SIMPLIFIED DESIGN OF STRUCTURAL ELEMENTS

STAIR, FOUNDATION AND COLUMN

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DECEMBER, 2016

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THIS THESIS PAPER IS

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Under the Supervision of

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DECLARATION

We hereby declare that the work performed in this thesis for the achievement of the degree of Bachelor of Science in Civil Engineering is "SIMPLIFIED DESIGN OF STRUCTURAL ELEMENTS-Stair, Foundation and Column". The whole work is carried out by the authors under the guidance and strict supervision of Dr. Enamur Rahim Latifee, Associate Professor, Department of Civil Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh.

It is also declare that the work performed in this thesis has not been submitted and will not be submitted, either in part or in full for the award of any other degree in this institute or any other institute or university.

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We would like to thank our classmates, seniors and friends for their continued help and encouragement.

Most importantly, we deeply thank our parents and siblings for their unconditional trust, timely support, encouragement and endless patience throughout our life.

ABSTRACT

The objective of our study is to introduce the concept of simplified design of building elements since the traditional method of design includes several steps, lengthy and time consuming. New designers or engineers may find it difficult to overcome within limited short time. In general traditional method described in our books, we have to assume a lot of parameters in many equations but in simplified design some of the parameters are made constant (like strength of reinforcement, ultimate strength of concrete, properties of cement etc are made constant depending on availability of the material) and some of the parameters (like wind load, resistance to earthquake, induced forces, earth or liquid pressure etc.) are ignored in order to shorten the design procedure and to make the design easy plus time efficient. This thesis paper on "**Simplified Design of Structural Elements- Stair, Foundation and Column,**" is prepared by following the provisions according to ACI Standard 318, *Building Code Requirements for Structural Concrete.*

The designs are formulated in excel which would help the designers & those who are interested in designing the foundation, column, stair in shortest possible time, with minimum amount of effort. Again elements types, design steps, design examples, Required tables to adopt data, Comparisons tables, graphs, figures with detailing etc. are also provided for Stair, Foundation,& Column design in a simplified way in this paper. Design for various types of same elements (like square footing, rectangular footing, square column, circular column, stair with different span and different strength etc.) are also included separately. Different websites have been created for different structural elements. Address of those websites are given in appendix. All through a simplified design of concrete structures for stair, foundation, column are implemented in this thesis paper.

It will help practicing engineers, the architects, and common non-technical persons for initial structural design, verifying existing design and to get rough idea on the design and check the assumptions, further checking abilities, and some way of reducing the design time required for smaller projects, reinforced concrete buildings of moderate size and height.

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List of Symbols and Abbreviations

ACI = American Concrete Institute.

ASCE = American Society of Civil Engineers.

BNBC = Bangladesh National Building Code.

DL = Dead load.

LL = Live load.

l = Length of span.

As = Area of steel.

f'c = Compressive strength of concrete.

fy = Grade/Yield strength of steel.

h = Thickness of slab

E = Modulus of elasticity.

I = Moment of inertia.

ρ = Steel ratio.

CHAPTER-01

Introduction

Most of the structures throughout the world are made of R.C.C. (Reinforced cement concrete). As a result, people are trying to simplify the design of R.C.C. building components in various countries at various times. We have adopted the same motto to make the design of R.C.C. components better, simple, time consuming and easy to use. To achieve that goal we have mainly worked on Foundation, Column and Stair design for normal residential, commercial buildings of moderate size and Height.

This paper on "**Simplified Design of Structural elements- Stair, Foundation and Column**" is prepared by following the provisions mentioned in ACI Standard 318, Building Code Requirements for Structural Concrete. The simplification of design with its attendant savings in design time result from avoiding building members proportioning details and material property selection which make it necessary to consider certain complex provision of the ACI standards. This situation often avoided by making minor changes in design approach. In various situations during our design specific recommendations are made to accomplish our goal.

This paper has been written as a time saving aid for use by those who consistently seek ways to simplify design procedures. The purpose of this paper is to give practicing engineers some way of reducing the design time required for smaller projects.

We have ignored complicated legal terminology without changing the intent or the objective of the code. Invention, innovation, and experimentation help to advance knowledge, but experience provides the confidence to trust our design practices.

1.1 Scope of simplified design

The simplified design approach presented in this thesis paper should be used within general guidelines and limitations mentioned in the paper. In addition, appropriate guidelines and limitations are given within each chapter for proper application of specific simplifying design procedures. Our designs will help practicing engineers to give idea about their assumption data in design, further checking abilities, and some way of reducing the design time required for smaller projects.

1.2 Purposes behind simplification of design

There are lots of commercial software available to solve structural design problems such as ETABS, STAAD Pro, etc. However, to use all of this software, a person must have some basic civil engineering knowledge and it also requires detail information input for modeling. The engineers, architects and ordinary people including home owner, contractors and others do not have any handy software available to get very quick design and estimation of materials. Moreover, no unpaid tool is available for them to have an idea of the size and cost of building elements, and even paid software, need detail data input. To overcome these shortcomings of the modern day software and to empower the engineers, architects and others to have structural design which is ready with very simple inputs excel file based, free of cost application is developed according to ACI-318-11 with visual output in figures. The user including the engineer, the architect, and common non-technical person can give very simple inputs in a excel sheet and instantly get the results there. It can be used for initial structural design, verifying existing design and detail. There are also a lot of methods for design a reinforced concrete building, but here we used simplified design method of reinforced concrete buildings.

The aim is to create a simplification in the design process with minimum user input. The design aids in the form of graphs, are being generated for regular cases- residential/commercial. The scope is limited to moderate size and height of buildings. Two websites has been created on our design to benefit the user and we have made it free to use. Many designs tools have been done in Microsoft office excel worksheet and uploaded to our websites. So, one can easily use those tools in internet using their computer or other devices.

1.3 The beneficiaries

The materials in this paper are not intended for well-trained, experienced structural engineers but rather for people who are interested in the topic but lack both training and experience in structural design. With this readership in mind, the computational work here is reduced to a minimum, using mostly simple mathematical procedures. A minimum background for the reader is assumed in fundamentals of structural mechanics.

1.4 How we have simplified design

One may have question in mind that how we have simplified the design where we have followed the same established procedure to solve the design problems. Actually we take the whole burden of carrying out the design on our shoulder and provide you a ready design of building components. What you have to do is just to input the required data (e.g. Column length, width, dead and live load etc.) and you will get the result instantly with detailing in figure. Thus we have simplified and reduce the design time.

1.5 Our Future goals

Since we started our thesis by simplification of foundation, but till now we have completed foundation, column, and stair for simplified design method. We hope to cover the full building components design solution in near future.

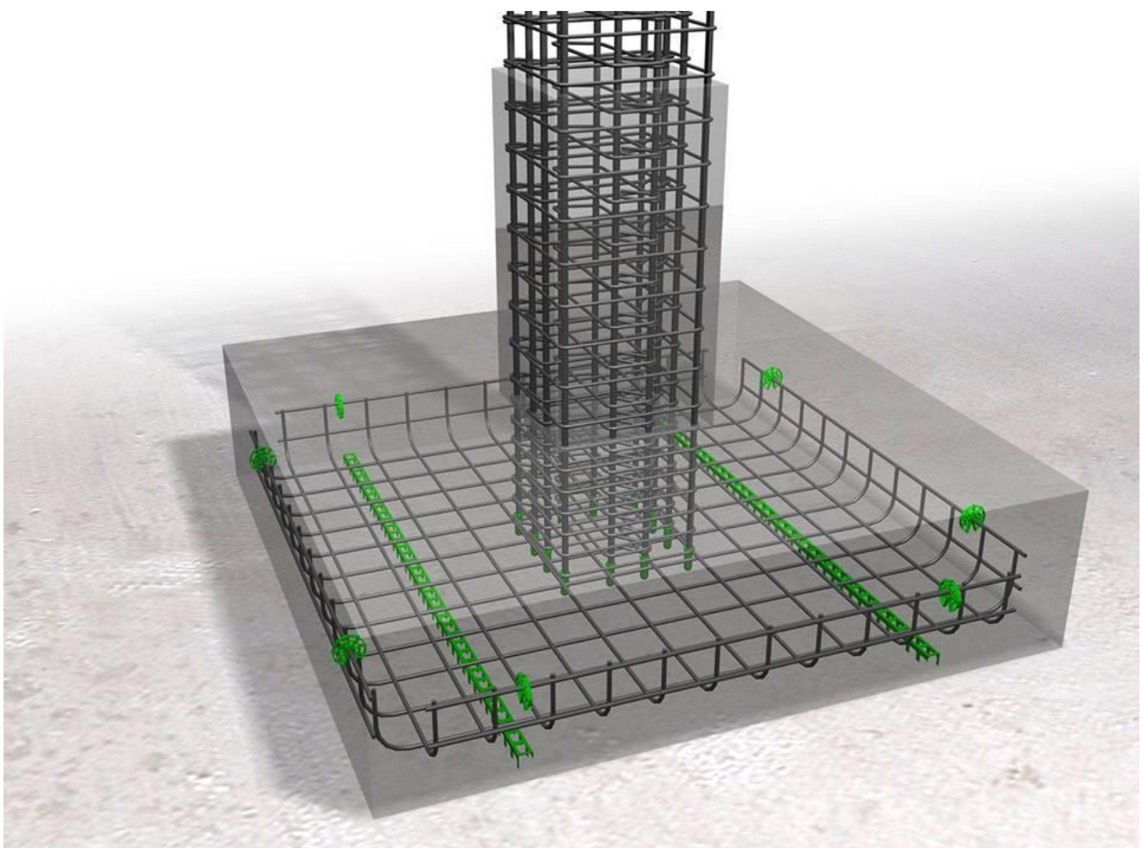


Figure 1.1: Foundation

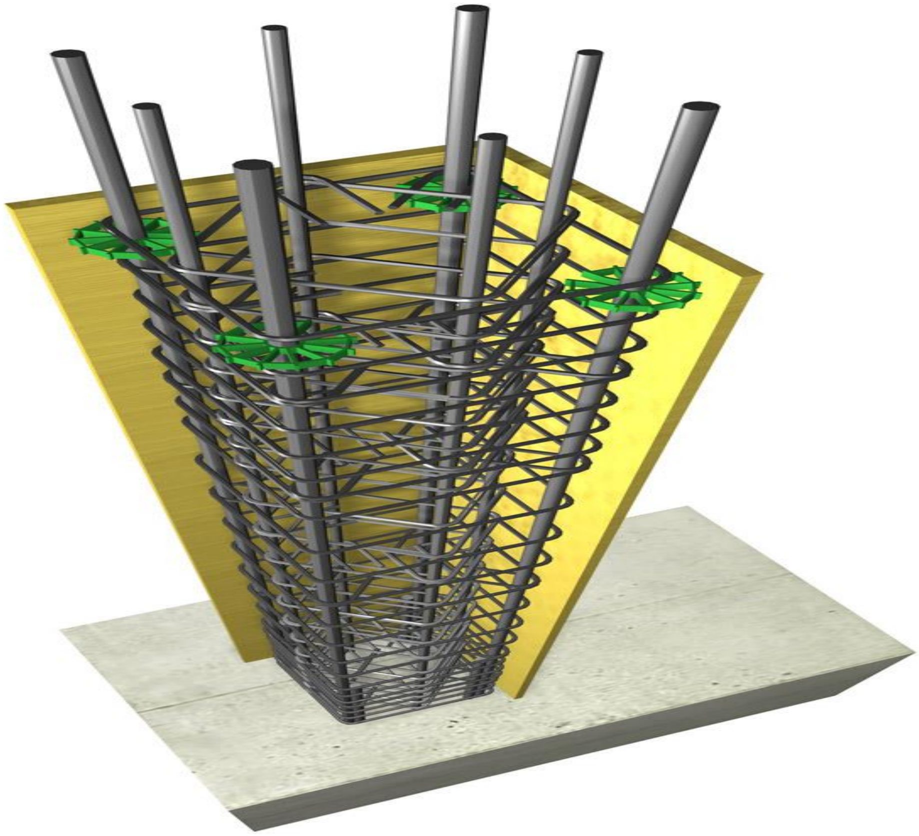


Figure 1.2: Column

Figure 1.3: Stair

Chapter 2

Literature Review

2.1 Stair

Stair consist of steps arranged in a series for purpose of giving access to different floors of a building. Since a stair is often the only means of communication between the various floors of a building, the location of the stair requires good and careful consideration.

2.1.1 Types of Stair

Straight Stair: These are the stairs along which there is no change in direction on any flight between two successive floors. The straight stairs can be of following types.

- Straight run with a single flight between floors
- Straight run with a series of flight without change in direction
- Parallel stairs
- Angle stairs
- Scissors stairs

Straight stairs can have a change in direction at an intermediate landing. In case of angle stairs, the successive flights are at an angle to each other. Scissor stairs are comprised of a pair of straight runs in opposite directions and are placed on opposite sides of a fire resistive wall.

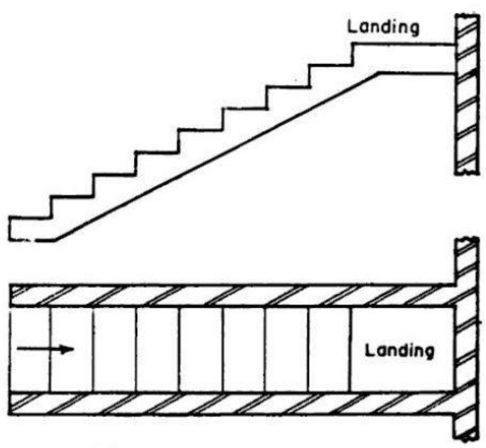


Figure 2.1: Straight Stair

Quarter Turn Stairs: They are provided when the direction of flight is to be changed by 90 degree. The change in direction can be effected by either introducing a quarter space landing or by providing winders at the junctions.

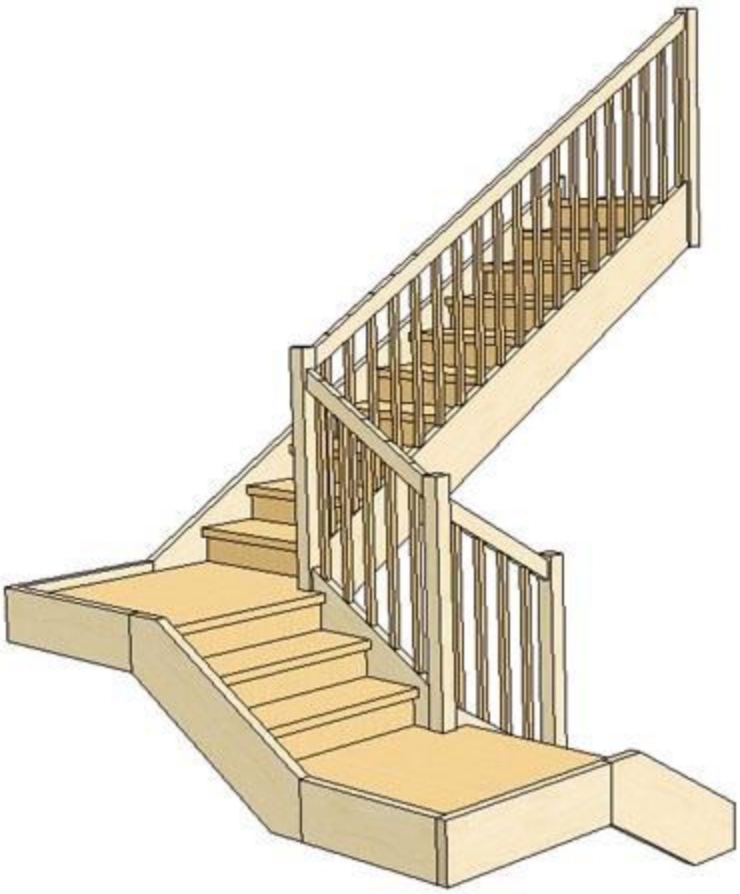


Figure 2.2: Quarter Turn Stairs

Half Turn Stairs: These stairs change their direction through 180^0. It can be either dog-legged or open newel type. In case of dog legged stairs the flights are in opposite directions and no space is provided between the flights in plan. On the other hand in open newel stairs, there is a well or opening between the flights and it may be used to accommodate a lift. These stairs are used at places where sufficient space is available.

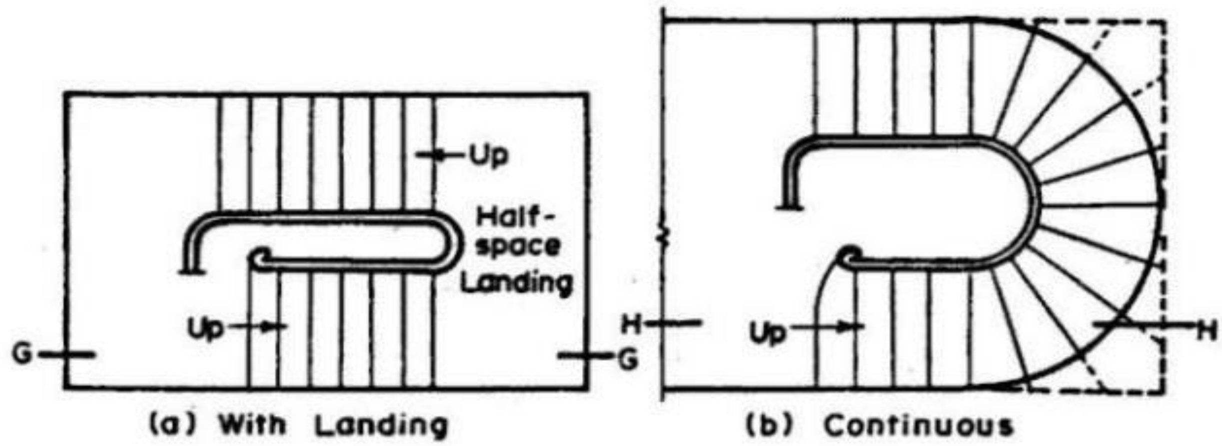


Figure 2.3: Half Turn Stairs

Three Quarter Turn Stairs: These types of stairs change their directions through 270^0. In other words direction is changed three times with its upper flight crossing the bottom one. In this type of construction an open well is formed.

Circular Stairs: These stairs, when viewed from above, appear to follow circle with a single center of curvature and large radius. These stairs are generally provided at the rear of a building to give access for servicing at various floors. All the steps radiate from a newel post in the form of winders. These stairs can be constructed in stone, cast iron or R.C.C.

Curved Stairs: These stairs, when viewed from above, appear to follow a curve with two or more center of curvature, such as ellipse.

