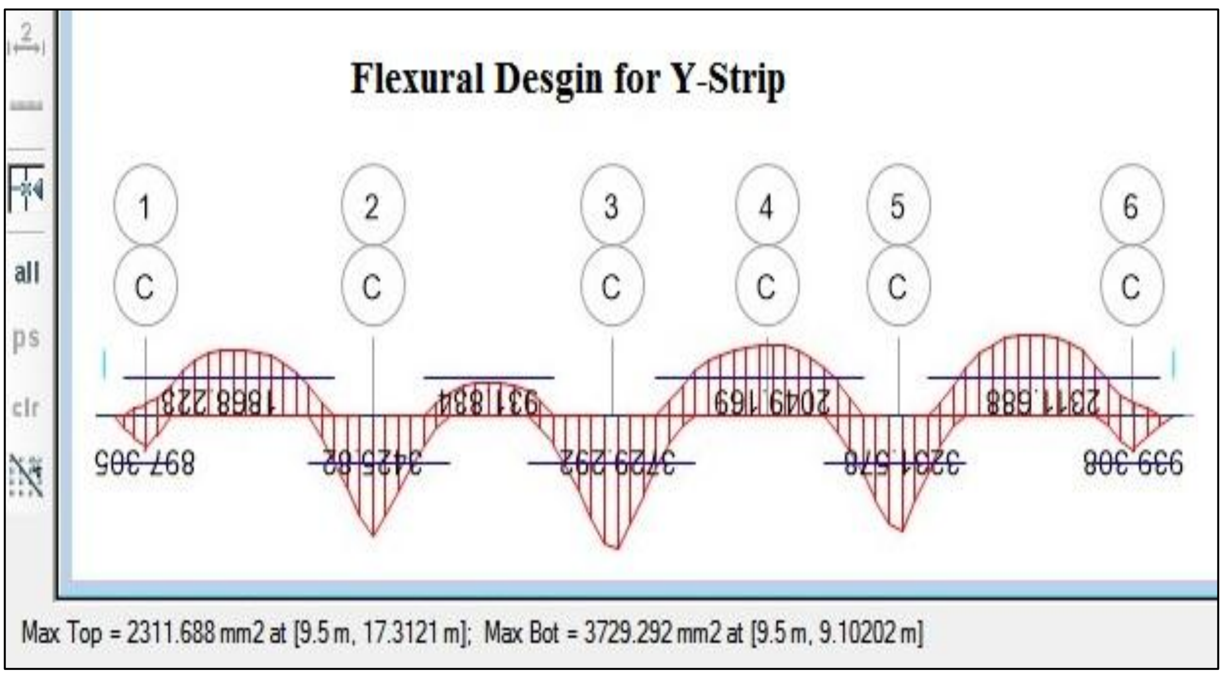


Figure C. 22 :Area of Steel and Flexural Design for Y-Strip

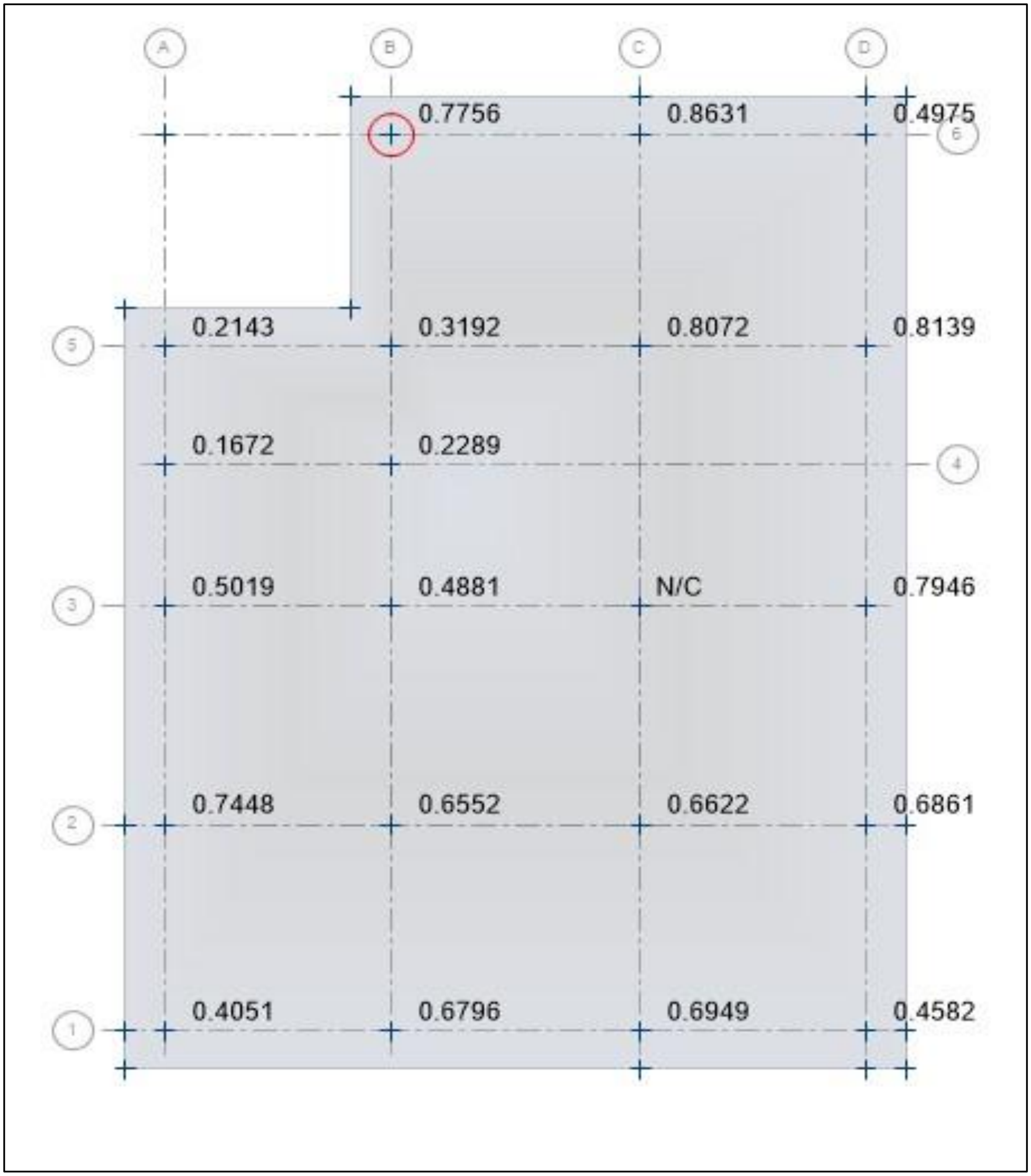
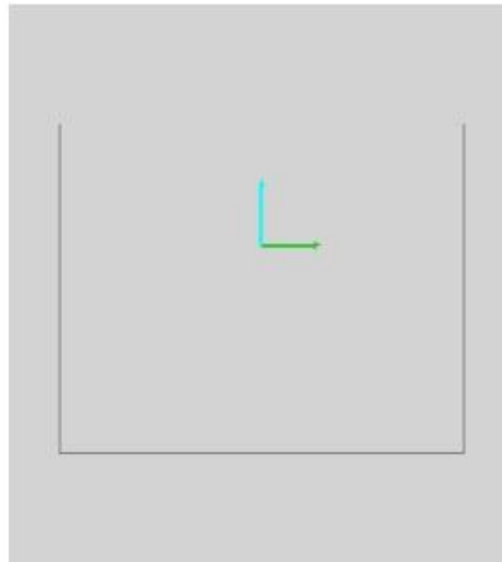


Figure C. 23: Raft Footing Punching Shear for concrete shear strength check

BS 8110-1997 Punching Shear Check & Design

Load Punching Check

Avg. Eff. Slab Thickness = 830 mm
Eff. Punching Perimeter = 7330.2 mm
Cover = 70 mm
Conc. Comp. Strength = 25 N/mm2
Reinforcement Ratio = 0.0000
Section Width x-22 = 2990 mm
Section Width x-33 = 2170.1 mm
Gamma_v2 = 0.362226
Gamma_v3 = 0.439002
Moment Mu2 = -2115.2817 kN-m
Moment Mu3= -9.8539 kN-m
Shear Force = -931.284 kN
Unbalanced Moment Mu2 = -766.2103 kN-m
Unbalanced Moment Mu3= -4.3259 kN-m
Max Design Shear Stress = 0.254516 N/mm2
Conc. Shear Stress Capacity = 0.279788 N/mm2
Punching Shear Ratio = 0.91



Column Punching Perimeter

Raft Maximum Column Punching Shear Check (O.K)

Figure C. 24: Raft Footing Maximum Punching Shear for concrete shear strength Check (O.K)