Geometrical Stairs: These stairs have no newel post and are of any geometrical shape. The change in direction in these stairs is achieved through winders. The stairs require more skill for its construction and are weaker than open newel stairs. In these stairs the open well between the forward and the backward flights is curved.

Spiral Stairs: These stairs are similar to circular stairs except that the radius of curvature is small and the stairs may be supported by a center post. Overall diameter of such stairs may range from 1 to 2.5 m.

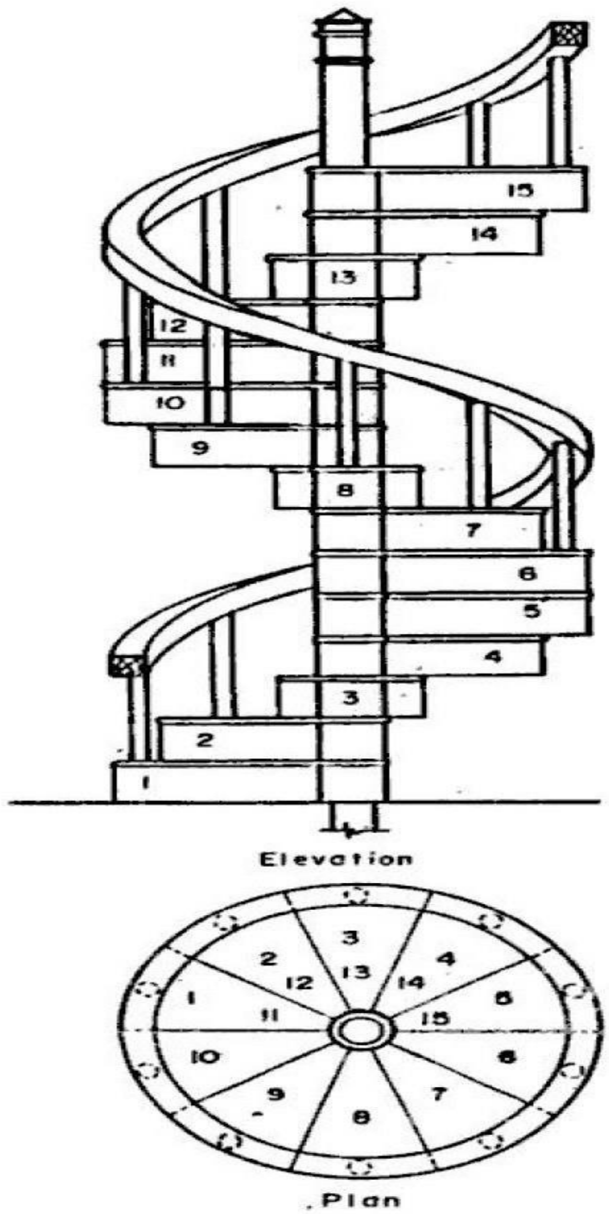


Figure 2.4: Spiral Stairs

2.1.2 Component of Stair Case

Step – The step is composed of the tread and riser.

Tread – The part of the stairway that is stepped on. It is constructed to the same specifications (thickness) as any other flooring. The tread "depth" is measured from the outer edge of the step to the vertical "riser" between steps. The "width" is measured from one side to the other.

Riser – The vertical portion between each tread on the stair. This may be missing for an "open" stair effect.

Nosing – An edge part of the tread that protrudes over the riser beneath. If it is present, this means that, measured horizontally, the total "run" length of the stairs is not simply the sum of the tread lengths, as the treads actually overlap each other slightly.

Starting step or Bull nose– Where stairs are open on one or both sides, the first step above the lower floor may be wider than the other steps and rounded. The balusters typically form a semicircle around the circumference of the rounded portion and the handrail has a horizontal spiral called a "volute" that supports the top of the balusters. Besides the cosmetic appeal, starting steps allow the balusters to form a wider, more stable base for the end of the handrail.

Handrails that simply end at a post at the foot of the stairs can be less sturdy, even with a thick post. A double bull nose can be used when both sides of the stairs are open.

Stringer , Stringer board or sometimes just String – The structural member that supports the treads and risers. There are typically two stringers, one on either side of the stairs; though the treads may be supported many other ways. The stringers are sometimes notched so that the risers and treads fit into them.

Winders– Winders are steps that are narrower on one side than the other. They are used to change the direction of the stairs without landings. A series of winders form a circular or spiral stairway. When three steps are used to turn a 90° corner, the middle step is called a kite winder as a kite-shaped quadrilateral.

Trim–Trim (e.g. quarter-round or baseboard trim) is normally applied where walls meet floors and often underneath treads to hide the reveal where the tread and riser meet. Shoe molding may be used between where the lower floor and the first riser meet. Trimming a starting step is a special challenge as the last riser above the lower floor is rounded.

Flexible, plastic trim is available for this purpose, however wooden molding are still used and are either cut from a single piece of rounded wood, or bent with laminations Scotia is concave molding that is underneath the nosing between the riser and the tread above it.

Banister, Railing or Handrail – The angled member for handholding, as distinguished from the vertical balusters which hold it up for stairs that are open on one side; there is often a railing on both sides, sometimes only on one side or not at all, on wide staircases there is sometimes also one in the middle, or even more. The term "banister" is sometimes used to mean just the handrail, or sometimes the handrail and the balusters or sometimes just the balusters.

Volute – A handrail end element for the bull nose step that curves inward like a spiral. A volute is said to be right or left-handed depending on which side of the stairs the handrail is as one faces up the stairs.

Turnout – Instead of a complete spiral volute, a turnout is a quarter-turn rounded end to the handrail.

Gooseneck – The vertical handrail that joins a sloped handrail to a higher handrail on the balcony or landing is a gooseneck.

Rosette – Where the handrail ends in the wall and a half-newel is not used, it may be trimmed by a rosette.

Easing – Wall handrails are mounted directly onto the wall with wall brackets. At the bottom of the stairs such railings flare to a horizontal railing and this horizontal portion is called a "starting easing". At the top of the stairs, the horizontal portion of the railing is called a "over easing".

Core rail– Wood handrails often have a metal core to provide extra strength and stiffness, especially when the rail has to curve against the grain of the wood. The archaic term for the metal core is "core rail".

Baluster – A term for the vertical posts that hold up the handrail .Sometimes simply called guards or spindles. Treads often require two balusters. The second baluster is closer to the riser and is taller than the first. The extra height in the second baluster is typically in the middle between decorative elements on the baluster. That way the bottom decorative elements are aligned with the tread and the top elements are aligned with the railing angle.

Newel– A large baluster or post used to anchor the handrail. Since it is a structural element, it extends below the floor and subfloor to the bottom of the floor joists and is bolted right to the floor joist. A half-newel may be used where a railing ends in the wall. Visually, it looks like half the newel is embedded in the wall. For open landings, a newel may extend below the landing for a decorative newel drop.

Finial – A decorative cap to the top of a newel post, particularly at the end of the balustrade.

Base rail or Shoe rail– For systems where the baluster does not start at the treads, they go to a base rail. This allows for identical balusters, avoiding the second baluster problem.

Fillet– A decorative filler piece on the floor between balusters on a balcony railing.

Figure 2.5: Components of Staircase

2.2 Foundation:

In simple words, a foundation is a structure that transfers loads of the structure to the earth.

Foundation of a structure is always constructed below the ground level so as to increase the lateral stability of the structure. It includes the portion of the structure below the ground level and is built, so as to provide a firm and level surface for transmitting the load of the structure on a large area of the soil lying underneath. The solid ground on which the foundation rests is called the Foundation Bed.

All the soil compress noticeably when loaded and cause the supported structure to settle. The two essential requirements in the design of foundation are that the total settlement of the structure be limited to a tolerably small amount and that differential settlement of the various parts of the structure be eliminated as nearly as possible.

2.2.1 Some Purposes of Foundation

All engineering structures are provided with foundations at the base to fulfill the following objectives and purposes;

i. To distribute the load of the structure over a large bearing area so as to bring intensity of loading within the safe bearing capacity of the soil lying underneath.
ii. To load the bearing surface at a uniform rate so as to prevent unequal settlement.
iii. To prevent the lateral movement of the supporting material.
iv. To secure a level and firm bed for building operations.
v. To increase the stability of the structure as a whole.

2.2.2 Types of Foundations

Foundations are broadly classified into two categories.

Shallow Foundation

Shallow foundation are those foundations in which the depth at which the foundation is placed is less than the width of the foundation ($D < B$). Shallow foundations are generally termed as spread footing as they transmit the load of the super structure laterally into the ground.

Classification of Shallow Foundation:

On the basis of design, the shallow foundations are classified as:

- Wall Footing
- Isolated column or Column Footing
- Combined Footing

- Cantilever (Strap) Footing
- Mat (Raft) Foundation

Wall Footing

This type of foundation runs continuous along the direction of the wall and helps to transmit the load of the wall into the ground. Wall footings are suitable where loads to be transmitted are small and are economical in dense sands and gravels. In this type of foundation the width is 2-3 times the width of the wall at ground level. Wall footing may be constructed through stone, brick, plain or reinforced cement concrete.

Figure 2.6: Wall footing

Column Footing

Column footings are suitable and economical for the depth greater than 1.5m. In this type of foundation the base of the column is enlarged. Column footing is in the form of flat slab and may be constructed through plain or reinforced concrete.

Figure 2.7: Column footing

Combined Footing

Combined footings are those foundations that are made common for two or more columns in a row. It is used when the footing for a column may extend beyond the property line. It is also suitable when the two columns are closely spaced and the soil on which the structure resist is of low bearing capacity. It may be rectangular or trapezoidal in shape.

Figure 2.8: Combined footing

Strap Footing

When an edge footing cannot be extended beyond the property line the edge footing is linked up with the other interior footing by means of a strap beam. Such footings are called as strap footing. It is also known as cantilever footing.

Figure 2.9: Strap footing

Mat Foundation

A mat foundation is a combined footing which covers the entire area beneath of a structure and supports all the walls and columns. It is also known as raft foundation. Mat foundation is applicable when:

- Allowable bearing pressure is low.
- The structure is heavy.
- The site is with highly compressible layer.

The mat foundation can be further classified into following types:

- Flat slab type.
- Flat Slab thickened under column.
- Two way beam and slab type.
- Flat slab with pedestals.
- Rigid frame mat.
- Piled mat.

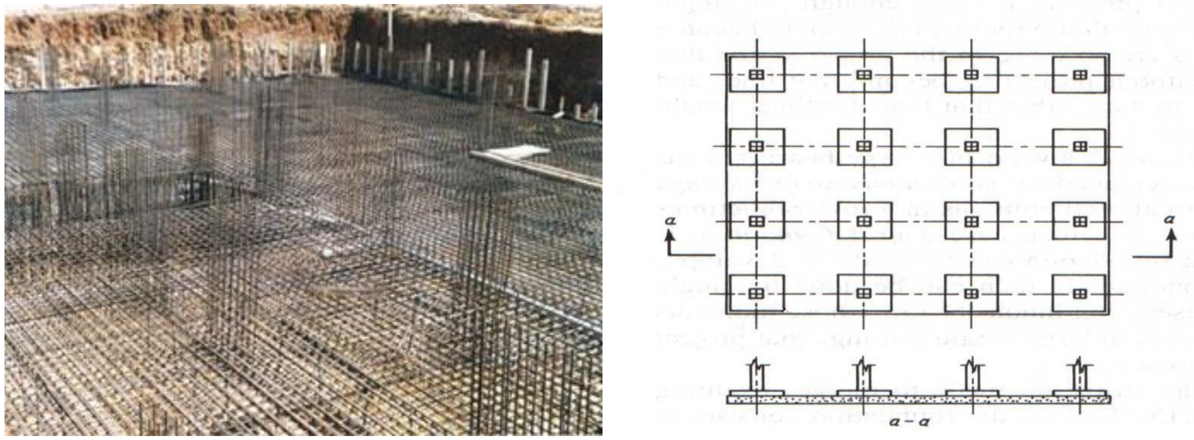


Figure 2.10: Mat or raft foundation

Deep Foundation

Deep Foundation are those foundations in which the depth of the foundation is greater than its width (D>B). The D/B ratio is usually 4-5 for deep foundation. Unlike shallow foundation, the deep foundation transmits the load of the superstructure vertically to the rock strata lying deep. Deep foundations are used when the shallow foundation cannot support the load of the structure.

Classification of Deep Foundation

The mat foundation can be further classified into following types:

- Pile Foundation
- Pier Foundation
- Well (Caissons) Foundation

Pile Foundation

Pile is a slender member with small area of cross-section relative to its length. They can transfer load either by friction or by bearing. Pile foundations are used when:

- The load is to be transferred to stronger or less compressible stratum, preferably rock.
- The granular soils need to be compacted.
- The horizontal and the inclined forces need to be carried from the bridge abutments and the retaining walls.

Figure 2.11: Pile foundation

Classification of Pile Foundation

The pile foundation can be further classified into following types on various basis such as function, material, method of installation which are listed below:

Based on Function:

- Bearing piles
- Friction piles
- Combined piles (Both bearing and friction)

Based on Material:

- Timber piles
- Concrete piles
- Steel piles

Based on Method of Installation:

- Large displacement piles
- Small displacement piles
- Non-displacement piles

Pier Foundation

Pier foundations are underground cylindrical structural member that support heavier load of the structure which shallow foundations cannot resist. Unlike pile foundation, pier foundation can only transfer load by bearing. Pier foundations are shallower in depth than the pile foundation. Pier foundations are used when:

- The top stratum is a decomposed rock underlying as sound rock strata.
- The soil is stiff clay that occur large resistance for driving the bearing pile.

Figure 2.12: Pier foundation

Well (Caissons) Foundation

The term caisson refers to box or a case. These are hollow inside and are usually constructed at the site and sunk in place into a hard bearing stratum. As they are expensive in construction, they are usually restricted to major foundation works. Well foundations are suitable when the soil contains large boulders obstructing the penetration during installation of pier or pile foundations. Caissons are used for bridge piers, abutments in rivers and lakes and other shore protection works. They are used to resist heavy vertical and horizontal loads and are used in the construction of large water front structures as pump houses.

Classification of Well Foundation

- Open Caissons
- Pneumatic Caissons
- Box Caissons

Figure 2.13: Well or Caisson foundation

2.2.3 Factors affecting the selection of Foundation:

On the basis of ground/soil condition :

- Shallow foundations are preferred where soil close to the surface is capable of supporting structure loads.
- Where the ground close to the surface is not capable of supporting structural loads, hard strata is searched for and deep foundation is required.
- Uniform stable ground requires relatively shallow foundation whereas filled up ground has low bearing capacity thus requires deep foundation.

On the basis of Loads from Building:

- In the case of low-rise building in a larger area, the extent of loading is relatively low, so shallow foundation can resist the load from the structures.
- In the case of the high-rise building built within less area have high loads. Therefore, the deep foundation is required as shallow foundation may not be able to resist such loads of greater intensity.

2.2.4 Bearing Capacity

Bearing Capacity:

Bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the **soil** which should not produce shear failure in the **soil**. Ultimate bearing capacity is the

theoretical maximum pressure which can be supported without failure; *allowable bearing capacity* is the ultimate bearing capacity divided by a factor of safety. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing capacity is based on the maximum allowable settlement. Bearing Capacity of soil varies with the types of soil and places.
A word file is added to pick up the bearing capacity values for using in the design as bearing capacity of soil plays an important role in foundation design.

Bearing Capacity Calculation

For Shallow Foundation:

Using Terzaghi's equation:

This equation can be used both for cohesion less and cohesive soil. The common equation is-

qult = cNc + ½ BγNγ + qNq

=(qu/2)Nc+½ BγNγ+(γdf) **Nq**

Where, *Nc*, *N*γ and *Nq* are non dimensional bearing capacity factors and functions only of the angle of internal friction, φ. Unconfined compressive strength, q and γ is the unit weight of soil. df is the depth of footing

Strip footing: qult = cNc + ½BγNγ + qNq

Square footing: qult = 1.3cNc + 0.4 BγNγ + qNq

Circular Footing: qult = 1.3cNc + 0.3 BγNγ + qNq

Where graphs are not given then we can use :

Nq=$tan^2(45 + \varphi/2)e$^$\pi\ tan\varphi$

Nc=(Nq-1)cotφ

Nγ=1.5 (Nq-1)tanφ

LIMITATIONS : In this case many factors like (qu,B,df,γ,φ) are unknown, so a user must have soil report to input the values .

Using Skempton's Bearing Capacity Equation (for Clay Soil):

Bearing capacity of footings founded on purely cohesive soils based on extensive investigations

qult = cNc

=(qu/2)Nc

The bearing capacity factor, Nc is given by

For strip footing:
$Nc = 5(1 + 0.2\ Df/B)$
For square and circular footings:
$Nc = 6(1 + 0.2\ Df/\ B)$

For rectangular footings:
$Nc = 5(1 + 0.2\ B/L)\ (1 + 0.2\ Df/B)$ for $Df/\ B \leq 2.5$
And $Nc = 7.5(1 + 0.2\ B/L)$ for $Df/B > 2.5$.
Or from the graph

<u>LIMITATIONS:</u> This method is valid only for clay soil, and a user must know depth, length, width of the footing and qu

<u>For Pile Foundation:</u>

Individual capacity of a bored pile on clay:

Qup = Qeb + Qsf

=Ap.qp + Af.qf

= (π*D^2/4). 9cu+ (πDL). α1cu [α1 =reduction factor=0.45 normally]

Where,

Qup = Ultimate bearing load of the pile

Qeb = End bearing resistance of the pile
Qsf = Skin friction resistance of the pile

Ap = Effective area of the tip of the pile

qp = 9cu = Theoretical unit tip-bearing capacity for cohesive soils

cu = Undrained shear strength of soil at the base

Af = Effective surface area of the pile

qf = α1cu = Theoretical unit friction capacity

REQUIREMENTS: Dia. Of the pile and cu must be known to the user.
Individual Capacity of a bored pile on Sand :

Qup = Qeb + Qsf

End Bearing, **Qeb = 1.2 * N * Ap**
=1.2*N*(π*D^2/4)

Skin Friction, **Qsf = β* po'* Af** [β = 1.5 – 0.135√z]
= β* γz*(πDL)

Where,
z = depth from GL to middle of the layer
N = Field N value from standard penetration test at the level of bottom
po' = effective overburden pressure
1. Skin friction of top 5` of pile should be neglected [due to loose soil at top]
2. Skin friction of bottom 2`-5` of pile should be neglected [due to induced soil at bottom]

Individual action of Pile Cap = Individual capacity of a pile x number of pile in the pile group
Group action of Pile Cap = 2/3 x Capacity of group pile

LIMITATIONS: In this case , N,D,γ, and z must be known to the user, besides calculating (Z) is tough for different layers of soil.

2.2.5 Bearing Capacity Values

RECOMMENDED VALUES OF SAFE BEARING CAPACITY FOR PRELIMINARY ANALYSIS

	TYPE OF ROCK OR SOIL	**SAFE BEARING CAPACITY** (kN/m^2)	**SAFE BEARING CAPACITY** (kg/cm^2)
	ROCKS		
1	Rocks (hard) without lamination and defects, for example granite, trap and diorite	3300	33
2	Laminated rocks, for example sand stone and lime stone in sound condition	1650	16.5
3	Residual deposits of shattered and broken bed rock and hard shale, cemented material	900	9

4	Soft rock	450	4.5
	NON-COHESIVE SOILS		
5	Gravel, sand and gravel mixture, compact and offering high resistance to penetration when excavated by tools. (Refer Note 5)	450	4.5
6	Coarse sand, compact and dry (with ground water level at a depth greater than width of foundation below the base of footing)	450	4.5
7	Medium sand, compact and dry	250	2.5
8	Fine sand, silt (dry lumps easily pulverized by fingers)	150	1.5
9	Loose gravel or sand gravel mixture; loose coarse to medium sand, dry (Refer Note 5)	250	2.5
10	Fine sand, loose and dry	100	1
	COHESIVE SOILS		
11	Soft shale, hard or stiff clay in deep bed, dry	450	4.5
12	Medium clay, readily indented with thumb nail	250	2.5
13	Moist clay and sand clay mixture which can be indented with strong thumb pressure	150	1.5
14	Soft clay indented with moderate thumb pressure	100	1.0
15	Very soft clay which can be penetrated several centimeters with the thumb	50	0.5
16	Black cotton soil or other shrinkable or expansive clay in dry condition (50 percent saturation) (Refer Note 2)	To be determined after site investigation	
17	Peat (Refer Note 2 & 3)		
18	Fills or made up ground (Refer Note 4 & 5)		

[Conversion: 1 kg/cm2 = 2048.197705 psf ; 1000 psf = 1 ksf ; 1Tsf = 2.24 ksf]

2.2.6 Load Calculation for Foundation

Purposes behind load calculation

For foundation design we have to assume a certain amount of load that may act on foundation. The designer who has no experience cannot assume properly for his design calculation. Keeping this in mind we have tried to give a primary idea to the designers that how much load that can be act upon the foundation. This file is applicable only for the design of foundation of low rise residential building. As this file is for usual low rise residential building, one way slab condition is ignored to simply the calculation.

2.3 Reinforced Concrete Columns

A column is a very important component in a structure. It is like the legs on which a structure stands. It is designed to resist axial and lateral forces and transfer them safely to the footings in the ground. Columns support floors in a structure. Slabs and beams transfer the stresses to the columns. So, it is important to design strong columns.

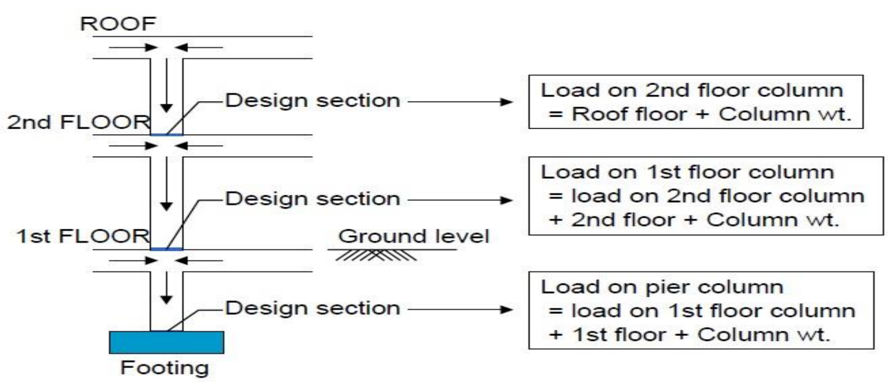


Figure 2.14: Load transfer concept in column

A column is a vertical structural member supporting axial compressive loads, with or without moments. The cross-sectional dimensions of a column are generally considerably less than its height. A reinforced concrete column can be defined as a structural member with a steel frame (reinforcement bars) composed of concrete that is been designed to carry compressive loads.

Figure 2.15: Reinforcement of Column sections

2.3.1 Column construction materials

In the modern construction industry, Columns are mostly constructed by concrete; apart from that materials such as Wood, Steel, Fiber-reinforced polymer, Cellular PVC, and Aluminum too are been used. The type of material is been decided on the scale, coast and application of the construction.

2.3.2 Effecting factors of column design

Column design does not depend only on axial loads, but also on many other factors. There are bending moments and torsion forces induced due to beam spans, wind loads, seismic loads, point loads and many other factors.

2.3.3 Types of Columns

A column may be classified based on different criteria such as:

1. Based on shape

- Rectangle
- Square
- Circular
- Polygon

2. Based on slenderness ratio

The ratio of the effective length of a column to the least radius of gyration of its cross section is called the slenderness ratio.

- Short RCC column, =< 10
- Long RCC column, > 10
- Short Steel column, =<50
- Intermediate Steel column >50 &<200
- Long Steel column >200

3. Based on type of loading

- Axial loaded column.
- A column subjected to axial load and uniaxial bending.
- A column subjected to axial load and biaxial bending.

4**. Based on pattern of lateral reinforcement**

- Tied RCC columns
- Spiral RCC columns

2.3.4 Short Column:

In our column design, we have mainly focused on short column as it is the most used type of column. The primary concept of short column is discussed shortly below:

When the ratio of effective length to the least lateral dimensions of the column is less than 12, then it is called short column.

The strength of short columns is controlled by the strength of the material and the geometry of the cross section. Reinforcing rebar is placed axially in the column to provide additional axial stiffness. Accounting for the additional stiffness of the steel, the nominal loading capacity P_n for the column in terms of the maximum compressive stress of the concrete f_c', the yield stress of the steel f_y, the gross cross section area of the column A_g, and the total cross section area of the steel rebar A_{st}

2.3.5 Types of Reinforcements for columns and their requirements

Longitudinal Reinforcement

● Minimum area of cross-section of longitudinal bars must be at least 0.8% of gross section area of the column.

● Maximum area of cross-section of longitudinal bars must not exceed 6% of the gross cross-section area of the column.

● The bars should not be less than 12mm in diameter.

● Minimum number of longitudinal bars must be four in rectangular column and 6 in circular column.

● Spacing of longitudinal bars measures along the periphery of a column should not exceed 300mm.

Transverse reinforcement

● It may be in the form of lateral ties or spirals.

● The diameter of the lateral ties should not be less than $1/4^{th}$ of the diameter of the largest longitudinal bar and in no case less than 6mm.

● The pitch of lateral ties should not exceed

- Least lateral dimension

-16 x diameter of longitudinal bars (small)

-300mm

Helical Reinforcement

● The diameter of helical bars should not be less than $1/4^{th}$ the diameter of largest longitudinal and not less than 6mm.

● The pitch should not exceed (if helical reinforcement is allowed);

-75mm

-$1/6^{th}$ of the core diameter of the column

● Pitch should not be less than, 25 mm or 3 x diameter of helical bar

Chapter 3

Methodology and Experimental Work

3.1 Stair

3.1.1 Design Steps of Stairs

Step 1: Determination of load on stair

On stair two types load usually work, Dead load and Live Load. Dead load comes from self-weight of the stair Components and from floor finish. Minimum live load for residential buildings stair according to BNBC is 4.96 KN/m² or 100 psf.

Total Factored Load, $W_U = W_{DL} + W_{LL}$

$W_{DL} = (1.2*DL)$ and $W_{LL} = (1.6*LL)$

Where, DL = Total Dead Load. (Self-Weight of Rise and Steps, Self-Weight of waist, Self-Weight Of landing slab)

LL = Total Live Load

Step 2: Determination of factored moments, M

Factored moment coefficient found in figure

Moment and shear values using ACI coefficients. (ACI Code 318-11, section 8.3.3)

CODE

Positive moment
End spans
Discontinuous end unrestrained .... $w_u \ell_n^2/11$
Discontinuous end integral with support..... $w_u \ell_n^2/14$
Interior spans..................................... $w_u \ell_n^2/16$

Negative moments at exterior face of first interior support
Two spans .... $w_u \ell_n^2/9$
More than two spans............................. $w_u \ell_n^2/10$

Negative moment at other faces of interior supports .... $w_u \ell_n^2/11$

Negative moment at face of all supports for
Slabs with spans not exceeding 10 ft;
and beams where ratio of sum of column stiffnesses to beam stiffness exceeds 8 at each end of the span .... $w_u \ell_n^2/12$

Negative moment at interior face of exterior support for members built integrally with supports
Where support is spandrel beam .... $w_u \ell_n^2/24$
Where support is a column........................ $w_u \ell_n^2/16$

Shear in end members at face of first interior support.. $1.15 w_u \ell_n/2$

Shear at face of all other supports.................. $w_u \ell_n/2$

Wu = Total factored load per unit length of beam or per unit area of slab

Ln = Clear span for positive moment and the average of the two adjacent clear Spans for negative moment.

Step 3: Determination of effective depth,d

The net tensile strain ε_t= 0.004 provides the maximum reinforcement ratio allowed by the ACI Code for beams.

$$\text{Maximum reinforcement ratio, } \rho \max = 0.85\beta 1 \frac{f'c}{fy} \frac{\varepsilon u}{\varepsilon u + 0.004}$$

Where, f'c = Compressive strength of concrete.
Fy = Tensile strength of steel
ε_u= 0.003 = Concrete crushing strain

$$Mu = \varphi \rho f y b d^2 (1 - 0.59 \frac{\rho f y}{f'c})$$

$$\text{Effective depth, d} = \sqrt{\frac{Mu}{\varphi \rho f y b (1 - 0.59 \frac{\rho f y}{f'c})}}$$

Where, Mu = Ultimate moment
φ = Reduction factor
b = Width of per feet strip
ρ = Reinforcement ratio

Step 4: Determination of area of Steel, As

As=$\frac{Mu}{\varphi fy(d - \frac{a}{2})}$Where, Ø= 0.9 for flexure design.

Checking the assumed depth, a= $\frac{Asfy}{0.85 f'cb}$

According to ACI Code 318-11, section 13.3.1 the minimum reinforcement in each direction shall be as mentioned below:
For 40 grade rebar: Asmin = 0.0020×b×h
60 grade rebar: Asmin = 0.0018×b×h
>60 grade rebar: Asmin = $\frac{0.0018 \times 60000}{fy} \times$ b × h

Step 5: Determining the spacing of the steel bars

Spacing= $\frac{area\ of\ the\ bar\ used * width\ of\ the\ strip}{required\ steel\ area}$

Note 2.1: Temperature and shrinkage reinforcement: Reinforcement for shrinkage and temperature stresses normal to the principal reinforcement should be provided on a structural slab in which the principal reinforcement extends in one direction only. ACI Code 318-11, section 7.12.2 specifies the minimum ratios of reinforcement area to gross concrete area (i.e. based on the total depth of the slab), but in no case may such reinforcing bars be placed farther apart than 5 times the slab thickness or more than 8 inch. In no case is the reinforcement ratio to be less than 0.0014.

3.1.2 Design Example of Stairs

Design a stair of 16 ft span. Using concrete with f'c = 2500 psi and steel with fy = 60000 psi.

Solution:

Dead load Calculation:

Rises & Steps =$\left(\frac{\frac{1}{2}*\frac{6}{12}*\frac{10}{12}*3.5*9*150}{1000}\right)$ = .98 k

Waist = $\left(\frac{\sqrt{7.5^2+5^2}*\frac{6}{12}*3.5*150}{1000}\right)$ = 2.37 k

Total Dead Load = Landing Slab + (Rises & steps+ waist)

= $\left(\frac{6*12.5}{1000}\right)+\left(\frac{.98+2.37}{3.5*9.01}\right)$

=.18 ksf

FF = 25psf or .025ksf

Dead load Calculation:

Rises & Steps =$\left(\frac{\frac{1}{2}*\frac{6}{12}*\frac{10}{12}*3.5*9*150}{1000}\right)$ = .98 k

Waist = $\left(\frac{\sqrt{7.5^2+5^2}*\frac{6}{12}*3.5*150}{1000}\right)$ = 2.37 k

Total Dead Load = Landing Slab + (Rises & steps+ waist)

= $\left(\frac{6*12.5}{1000}\right)+\left(\frac{.98+2.37}{3.5*9.01}\right)$

=.18 ksf

FF = 25psf or .025ksf

Live load Calculation:

According to BNBC Minimum live load for residential building stair is 100 psf or 0.1 ksf

Total Load, W = (0.1*1.6)+(1.2*(0.18+.025)) = .406 ksf

M+ = $\frac{Wl^2}{14} = \frac{.406*16^2}{14} = 7.424\ k - ft/ft$

M- = $\frac{Wl^2}{9} = \frac{.406*16^2}{9} = 11.55\ k - ft/ft$

d = (6-1) = 5”

fy = 60000 psi

f’c= 2500 psi

Pmax = .85*β1*$\frac{2500}{60000} * \frac{.003}{.003+.004} = .013$

Mu = ϕ*Pmax*fy*b*d²

d²= $\frac{11.55*12}{.9*.013*60*12*\left(1-0.59*\frac{.013*60}{2.5}\right)} = 20.16$

d=4.49”<6” (ok)

Asmin= (.0018*12*6)=.13in²

+As=$\frac{M*12}{\varphi*fy*(d-\frac{a}{2})} = \frac{7.424*12}{0.9*60*(5-\frac{.85}{2})} = 0.36\ in^2(controlled)$

a=$\frac{As*fy}{.85*f'c*b} = \frac{.36*60}{.85*2.5*12} = 0.85\ in$ (ok)

Use ϕ 12mm @5.5”c/c alt ckd

-As= $\frac{11.55*12}{0.9*60*\left(5-\left(\frac{1.41}{2}\right)\right)} = .62\ in^2(controlled)$

a=$\frac{As*fy}{.85*f'c*b} = \frac{.6*60}{.85*2.5*12} = 1.41\ in\ (ok)$

The distance between two cranked rods is 11”

So, required reinforcement = $0.62 - \left(.175 * \frac{12}{11}\right) = .41in^2$

The extra negative reinforcement required

=$\frac{.41}{.175} * \frac{11}{12} = 2.15$; so use 3-ϕ12mm as extra top

For shrinkage, Asmin = .0018*12*6 = .13 in²

Now , $\frac{.121}{.13} * 12 = 11"$; use φ10mm@11"$c/c$

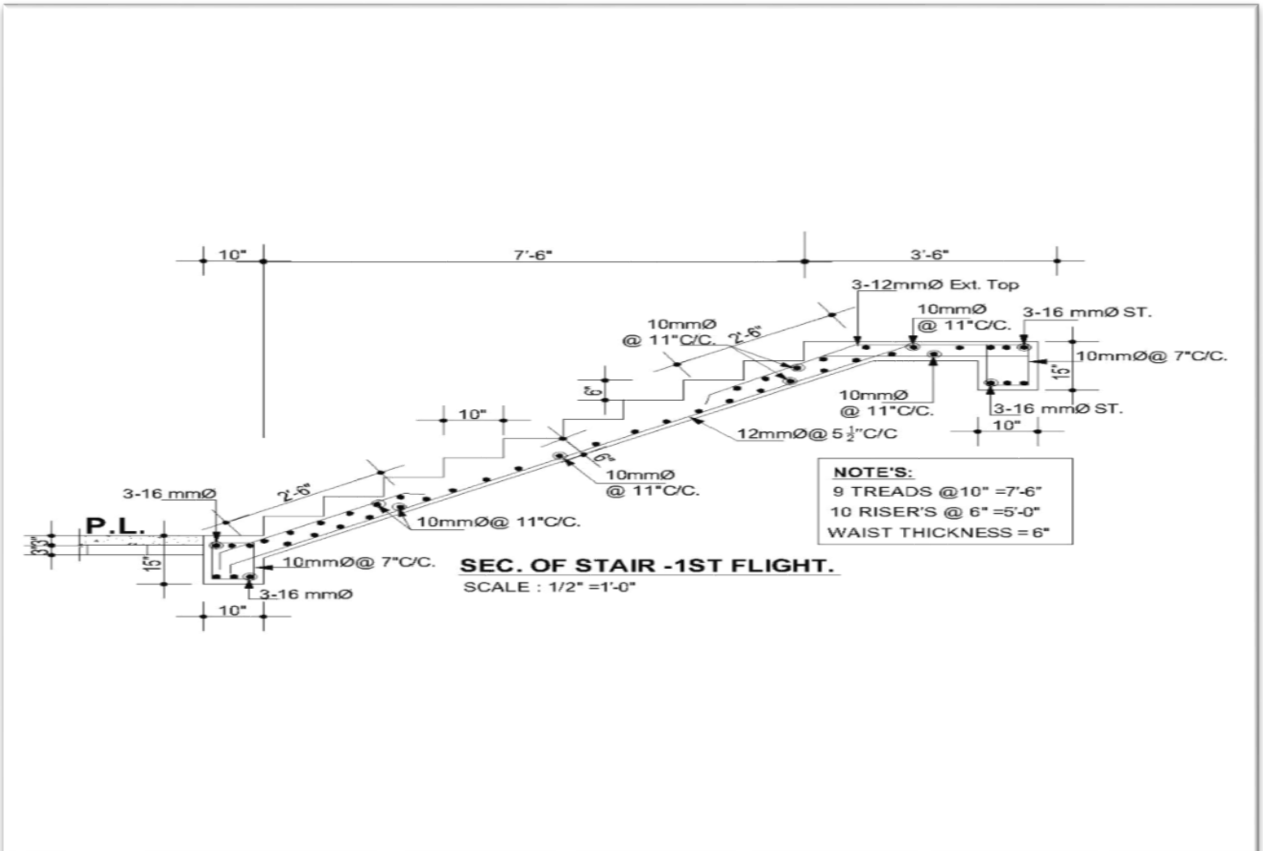


Figure 3.1 : Reinforcement Detailing of Stair

3.2 Foundation

3.2.1 Design Steps of Rectangular Foundation

Steps to be followed for design of Rectangular footings:-

Calculate Dead load and live load on foundation.

Determine pressure of material below ground level = Footing depth below G.L. * Unit wt. of soil & concrete on average

Calculate Allowable bearing capacity of soil, qa (From soil report or calculation)

Calculate required area of foundation assuming about 3% of (DL+LL) as self weight in excess of soil.

Req. Area, A=(DL+LL+ self weight)/qa
= ((DL+LL)+(DL+LL)*3%)/qa
=((DL+LL)*1.03)/qa

5. Calculate Surcharge of footing, Sf = $bh^2/6$

6. Calculate q = (p/Af)+(M from column/Sf)

7. If q < Allowable bearing pressure then ok otherwise one have to increase footing area.
8. Calculate net under pressure producing shear and bending.
   qnet= (1.2DL+1.4LL)/Provided area
9. Determine thickness of footing.
10. Considering punching shear, Allowable punching strength
    Vpa= 4* phi *Sqrt(f'c)* b*d
11. Considering beam shear, Allowable beam shear strength Vba= 2* phi *f'c * b* d
12. Minimum thickness =9” (According to the code)
13. Clear cover = 2” (minimum)
14. Determine flexure reinforcements
    As = Mu/{phi*fy*(d-a/2)} ; Mu=$wL^2/2$
    a= Asfy/(.85*f’c*b)
15. For rectangular foundation (oblong foundation) reinforcement under the column for a band width along short direction shall be calculated using the relation shown below.

Reinforcement in band width =2/(β+1)

Where, β= (Long side of the foundation / Short side of the foundation)

Here, Band width = width of the short side of the foundation

16. Express your design in a figure with reinforcement detailing.

Reference book: Design of concrete structure By Nilson/ Darwin/ Donal (13th edition)

3.2.2 Design example of Rectangular footing

Q2. A square column of 16*16 in is to carry DL of 158kips and LL of 60 kips. Allowable bearing capacity of soil is 2.5 ksf at 6' depth below ground level. Ratio of length of width of footing is 1.6. Assuming 3% self weight. Design the footing if f'c = 4ksi, and fy = 60 ksi.
Solution : **1. Required Area of footing** , A= ((158+60)*1.03)/2.5
= 89.816 ft²

Given, L/B = 1.6

L= 1.6*B

Now, Area, A = Length * Width

89.416 = L * B

89.416 = 1.6 B * B

B=7.49 ft

So, B= 7.5 ft (say)
So, L= 1.5* 7.5= 11.98 ft = 12 ft (say)
2. qu net =(1.2*158+1.6*60)/(12*7.5)
= 3.17 k/ft²
3. Try h =16 in . So, d = (16-3)in = 13in
4. Punching shear check (Two way shear):
Vp = (1.2*158+1.6*60)-(((29*29)/144)*3.17) = 267 kips
Va= (4*.75 *SQRT(4000)*29*4*13)/1000 =286 kips
As, Va > Vp , So [OK]
5. Beam shear check (one way shear) :
Vb = 4.335*3.17* = 13.77 kips
Va =(2*.75*SQRT(4000)*12*13)/1000 = 14.79 kips
As, Va > Vb , So [OK]
So, thickness, h =16 in and depth, d =13 in

6. Re bar for Long direction :

M = $wL^2/2$ = $3.17*5.335^2/2$ = 45.11 k-ft

As = (45.11*12)/(.9*60*(13-(1.2/2)))=.81 in^2 [Controls]

a = (.81*60)/(.85*4*12) =1.19 in [OK]

As min = (200*12*13)/60000 = .51 in^2

Use ϕ20 @ 7" c/c at bottom along long direction.

7. Re bar for Short direction :

M = $wL^2/2$ = $3.17*3.085^2/2$ =15.06 k-ft

As = (15.06*12)/(.9*60*(12-(0.4/2)))= .28 in^2

a= (.28*60)/(.85*4*12) = .4 in^2

As min = (200*12*12)/60000 =.475 in^2 [Controls]

So, Total As in short direction = .475 *12 =5.4 in^2

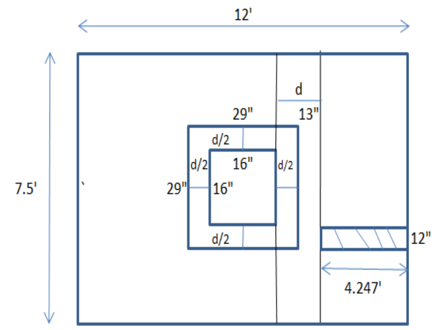
8. As band =(2/(β+1))*As total = ((2/1.6+1))*5.7 =4.38 in^2 = 4.38/7.5 =.584 in^2/ft

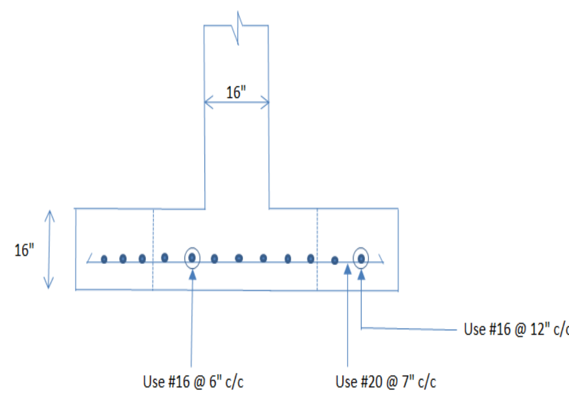
[β= Long direction of footing/ short direction of footing]

Use, ϕ16 @ 6" c/c for 7.5 " band width

For rest of the short direction, As = 5.7-4.384 = 1.31/(12-7.5) =.29 in^2

Use, ϕ16 @12" c/c for 4.5' length.





3.2.3 Design Steps of Square Foundation

<u>Steps to be followed for design of Square footings</u>

1. Calculate Dead load and live load on foundation.
2. Determine pressure of material below ground level = Footing depth below G.L. * Unit wt. of soil & concrete on average
3. Calculate Total surcharge adding extra surcharge if any.
4. Net permissible soil pressure , qnet = Permissible soil pressure - Total surcharge
5. Area of footing, Af =(1.2DL+1.6LL)/qnet
6. Assume footing size according to the area of footing. i.e . (Length = width) of footing = Sqrt (Area of footing)
7. Calculate Surcharge of footing, Sf = $bh^2/6$
8. Calculate q = (p/Af)+(M from column/Sf)
9. If $q <$ Allowable bearing pressure then ok otherwise one have to increase footing area.
10. Calculate Footing projection , c = (Footing length- Column length)/2
11. Max. reinforcement ratio,ρ=.0018*1.11 =.002 [Note: say h/d = 1.11, Minimum steel ρ is $0.0018\times bh$ or 0.002 bd]
12. Calculate Rn = ρ*fy*(1-(.5*ρ*fy)/(.85*f'c))
13. Calculate, Mu = qu*$c^2/2$ = (Pu/Af)*($c^2/2$) ; Pu = Factored (DL+LL)
14. Calculate Depth, d =Sqrt(Mu/phi*Rn)
15. Calculate h = d+4 >10 in; Considering 4" clear cover+diameter of bar
16. Considering punching shear, Allowable punching strength
    Vpa= 4* phi *Sqrt(f'c)* b*d
17. Considering beam shear, Allowable beam shear strength Vba= 2* phi *f'c * b* d
18. Calculate Bending Moment, M =$wL^2/2$
19. Determine flexure reinforcements
    As = Mu/{phi*fy*(d-a/2)} ; Mu=$wL^2/2$
    a= Asfy/(.85*f'c*b) ; Provide the reinforcements on both sides
20. Express your design in a figure with reinforcement detailing.

Reference book: Simplified design of reinforced concrete building By Mahmoud E Kamara and Lawrence C Novak & *Design of concrete structure By Nilson/ Darwin/ Donal (13th edition)*

3.2.4 Example of a square footing design

Q.1. Design footings for the interior column of building No.2 (5 story flat plate). Assume, base of footing location 5' below ground level. Permissible soil pressure , qa = 6 ksf .

1.Design Data :

Service surcharge = 50 pcf

Assume, Weight of soil and concrete above footing base =100 pcf

(When soil is wet packet use weight of soil = 130 Pcf)

Interior column = 16" x 16"

4 no 8 bars (No sway frame)

8 no 10 bars (Sway frame)

f'c = 4000 psi (for both footing and column)

2.Load Combination :

a) Gravity loads: PDL = 351 kips , PLL = 56.4 kips

b) Gravity loads + Wind, PDL = 339.4 kips

PLL = 56.4 kips , Mservice = 75.4 k-ft

3. Base Area Footing :

weight of surcharge = (0.100 x 5) = 0.5 ksf

extra surcharge = 50 psf =0.05 ksf

[If there is no extra surcharge, ignore this term]

Total surcharge = (0.5+0.05) = 0.55 ksf

So, Net permissible soil pressure = (6 – 0.55) = 5.45 ksf

Area of footing , Af = (351+56.4)/5.45 = 74.75 sq. ft.

Try 9' x 9' square footing . (Af = 81 sq. ft.)

Now, we know , Sectional Modulus , S = I/C

or, S = I/C = (bh3/1 2) / (h/ 2)

so, S = bh2/6

S = (9*9^2)/6 = 121.5 ft3

As, Af = 81 ft2

Now, q = p/Af+M/Sf

=((351+56.4)/81)+(75.4/121.5)

= 5.65 > 5.45 (Not ok)

Try, 9.5' x 9.5' square footing (Af = 90.25 ft2)

q =((351+56.4)/90.25)+(75.4/142.2)

= 5.04 < 5.45 (Ok)

4. Footing Thickness :

Footing projection , c =(9.5-(16/12))/2

Now, ρ = 0.0018 x 1.11 = 0.002

Rn = ρ fy (1-(.5* ρ fy)/(.85f'c))

= 0.002 x 60000 (1-(.5*.002*60000)/(.85*4000))

= 117.9 psi

d^2 required =Mu/(phi*Rn) =(Mu*1000)/(.9*117.9) .... (1)

Again, Mu = (p/Af)(c^2/2) .... (2) (as, (Pu / Af) = qu)

Now, from eqn. (1) , d^2req = 9.43 Mu

= 9.43x(p/Af)(c^2/2) ((from eqn. 2)

dreq =2.17c*Sqrt(p/Af)

so, drequired = 2.2 c * Sqrt(p/Af)

h = 2.2 c* Sqrt(p/Af) +4 (considering, 4" clear cover + dia of bar)

h = 2.2 *4.08*Sqrt(1.2*351+1.6*56.4/90.25) + 4

= 25.4 in > 10 in (Ok)

Try, h = 27 in.

So, d = (27-4) in

= 23 in.

5.Qu net = Factored load/ Area of footing

=(1.2*351+1.6*56.4)/(9.5*9.5) =511.44/90.25 =5.67 ksf

6. Considering punching Shear or Two way shear :

Punching shear , Vp = 511.44- (39*39)/144*5.67

=451.55 Kips

Allowable shear, Va = 4φ Sqrt(f'c)b d

= (4*.75*Sqrt(4000) *(39*4)*23)/1000

= 680.77 Kips

As, Va > Vp , so [OK]

6. Considering beam Shear or One way shear :

Beam shear , Vb = qu * Beam strip length * (c-d)

=5.67*9.5*2.167

=116.72 Kips

Allowable shear, Va = 2φSqrt(f'c) b d

= (2*.75*Sqrt(4000)*(9.5*12)*23)/1000

= 248.71 Kips

As, Va > Vb , so [OK]

7. The Bending Moment :

M =(5.67*9.5*(2.167+(23/12))^2*12)/2

=5575.30 Kip-in

8. Reinforcements :

As =M/(phi*fy*(d-a/2))

=5575.30/(.9*60*(23-7.98/2))

= 5.43 in^2 ; Controls

a=As*fy/.85f'cb

=(5.43*60)/*(.85*4*12)

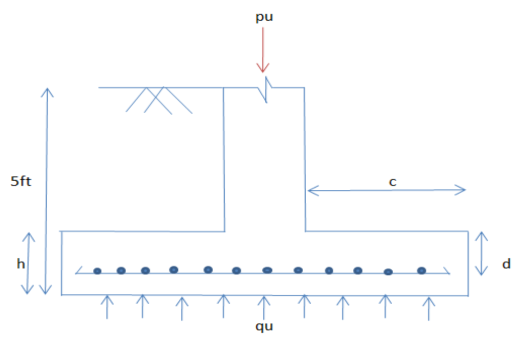
=7.98 in [ok]

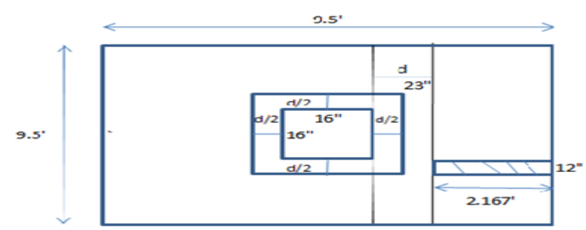
As min = 200*b*d/fy

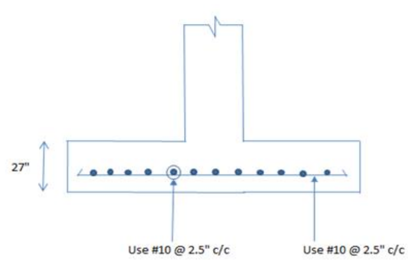
=(200*12*23)/60000

=0.92 in^2

Use #10 bar in each direction @ 2.5in c/c







3.3 Column

3.3.1 Design Example of square column

Design a square column to support a concentric load of 700 kips. Initially assume that approximately 2% longitudinal steel is desired, f'c = 3000 psi and fy = 60,000 psi

Solution:

Selecting column dimension and bar size

$\varphi Pn\ (max) = 0.80 \varphi Ag\ [0.85f'c + \rho g\ (fy - 0.85f'c)]$

$700 = 0.80 \times 0.65 \times Ag[(0.85 \times 3) + 0.02\{60 - (0.85 \times 3)\}]$

Ag = 236.55 in^2 or 237 in^2

Use a 16×16 inch column

Amount of reinforcement to be used = $16^2 \times 0.03 = 7.68\ in^2$

Use 4#14 bars (9 in^2)

Spacing of tie bar

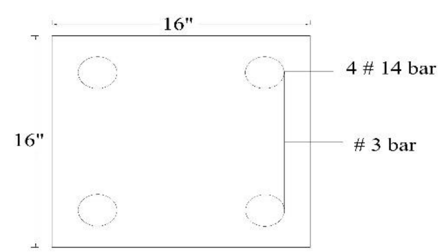
Lest of the below three criteria

16db of main bar = 16×1.75 = 28 in^2

48db of tie bar = 48×0.375 = 18 in^2

Least die of column = 16 in^2

Use 8 in C/C at top and bottom and 16 in C/C at middle span



3.3.2 Design Example of circular column:

Design a round spiral column to support an axial dead load P_D of 240 K and an axial live load P_L of 300 k. Initially assume that approximately 2% longitudinal steel is desired, f'c = 4000 psi, and fy= 60,000 psi.

Solution:

Selecting column dimension and bar size

P_u = 1.2* (240 k) + 1.6* (300 k) = 768 K

$\varphi P_n = \varphi\ 0.85[0.85f'_c (A_g - A_{st}) + f_y A_{st}]$

768 k = (0.75) (0.85) [(0.85) (4ksi) (A_g – 0.02A_g) + (60 ksi) (0.02A_g)]

Ag = 266 in²

Diameter of column, d = $\sqrt{\frac{266 \times 4}{3.1416}}$ = 18.4 in or 18 in.

Column area to be use = $\frac{3.1416 \times 18^2}{4}$ = 254.47 in² or 255 in²

Using a column diameter with a gross area less than the calculated gross area (255 in² < 266 in²) results in a higher percentage of steel than originally assumed.

768 k = (0.75) (0.85) [(0.85) (4ksi) (255 in² – A_{st}) + (60 ksi) A_{st}]

A_{st} = 5.97 in²

Use 6 #9 bars (6.00 in²)

Design of spiral

$A_c = \frac{3.1416 \times 15^2}{4} = 177\ in^2$

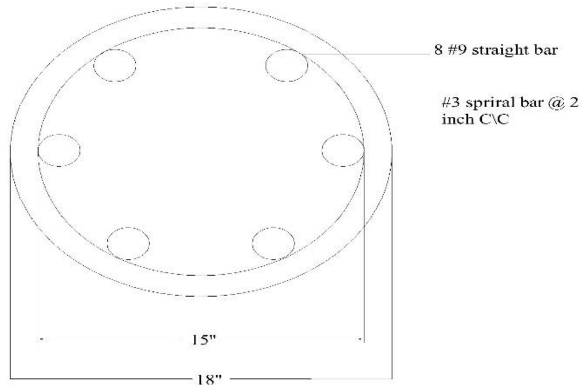
Minimum $\rho s = (0.45)\left(\frac{Ag}{Ac} - 1\right)\frac{f'c}{fy} = (0.45)\left(\frac{255 in^2}{177 in^2} - 1\right)\frac{4\ ksi}{60\ ksi} = 0.0132$

Assume a #3 spiral, d_b = 0.375 in and a_s = 0.11 in²

$$\rho s = \frac{4as\,(Dc-db)}{sDc^2}$$

$$0.0132 = \frac{4\times0.11\ In^2)(15\ in-0.375\ in)}{s\times15\ in^2}$$

s = 2.17 in or 2 in.



Chapter 4

Result and Discussion

4.1 Stair Design result and analysis

An Excel calculation based website has been created on simplified design of stair of reinforced concrete buildings of moderate size and height. The users including the engineers, the architects, and common non-technical person can give very simple inputs, e.g. Span, Thickness of waist, Thickness of slab, and Loads etc. in this excel sheet and instantly get the visual results there. It can be used for initial structural design, verifying existing design and to get rough idea on the design and check the assumptions. Link of this website is given below:

http://designofstair.weebly.com/

4.1.1 Simplified design of stair

User needs to input data in the green colored cell. He will find final result at bottom. User has to give the following information about the stair i.e. span of the stair, waist thickness, yield strength and diameter of steel.

This analysis includes thickness of the slab, area of required steel and spacing of the rebar. Reinforcement detailing of stair has shown in the bottom of the excel file to better understand the position and spacing of reinforcement of stair.

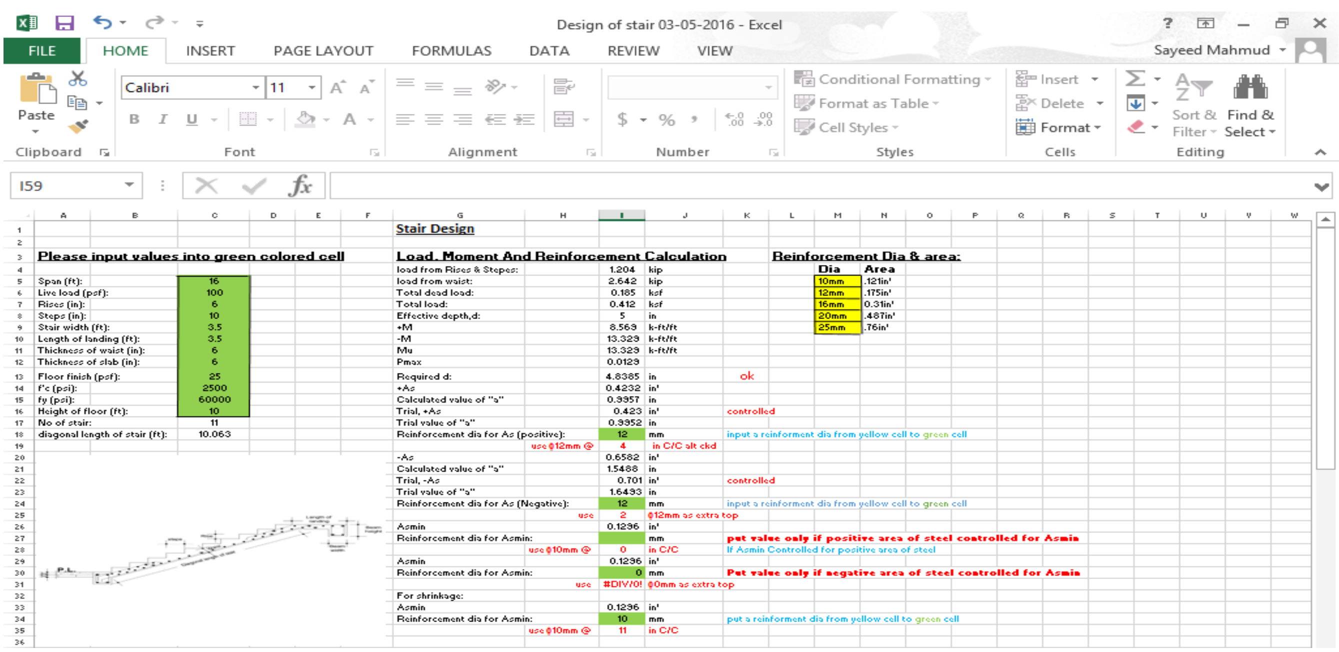


Figure 4.1 (a): Design of stair excel file screenshot

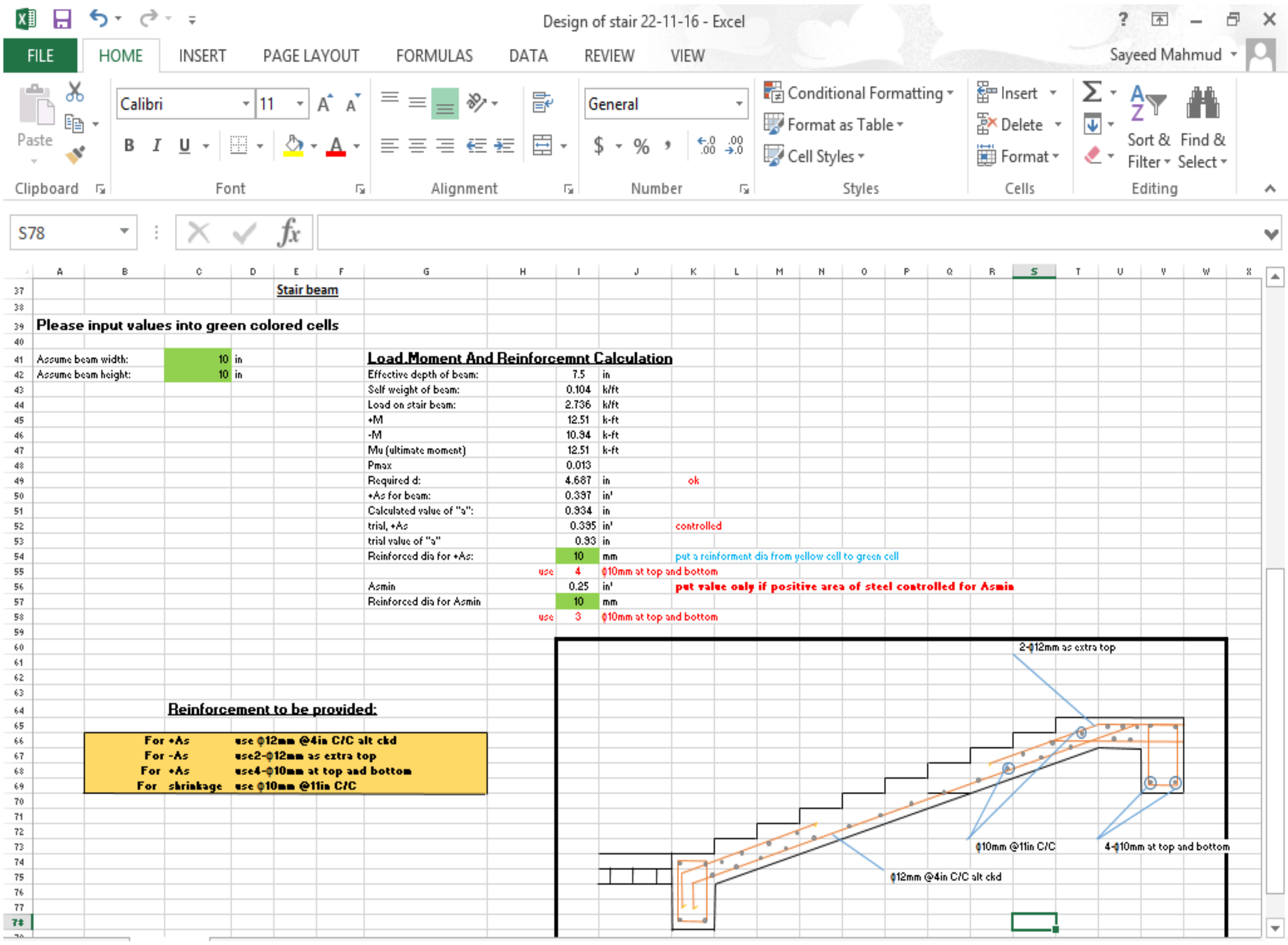


Figure 4.1 (b): Design of stair excel file screenshot

4.1.2 Comparison Results

We have calculated required reinforcement for 16 feet span of stair with several concrete and steel strength. And from comparison we can say that for a 16 feet span stair, maximum positive reinforcement is 0.36 in² and negative reinforcement is 0.62 in² if the slab thickness is 6 inch.

Design of Stair

Span length 16'

Slab Thickness 6"

f'c	2500 psi	2500 psi	3000 psi	3000 psi	3500 psi	3500 psi
fy	60000 psi	72500 psi	60000 psi	72500 psi	60000 psi	72500 psi
Required depth,d	4.64 in	4.52 in	4.22 in	4.15 in	3.89 in	3.86 in
Positive Moment	7.5 k-ft	7.5 k-ft	7.5 k-ft	7.5 k-ft	7.5 k-ft	7.5 k-ft
Negative Moment	11.9 k-ft	11.9 k-ft	11.9 k-ft	11.9 k-ft	11.9 k-ft	11.9 k-ft
Positive still area	.36 in²	.30 in²	.36 in²	.297 in²	.35 in²	.29 in²
Negative still area	0.62 in²	.51 In²	.59 in²	.49 in²	.59 in²	.49 in²

4.1.3 Website on Stair Design

Website has been created on Stair design as mentioned above providing all our works into it including design calculations in excel files (Screen shots are mentioned above). This website contains information's about stair, design sample, design steps. We are still working on modifying the website to make it better to best and trying to add more and more information regarding Stair. The screenshots of the websites are shown below:

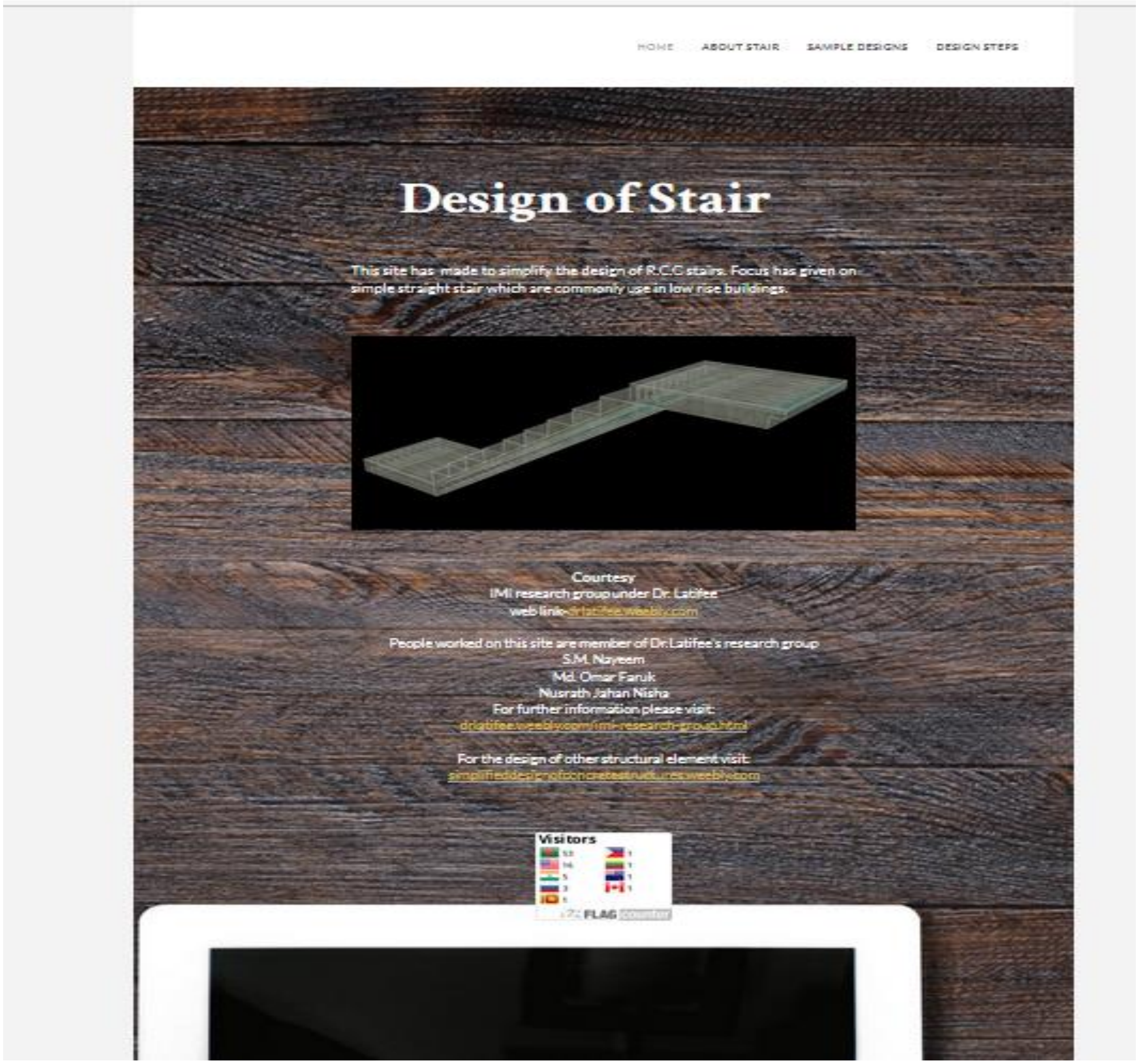


Figure 4.2 (a): Design of stair web page screenshot

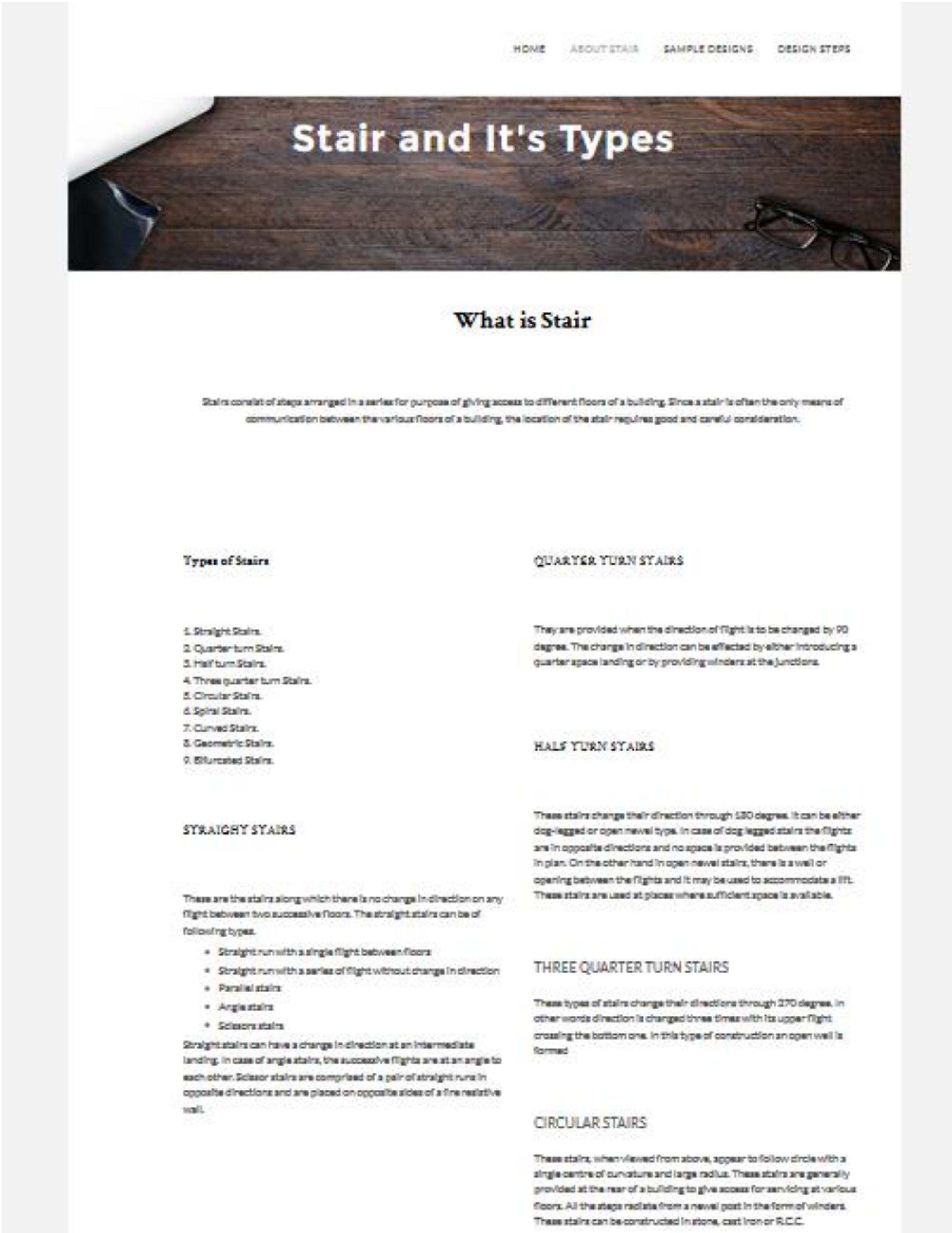


Figure 4.2 (b): Design of stair web page screenshot

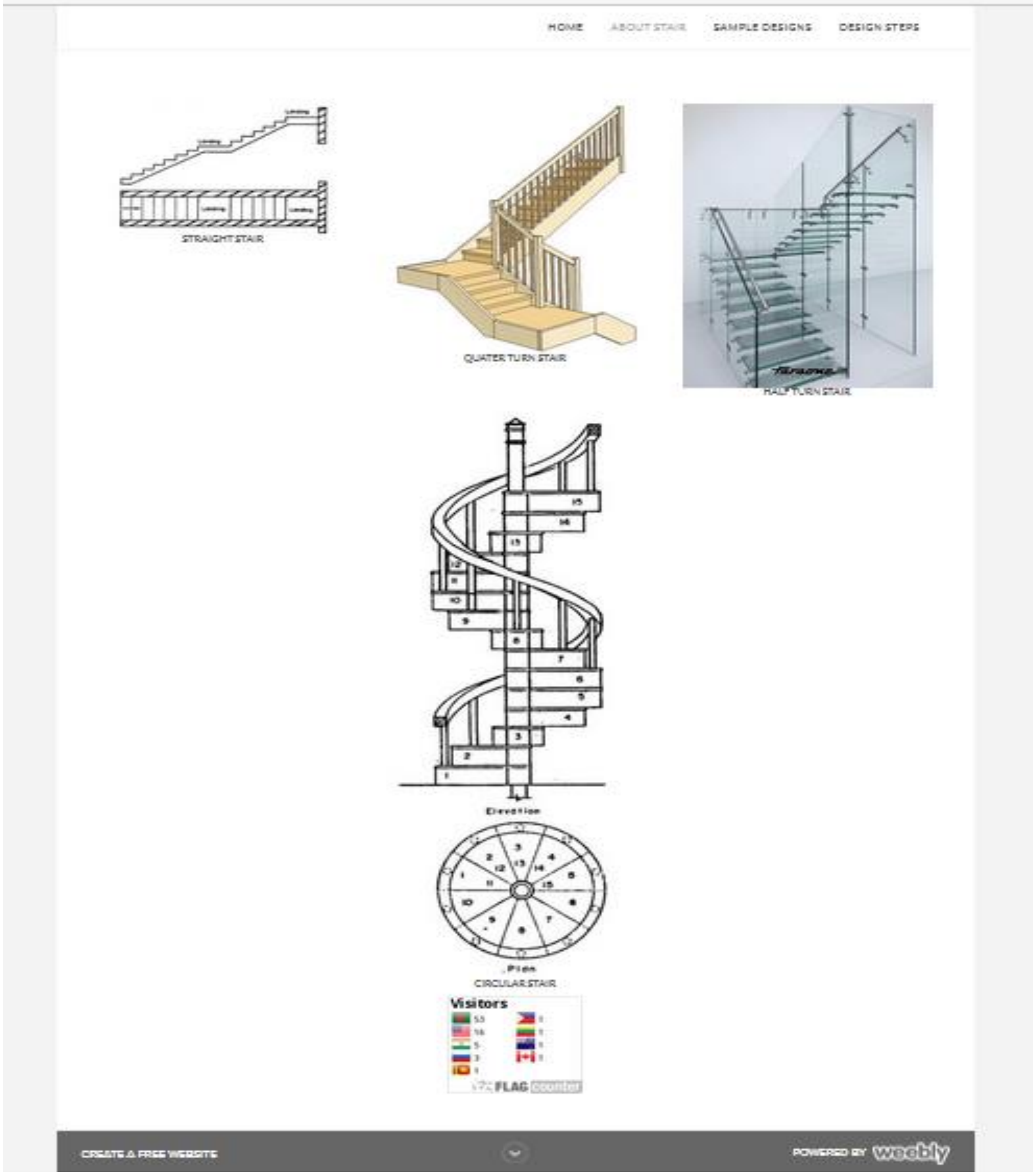


Figure 4.2 (c): Design of stair web page screenshot

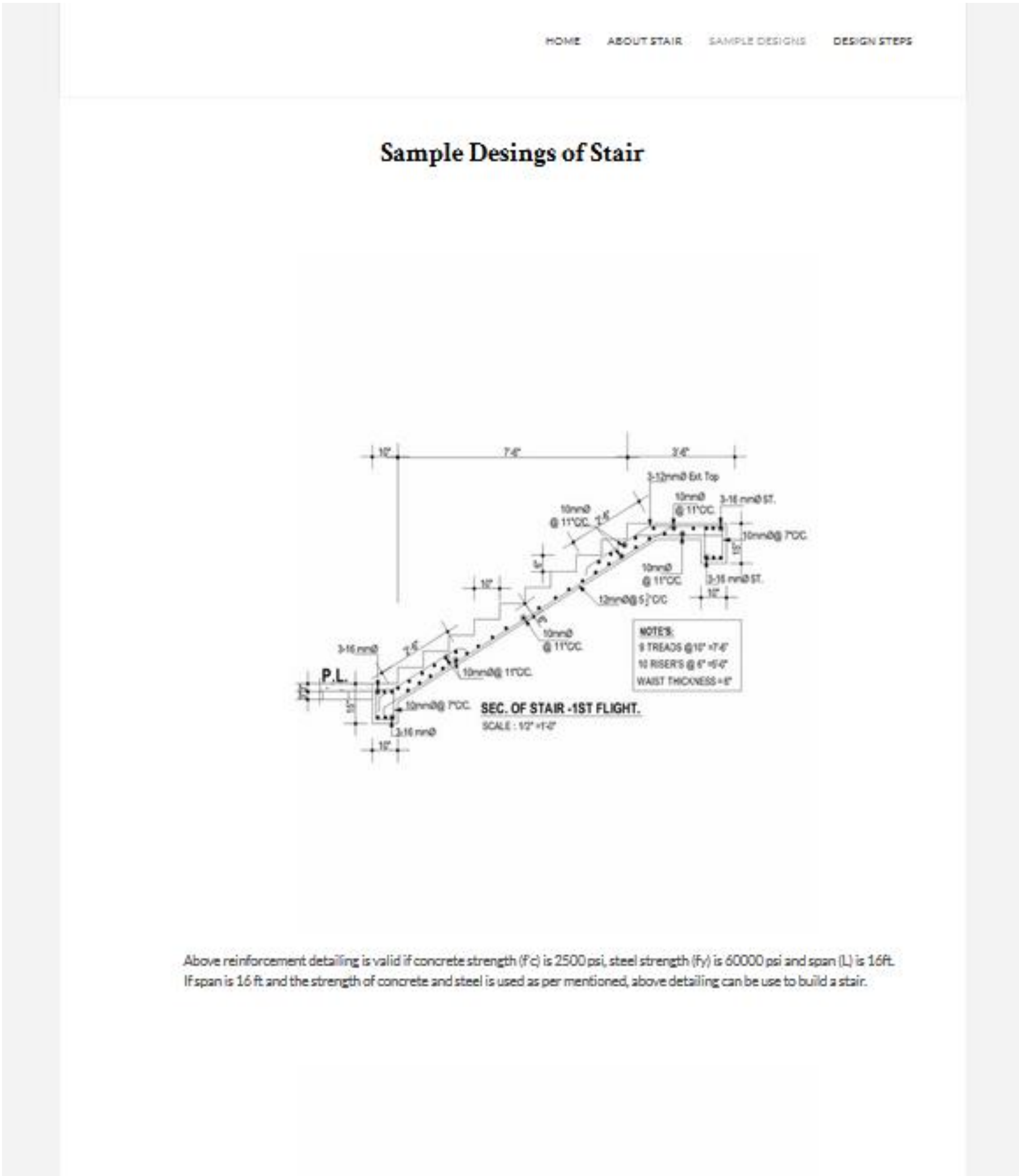
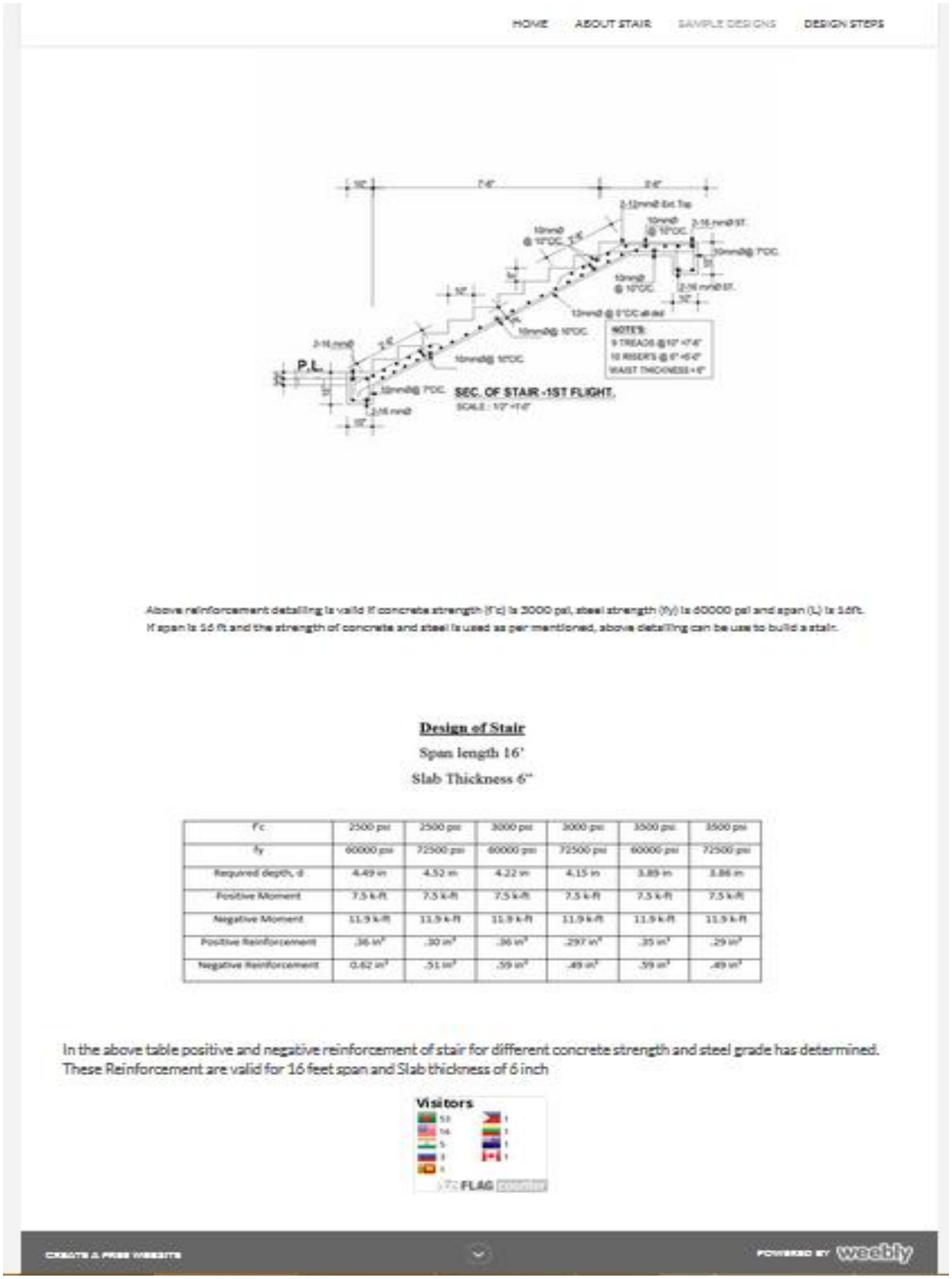


Figure 4.2 (d): Design of stair web page screenshot



HOME ABOUT STAIR SAMPLE DESIGNS DESIGN STEPS

SEC. OF STAIR -1ST FLIGHT.

Above reinforcement detailing is valid if concrete strength (f'c) is 3000 psi, steel strength (fy) is 60000 psi and span (L) is 16ft. If span is 16 ft and the strength of concrete and steel is used as per mentioned, above detailing can be use to build a stair.

Design of Stair

Span length 16'

Slab Thickness 6"

F'c	2500 psi	2500 psi	3000 psi	3000 psi	3500 psi	3500 psi
fy	60000 psi	72500 psi	60000 psi	72500 psi	60000 psi	72500 psi
Required depth, d	4.49 in	4.52 in	4.22 in	4.15 in	3.89 in	3.86 in
Positive Moment	7.5 k-ft	7.5 k-ft	7.5 k-ft	7.5 k-ft	7.5 k-ft	7.5 k-ft
Negative Moment	11.9 k-ft	11.9 k-ft	11.9 k-ft	11.9 k-ft	11.9 k-ft	11.9 k-ft
Positive Reinforcement	.36 in²	.30 in²	.36 in²	.297 in²	.35 in²	.29 in²
Negative Reinforcement	0.62 in²	.51 in²	.59 in²	.49 in²	.59 in²	.49 in²

In the above table positive and negative reinforcement of stair for different concrete strength and steel grade has determined. These Reinforcement are valid for 16 feet span and Slab thickness of 6 inch

Visitors

FLAG counter

CREATE A FREE WEBSITE

POWERED BY weebly

Figure 4.2 (e): Design of stair web page screenshot

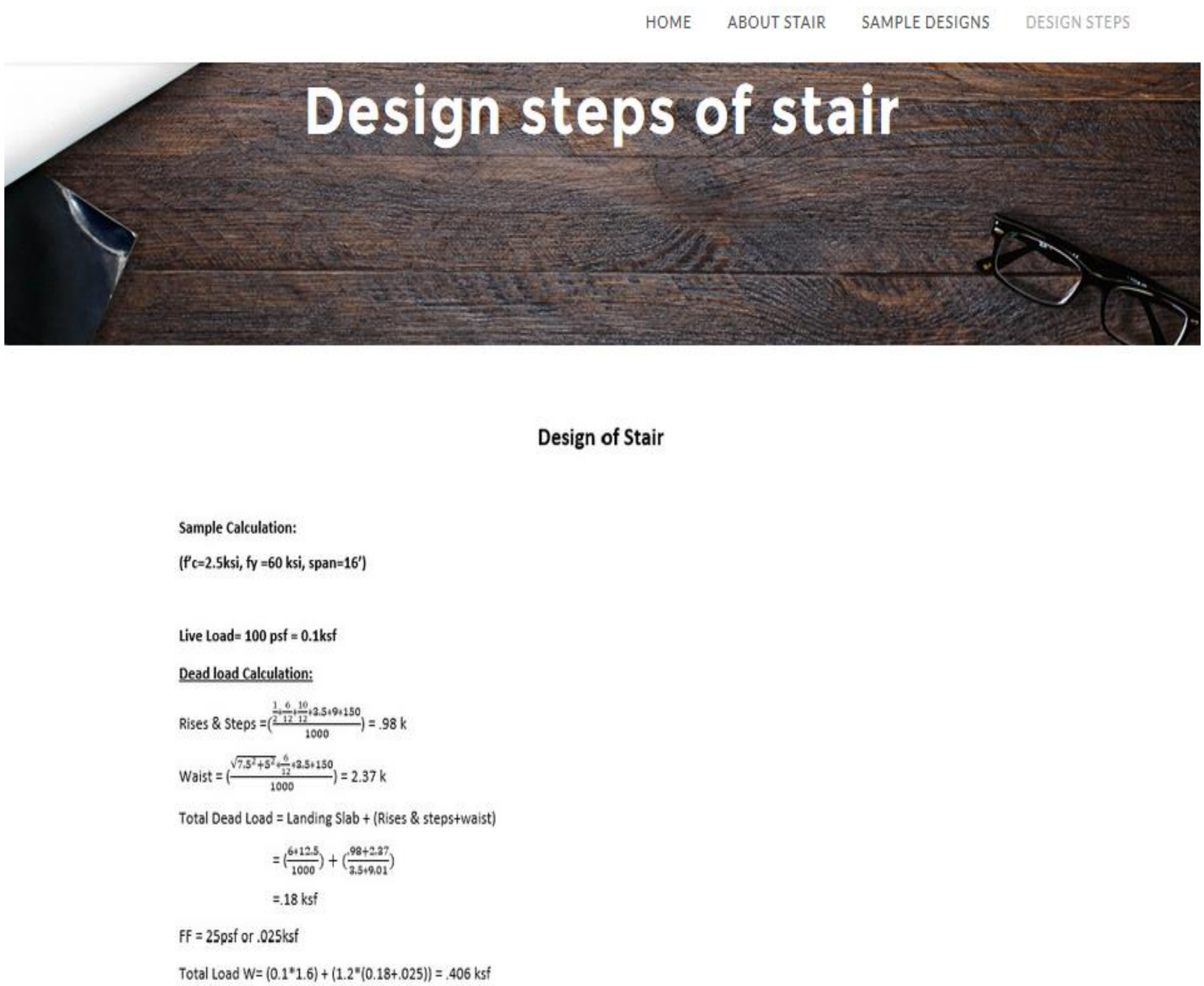
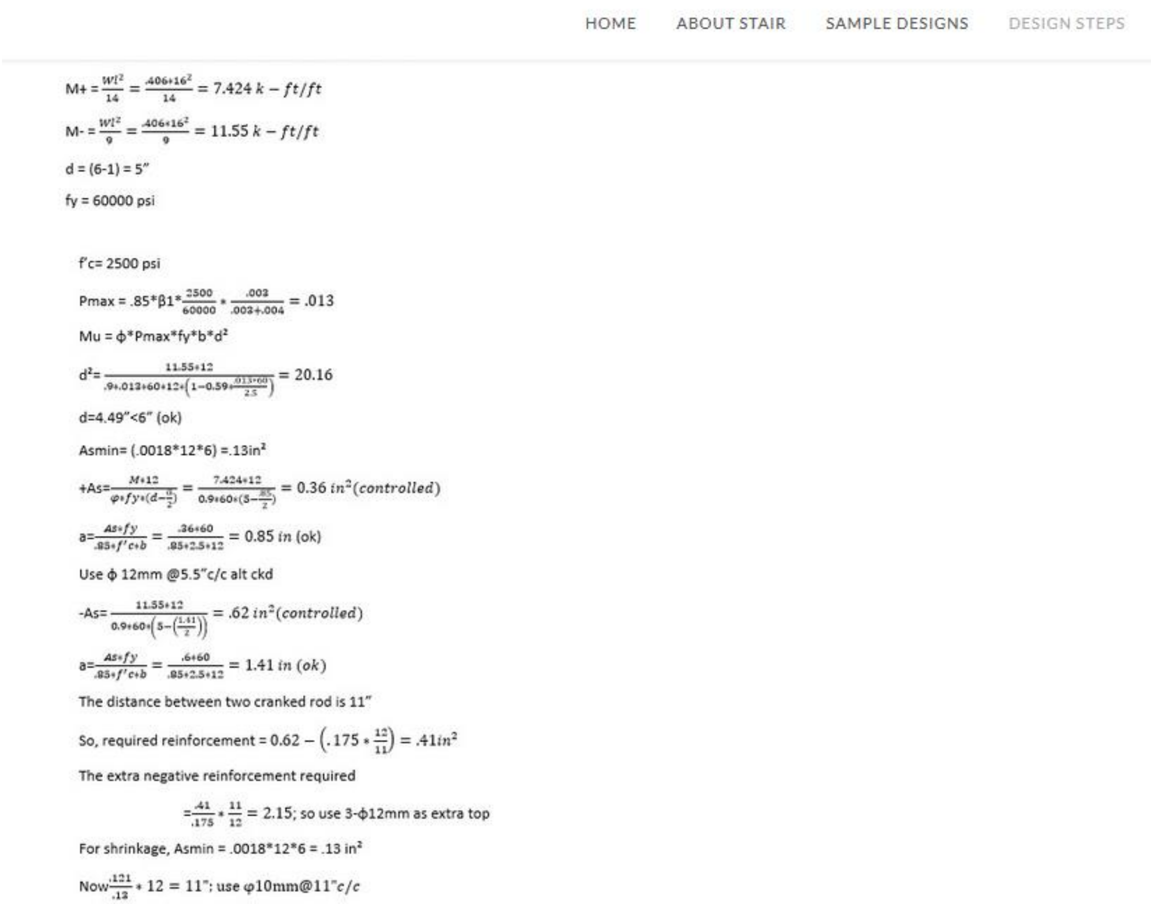


Figure 4.2 (f): Design of stair web page screenshot


HOME ABOUT STAIR SAMPLE DESIGNS DESIGN STEPS

M+ = $\frac{wl^2}{14} = \frac{.406*16^2}{14} = 7.424\ k - ft/ft$

M- = $\frac{wl^2}{9} = \frac{.406*16^2}{9} = 11.55\ k - ft/ft$

d = (6-1) = 5″

fy = 60000 psi

f′c= 2500 psi

Pmax = .85*β1*$\frac{2500}{60000} * \frac{.003}{.003+.004} = .013$

Mu = ϕ*Pmax*fy*b*d²

d²= $\frac{11.55*12}{.9*.013*60*12*\left(1-0.59*\frac{.013*60}{2.5}\right)} = 20.16$

d=4.49″<6″ (ok)

Asmin= (.0018*12*6) =.13in²

+As=$\frac{M*12}{\varphi*fy*(d-\frac{a}{2})} = \frac{7.424*12}{0.9*60*(5-\frac{.85}{2})} = 0.36\ in^2(controlled)$

a=$\frac{As*fy}{.85*f'c*b} = \frac{.36*60}{.85*2.5*12} = 0.85\ in$ (ok)

Use ϕ 12mm @5.5″c/c alt ckd

-As= $\frac{11.55*12}{0.9*60*\left(5-\left(\frac{1.41}{2}\right)\right)} = .62\ in^2(controlled)$

a=$\frac{As*fy}{.85*f'c*b} = \frac{.6*60}{.85*2.5*12} = 1.41\ in\ (ok)$

The distance between two cranked rod is 11″

So, required reinforcement = $0.62 - \left(.175 * \frac{12}{11}\right) = .41 in^2$

The extra negative reinforcement required

$=\frac{.41}{.175} * \frac{11}{12} = 2.15$; so use 3-ϕ12mm as extra top

For shrinkage, Asmin = .0018*12*6 = .13 in²

Now$\frac{.121}{.13} * 12 = 11''$; use φ10mm@11″c/c

Figure 4.2 (g): Design of stair web page screenshot

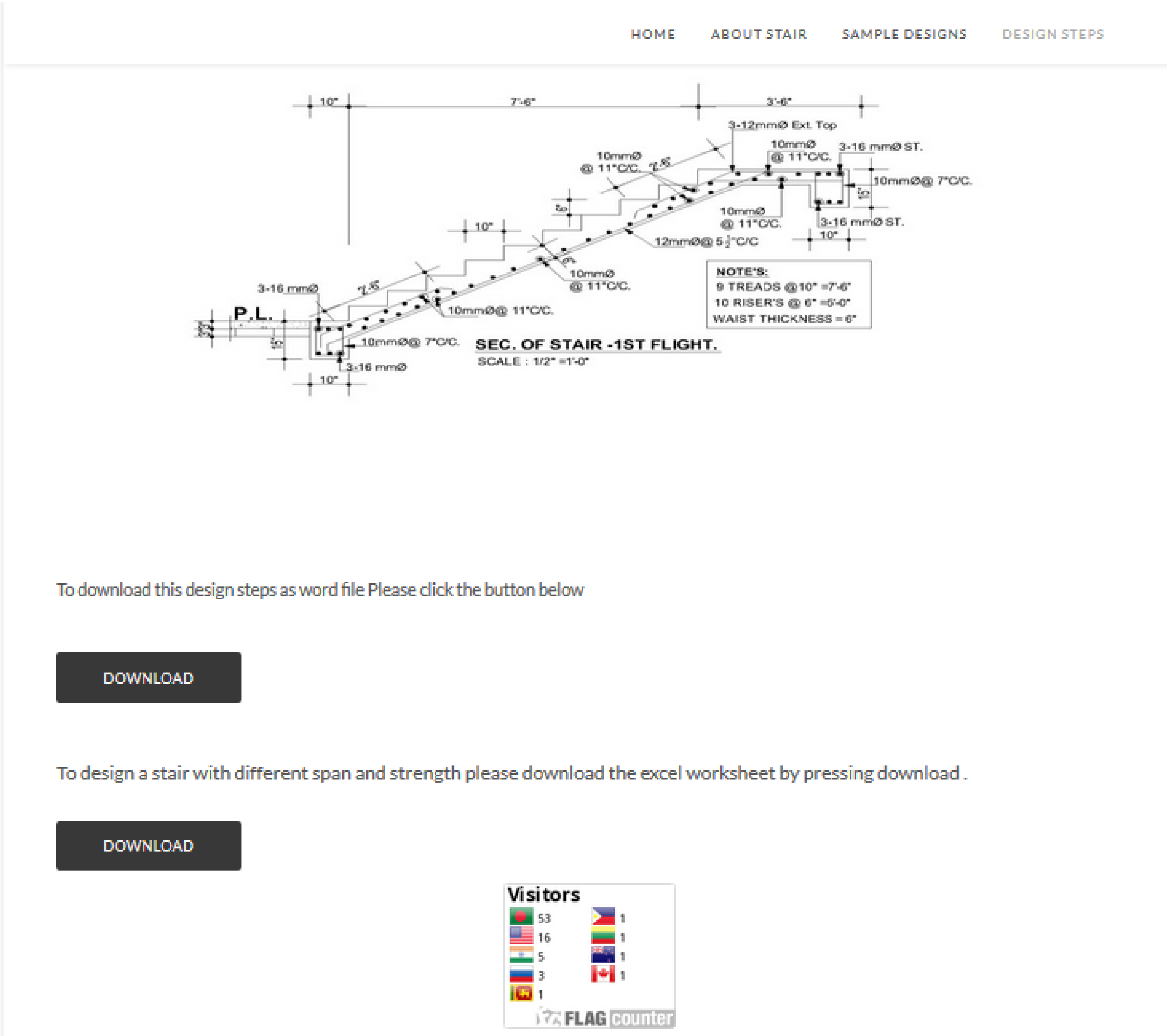


Figure 4.2 (h): Design of stair web page screenshot

4.2 Foundation Design result and analysis

An Excel calculation based website has been created on simplified design of foundation of reinforced concrete buildings of moderate size and height. The users including the engineers, the architects, and common non-technical person can give very simple inputs, e.g. Column width, Column length, bearing capacity of soil, Loads etc. in this excel sheet and instantly get the visual results there. It can be used for initial structural design, verifying existing design and to get rough idea on the design and check the assumptions. Link of this website is given below:

http://simplifythefoundationdesign.weebly.com/

4.2.1 Load Calculation for Foundation

One has to input data in the blue colored cell. He will find result right bottom to the input data box. Different excel sheet is prepared for different criteria. The first Sheet is about the interior column with 4 beams around it. On the basis of input data it will give you the total loads on that particular column. To get the clear idea necessary figures are included. The second and third sheet is about interior column with 3 beams around and exterior column with 2 beams respectively.

(a) Interior Column with Four beams

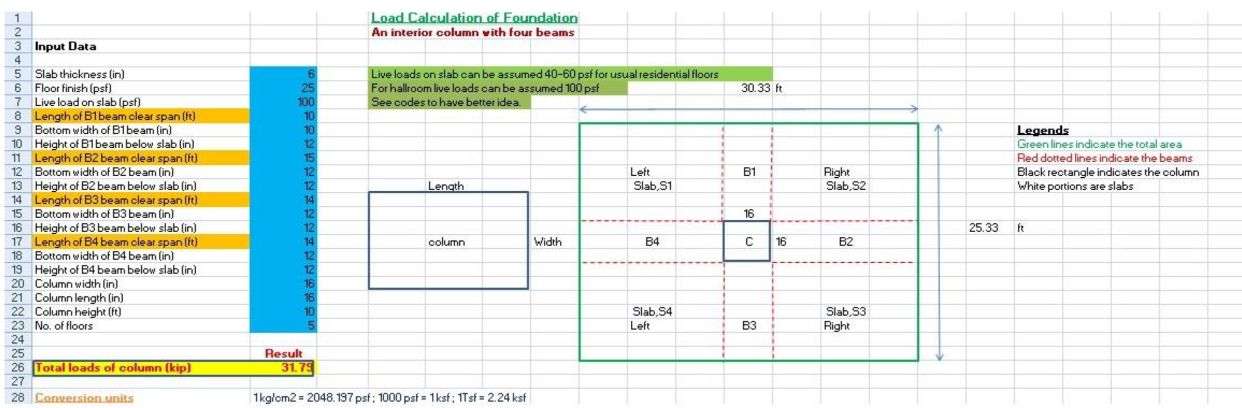


Figure 4.3 (a): Load Calculation For Foundation (Interior Column with four beams) excel file Screenshot

28	Conversion units	1kg/cm2 = 2048.197 psf ; 1000 psf = 1ksf ; 1Tsf = 2.24 ksf	
29	Calculation :-		
30	**Calculation for slab**		
31	loads on slab	0.2	
32			
33	**Calculation for B1 beam at right side**		
34	Self weight of the B1 beam (kip/ft)	0.125	
35	short direction=	10	
36	long direction=	15	
37	m=	0.67	
38		Triangular	Trapezoidal
39	Amount of load=	0.67	0.85
40	load pattern on B1 (from right slab)	Triangular	
41	Loads on B1 from the right side slab(kip/ft)	0.67	
42			
43	**Calculation for B1 beam at left side**		
44			
45	short direction=	10	
46	long direction=	14	
47	m=	0.71	
48		Triangular	Trapezoidal
49	Amount of load=	0.67	0.83
50	load pattern on B1 (from Left slab)	Triangular	
51	Loads on B1 from the left side slab	0.67	
52	Total loads on B1 Beam (kip/ft)	1.46	
53			
54			
55			
56	**Calculation for B2 beam at upper side**		
57	Self weight of the B2 beam (kip/ft)	0.15	
58	short direction=	14	
59	long direction=	15	
60	m=	0.93	
61		Triangular	Trapezoidal

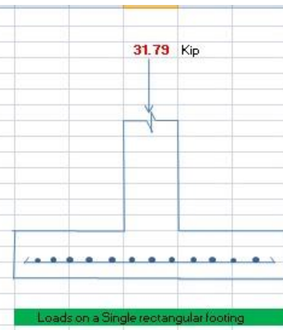


Figure 4.3 (b): Load Calculation For Foundation (Interior Column with four beams) excel file Screenshot

59	long direction=	15	
60	m=	0.93	
61		Triangular	Trapezoidal
62	Amount of load=	0.93	0.99
63	load pattern on B2 (from upper slab)	Trapezoidal	
64	Loads on B2 from the upper side slab (kip/ft)	0.99	
65			
66	**Calculation for B2 beam at lower side**		
67			
68	short direction=	10	
69	long direction=	15	
70	m=	0.67	
71		Triangular	Trapezoidal
72	Amount of load=	0.67	0.85
73	load pattern on B2 (from lower slab)	Trapezoidal	
74	Loads on b2 from the lower side slab	0.85	
75	Total loads on B2 Beam (kip/ft)	2.00	
76			
77			
78			
79	**Calculation for B3 beam at right side**		
80	Self weight of the B3 beam (kip/ft)	0.15	
81	short direction=	14	
82	long direction=	15	
83	m=	0.93	
84		Triangular	Trapezoidal
85	Amount of load=	0.93	0.99

Figure 4.3 (c): Load Calculation For Foundation (Interior Column with four beams) excel file Screenshot

83	m=	0.93			
84		Triangular	Trapezoidal		
85	Amount of load=	0.93	0.99		
86	load pattern on B3 (from right slab)	Triangular			
87	Loads on B3 from the right side slab (kip/ft)	0.93			
88					
89	**Calculation for B3 beam at left side**				
90					
91	short direction=	14			
92	long direction=	14			
93	m=	1.00			
94		Triangular	Trapezoidal		
95	Amount of load=	0.93	0.93		
96	load pattern on B3 (from Left slab)	Triangular			
97	Loads on B3 from the left side slab	0.93			
98	Total loads on B3 Beam (kip/ft)	2.02			
99					
100					
101	**Calculation for B4 beam at upper side**				
102	Self weight of the B4 beam (kip/ft)	0.15			
103	short direction=	10			
104	long direction=	14			
105	m=	0.71			
106		Triangular	Trapezoidal		
107	Amount of load=	0.67	0.83		
108	load pattern on B4 (from upper slab)	Trapezoidal			
109	Loads on B4 from the upper side slab (kip/ft)	0.83			

Figure 4.3 (d): Load Calculation For Foundation (Interior Column with four beams) excel file Screenshot

103	short direction=	10		
104	long direction=	14		
105	m=	0.71		
106		Triangular	Trapezoidal	
107	Amount of load=	0.67	0.83	
108	load pattern on B4 (from upper slab)	Trapezoidal		
109	Loads on B4 from the upper side slab (kip/ft)	0.83		
110				
111	**Calculation for B4 beam at lower side**			
112				
113	short direction=	14		
114	long direction=	14		
115	m=	1.00		
116		Triangular	Trapezoidal	
117	Amount of load=	0.93	0.93	
118	load pattern on B4 (from Lower slab)	Triangular		
119	Loads on B4 from the lower side slab	0.93		
120	Total loads on B4 Beam (kip/ft)	1.91		
121				
122	Self weight of column (kip)	2.67		
123	Total loads of column (kip)	31.79		
124				

Figure 4.3 (e): Load Calculation For Foundation (Interior Column with four beams) excel file Screenshot

b)Interior Column with Three beams

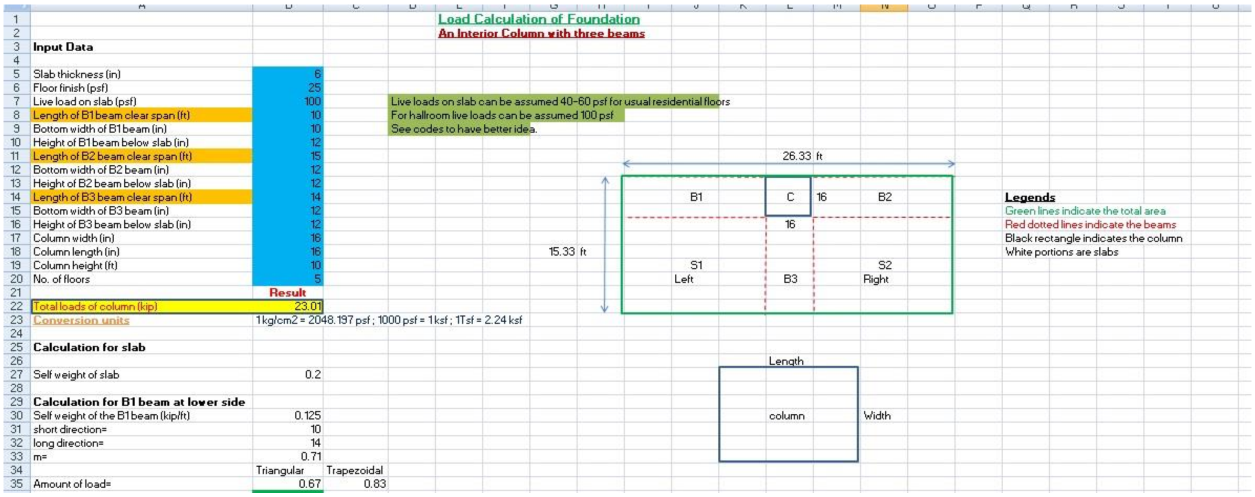


Figure 4.3 (f): Load Calculation For Foundation (Interior Column with Three beams) excel file Screenshot

Figure 4.3 (g): Load Calculation For Foundation (Interior Column with Three beams) excel file Screenshot

58	load pattern on B3 (from right slab)	Triangular	
59	Loads on B3 from the right side slab (kip/ft)	0.93	
60			
61	**Calculation for B3 beam at left side**		
62			
63	short direction=	10	
64	long direction=	15	
65	m=	0.67	
66		Triangular	Trapezoidal
67	Amount of load=	0.67	0.85
68	load pattern on B3 (from Left slab)	Trapezoidal	
69	Loads on B3 from the left side slab	0.85	
70	Total loads on B3 Beam (kip/ft)	1.94	
71			
72	Self weight of column (kip)	2.67	
73	Total loads of column (kip)	23.01	
74			
75			
76			

Figure 4.3 (h): Load Calculation For Foundation (Interior Column with Three beams) excel file Screenshot

c) Exterior Column with Two beams

1			Load Calculation of Foundation	
2			An Exterior Column with two Beam	
3	**Input Data**			
4				
5	Slab thickness (in)	6	Live loads on slab can be assumed 40-60 psf for usual residential floors	
6	Floor finish (psf)	25	For hallroom live loads can be assumed 100 psf	
7	Live load on slab (psf)	100	See codes to have better idea.	
8	Length of B1 beam clear span (ft)	10		
9	Bottom width of B1 beam (in)	10		
10	Height of B1 beam below slab (in)	12		
11	Length of B2 beam clear span (ft)	15		
12	Bottom width of B2 beam (in)	12		
13	Height of B2 beam below slab (in)	12		Legends
14	Column width (in)	16		Green lines indicate the total area
15	Column length (in)	16		Red dotted lines indicate the beams
16	Column height (ft)	10		Black rectangle indicates the column
17	No. of floors	5		White portions are slabs
18		Result		
19	Total loads of column (kip)	17.44		
20	Conversion units	1 kg/cm2 = 2048.197 psf ; 1000 psf = 1 ksf ; 1Tsf = 2.24 ksf		
21				
22	**Calculation for slab**			
23				
24	Self weight of slab	0.2		
25				

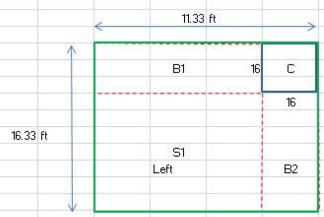


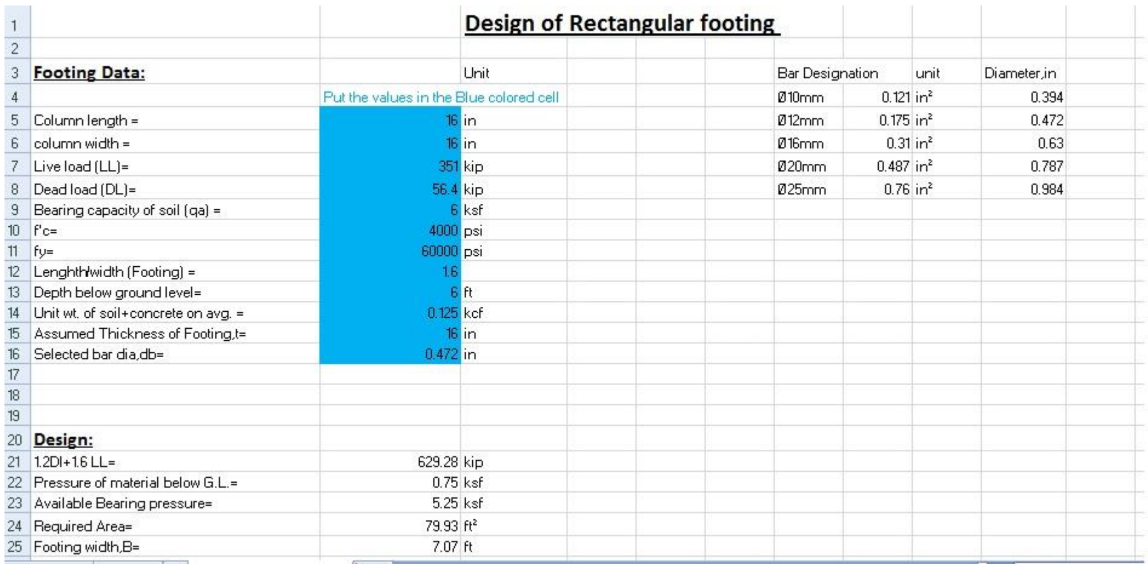
Figure 4.3 (i): Load Calculation For Foundation (Exterior Column with Two beams) excel file Screenshot

26	**Calculation for B1 beam at lower side**		
27	Self weight of the B1 beam (kip/ft)	0.125	
28	short direction=	10	
29	long direction=	15	
30	m=	0.67	
31		Triangular	Trapezoidal
32	Amount of load=	0.67	0.85
33	load pattern on B1 (from Lower slab)	Triangular	
34	Loads on B1 from the lower side slab	0.67	
35	Total loads on B1 Beam (kip/ft)	0.79	
36			
37	**Calculation for B2 beam at right side**		
38	Self weight of the B2 beam (kip/ft)	0.15	
39	short direction=	10	
40	long direction=	15	
41	m=	0.67	
42		Triangular	Trapezoidal
43	Amount of load=	0.67	0.85
44	load pattern on B2 (from right slab)	Trapezoidal	
45	Loads on B2 from the right side slab (kip/ft)	0.85	
46			
47	Self weight of column (kip)	2.67	
48	Total loads of column (kip)	17.44	
49			
50			
51			
52			

Figure 4.3 (j): Load Calculation For Foundation (Exterior Column with Two beams) excel file Screenshot

4.2.2 Rectangular Foundation Design

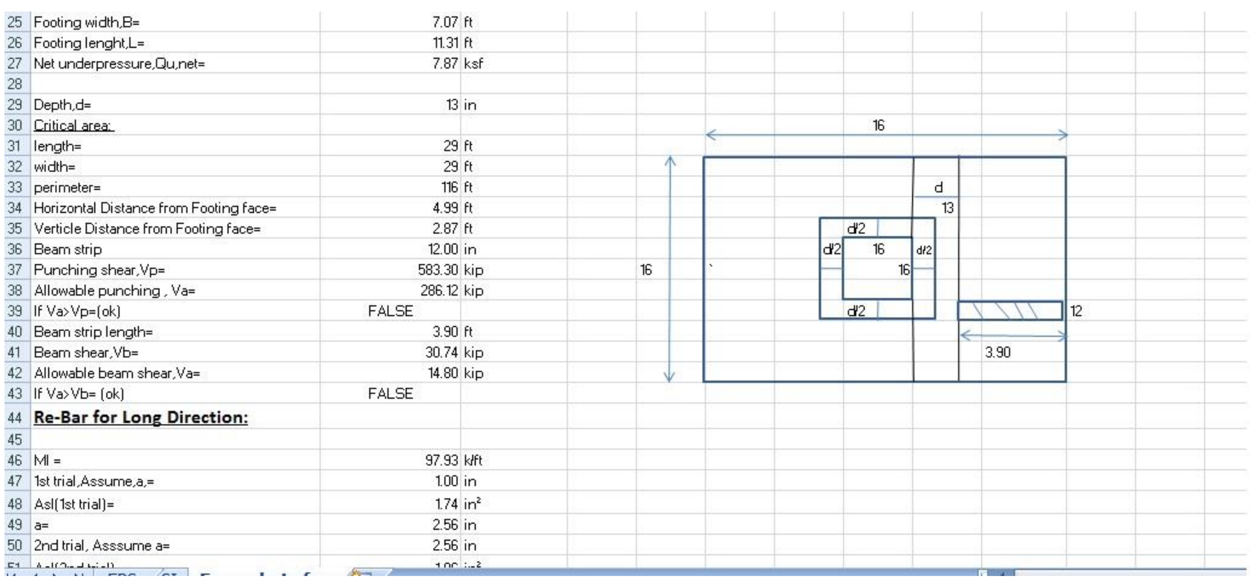
Users have to input his / her data in the blue colored cell. Among inputs there are-column width, column length, bearing capacity of soil, dead and live loads etc .Green colored cell is indicating the required result. Designs are performed in both FPS and SI units. Both are mentioned in the excel file in two different sheets. Requires Data like steel area, bearing capacity values for different soils etc are added so that users can easily input their required values. Figures are included with reinforcement detailing. A Design example is also being added for better understanding.



Design of Rectangular footing

Footing Data:		Unit	Bar Designation	unit	Diameter,in
	Put the values in the Blue colored cell		Ø10mm	0.121 in²	0.394
Column length =	16	in	Ø12mm	0.175 in²	0.472
column width =	16	in	Ø16mm	0.31 in²	0.63
Live load (LL)=	351	kip	Ø20mm	0.487 in²	0.787
Dead load (DL)=	56.4	kip	Ø25mm	0.76 in²	0.984
Bearing capacity of soil (qa) =	6	ksf			
f'c=	4000	psi			
fy=	60000	psi			
Lenghth/width (Footing) =	1.6				
Depth below ground level=	6	ft			
Unit wt. of soil+concrete on avg. =	0.125	kcf			
Assumed Thickness of Footing,t=	16	in			
Selected bar dia,db=	0.472	in			
Design:					
1.2Dl+1.6 LL=	629.28	kip			
Pressure of material below G.L.=	0.75	ksf			
Available Bearing pressure=	5.25	ksf			
Required Area=	79.93	ft²			
Footing width,B=	7.07	ft			

Figure 4.4 (a): Rectangular Foundation design excel file screenshot



Footing width,B=	7.07	ft
Footing lenght,L=	11.31	ft
Net underpressure,Qu,net=	7.87	ksf
Depth,d=	13	in
Critical area:		
length=	29	ft
width=	29	ft
perimeter=	116	ft
Horizontal Distance from Footing face=	4.99	ft
Verticle Distance from Footing face=	2.87	ft
Beam strip	12.00	in
Punching shear,Vp=	583.30	kip
Allowable punching , Va=	286.12	kip
If Va>Vp=(ok)	FALSE	
Beam strip length=	3.90	ft
Beam shear,Vb=	30.74	kip
Allowable beam shear,Va=	14.80	kip
If Va>Vb= (ok)	FALSE	
Re-Bar for Long Direction:		
Ml =	97.93	k/ft
1st trial,Assume,a,=	1.00	in
Asl(1st trial)=	1.74	in²
a=	2.56	in
2nd trial, Asssume a=	2.56	in

Figure 4.4 (b): Rectangular Foundation design excel file screenshot

49	a=	2.56	in
50	2nd trial, Asssume a=	2.56	in
51	Asl(2nd trial)=	1.86	in²
52	a=	2.73	in
53	Final Asl=	1.87	in²
54	As min=	0.52	in²
55	Areq=	1.87	in² Green cell indicates the required steel area
56	If Asl>Asmin=Al; controls	TRUE	
57	If Asl<Asmin=Asmin; controls	FALSE	
58	Reinforcement dia for AS	20.00	mm
59	use ϕ20mm @	3.00	in C/C
60			
61			
62			
63	**Re-Bar for Short Direction:**		
64			
65			
66	Ms=	32.36	k/ft
67	1st trial,Assume,a=	1.00	in
68	Ass(1st trial)=	0.58	in²
69	a=	0.85	in
70	2nd trial,Assume a=	0.85	in
71	Ass(2nd trial)=	0.57	in²
72	a=	0.84	in
73	Final Ass=	0.57	in²
74	As min=	0.48	in²

Figure 4.4 (c): Rectangular Foundation design excel file screenshot

70	2nd trial,Assume a=	0.85	in
71	Ass(2nd trial)=	0.57	in²
72	a=	0.84	in
73	Final Ass=	0.57	in²
74	As min=	0.48	in²
75	As req=	0.57	in²
76	If Ass>Asmin=Al; controls	TRUE	
77	If Ass<Asmin=Asmin; controls	FALSE	
78	Perpendicular distance of short size=	11.31	ft
79	Total As in short direction=	6.47	in
80			
81	Long distance of footing=	11.31	ft
82	short distance of footing=	7.07	ft
83	β=	1.60	
84	As band=	4.97	in²
85	As band per feet=	0.70	in²
86	Reinforcement dia for AS	20.00	mm
87	use ϕ20mm @	8.00	in C/C
88	As rest	1.49	in²
89	As rest per feet=	0.35	in²
90	Reinforcement dia for AS	20.00	mm
91	use ϕ20mm @	16.00	in C/C
92			
93	Min. Lap slice length=	14.16	in²
94			

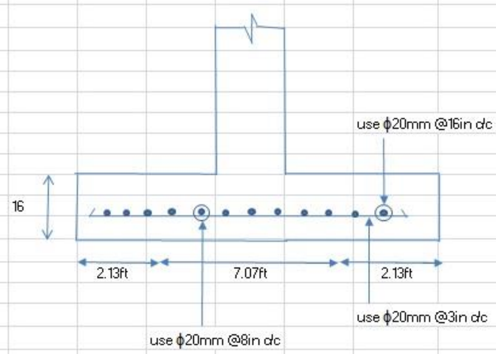


Figure 4.4 (d): Rectangular Foundation design excel file screenshot

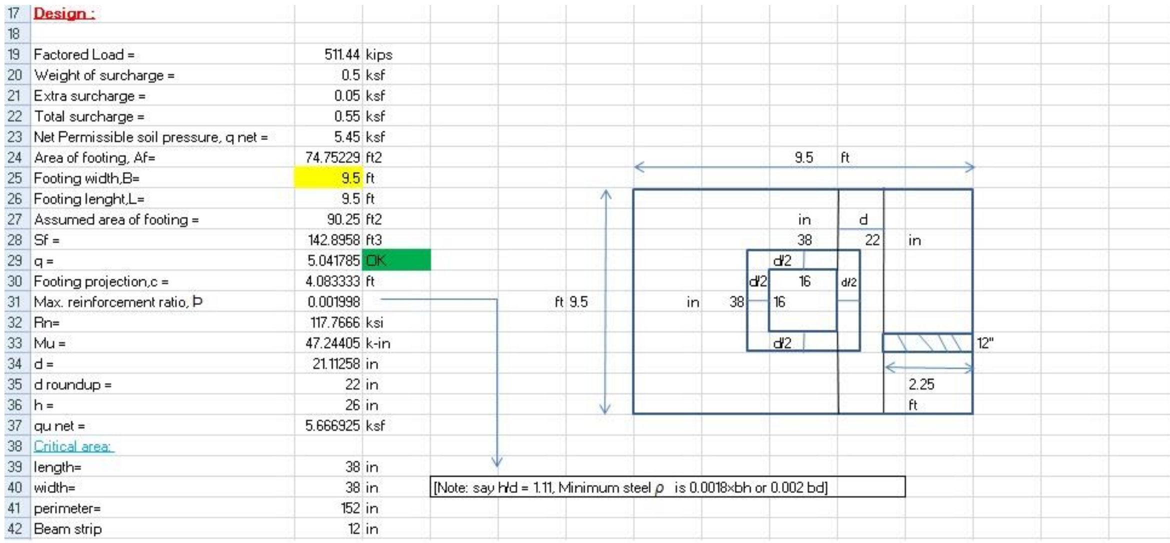
4.2.3 Square Footing Design

Square footings or foundation are one of the most used foundations. The reinforcement is uniformly distributed over the width of footing in each of the two layers in square foundations. The spacing's of the bars are constant. The moments for which the two layers are designed are the same. However the effective depth d for the upper layer is less by 1 bar diameter than that of the lower layer. Instead of using different spacing or different bar diameters in each of the two layers, it is customary to determine as based on average depth and to use the same arrangement of the reinforcement for both layers.

Users have to input his / her data in the yellow colored cell. Green colored cell is indicating the required result. Designs are performed in FPS unit. Required Data like steel area (marked by box), bearing capacity values for different soils etc are added so that users can easily input their requires values. Figures are included with reinforcement detailing. A Design example is given for better understanding.

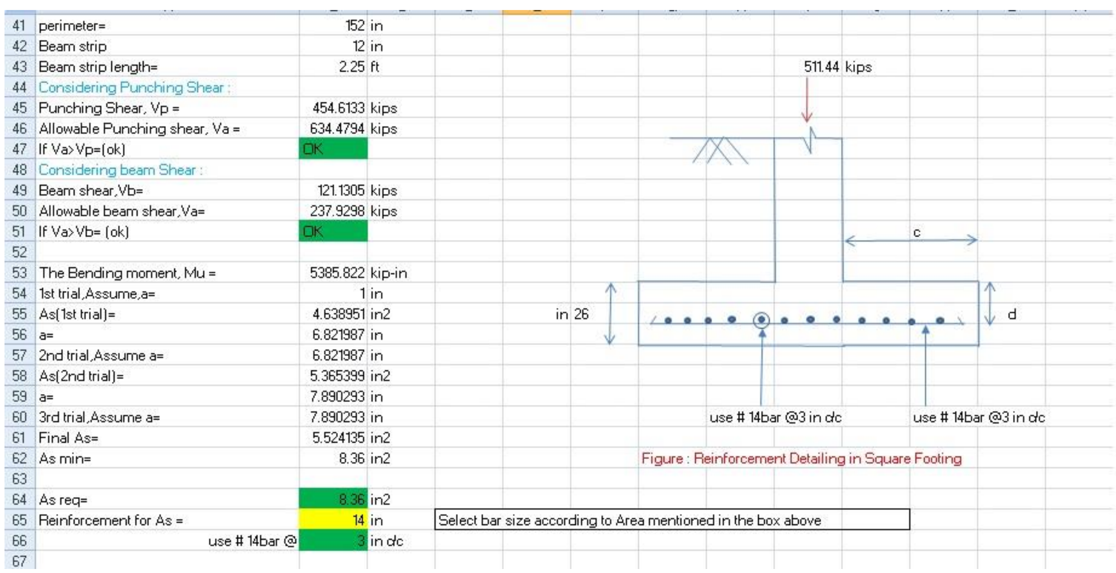
1			Design of Square Footing			
2						
3	Given Data :		Unit			
4		Put the values in the Yellow coloured cell		Bar Designation		Unit
5	Footing below G.L. =	5	ft	#3	0.11	in^2
6	Permissible soil pressure, qa =	6	ksf	#4	0.2	in^2
7	Service surcharge =	50	pcf	#5	0.31	in^2
8	Wt. of soil & concrete above footing =	100	pcf	#6	0.44	in^2
9	Column Length =	16	in	#7	0.6	in^2
10	Column width =	16	in	#8	0.79	in^2
11	f'c =	4000	psi	#9	1	in^2
12	fy =	60000	psi	#10	1.27	in^2
13	Dead load =	351	kips	#11	1.56	in^2
14	Live load =	56.4	kips	#14	2.25	in^2
15	Service moment =	75.4	kip-ft	#18	4	in^2
16						
17	Design :					

Figure 4.5 (a): Square Foundation design excel file screenshot



17	**Design :**		
18			
19	Factored Load =	511.44	kips
20	Weight of surcharge =	0.5	ksf
21	Extra surcharge =	0.05	ksf
22	Total surcharge =	0.55	ksf
23	Net Permissible soil pressure, q net =	5.45	ksf
24	Area of footing, Af=	74.75229	ft2
25	Footing width,B=	9.5	ft
26	Footing lenght,L=	9.5	ft
27	Assumed area of footing =	90.25	ft2
28	Sf =	142.8958	ft3
29	q =	5.041785	OK
30	Footing projection,c =	4.083333	ft
31	Max. reinforcement ratio, Þ	0.001998	
32	Rn=	117.7666	ksi
33	Mu =	47.24405	k-in
34	d =	21.11258	in
35	d roundup =	22	in
36	h =	26	in
37	qu net =	5.666925	ksf
38	Critical area:		
39	length=	38	in
40	width=	38	in
41	perimeter=	152	in
42	Beam strip	12	in

Figure 4.5 (b): Square Foundation design excel file screenshot



41	perimeter=	152	in
42	Beam strip	12	in
43	Beam strip length=	2.25	ft
44	Considering Punching Shear :		
45	Punching Shear, Vp =	454.6133	kips
46	Allowable Punching shear, Va =	634.4794	kips
47	If Va>Vp=(ok)	OK	
48	Considering beam Shear :		
49	Beam shear,Vb=	121.1305	kips
50	Allowable beam shear,Va=	237.9298	kips
51	If Va>Vb= (ok)	OK	
52			
53	The Bending moment, Mu =	5385.822	kip-in
54	1st trial,Assume,a=	1	in
55	As(1st trial)=	4.638951	in2
56	a=	6.821987	in
57	2nd trial,Assume a=	6.821987	in
58	As(2nd trial)=	5.365399	in2
59	a=	7.890293	in
60	3rd trial,Assume a=	7.890293	in
61	Final As=	5.524135	in2
62	As min=	8.36	in2
63			
64	As req=	8.36	in2
65	Reinforcement for As =	14	in
66	use # 14bar @	3	in c/c
67			

Figure 4.5 (c): Square Foundation design excel file screenshot

4.2.4 Website on Isolated Foundation Design

As early said, A website has been created on Foundation design providing all our works into it including design calculations in excel files (Screen shots are mentioned above). This website contains eight tabs with different topics. We are still working on modifying the website to make it better to best and trying to add more and more information regarding foundation and its design. The screenshots of the websites are shown below:

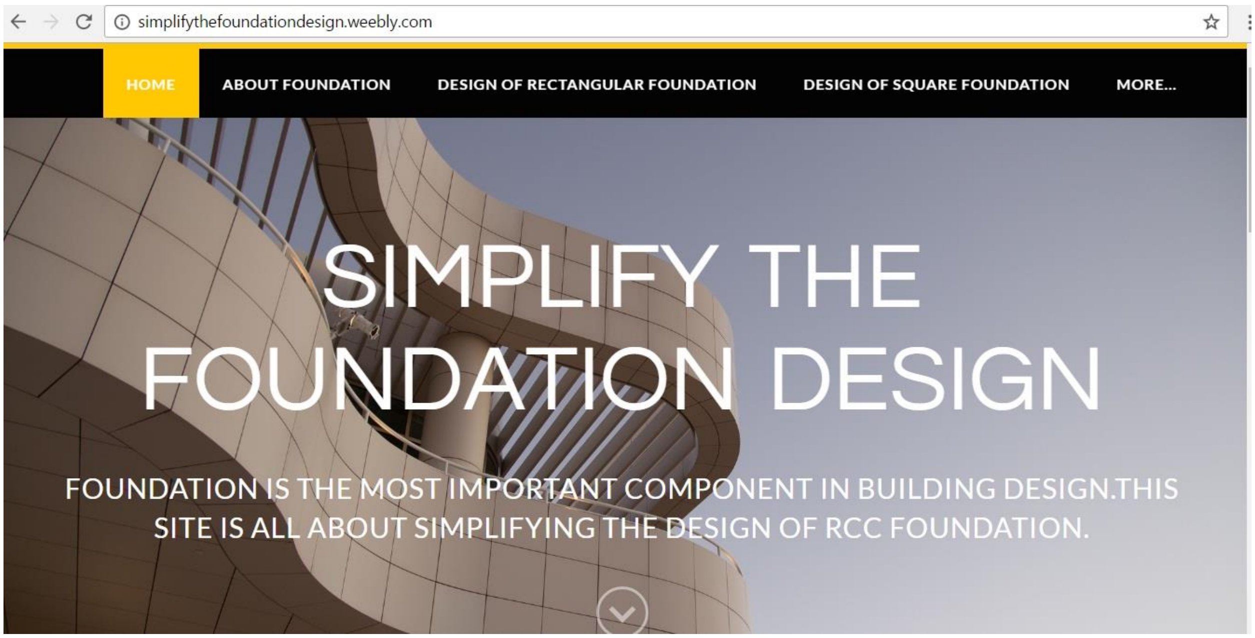


Figure 4.6 (a): Home page of Simplify the foundation design web page screenshot

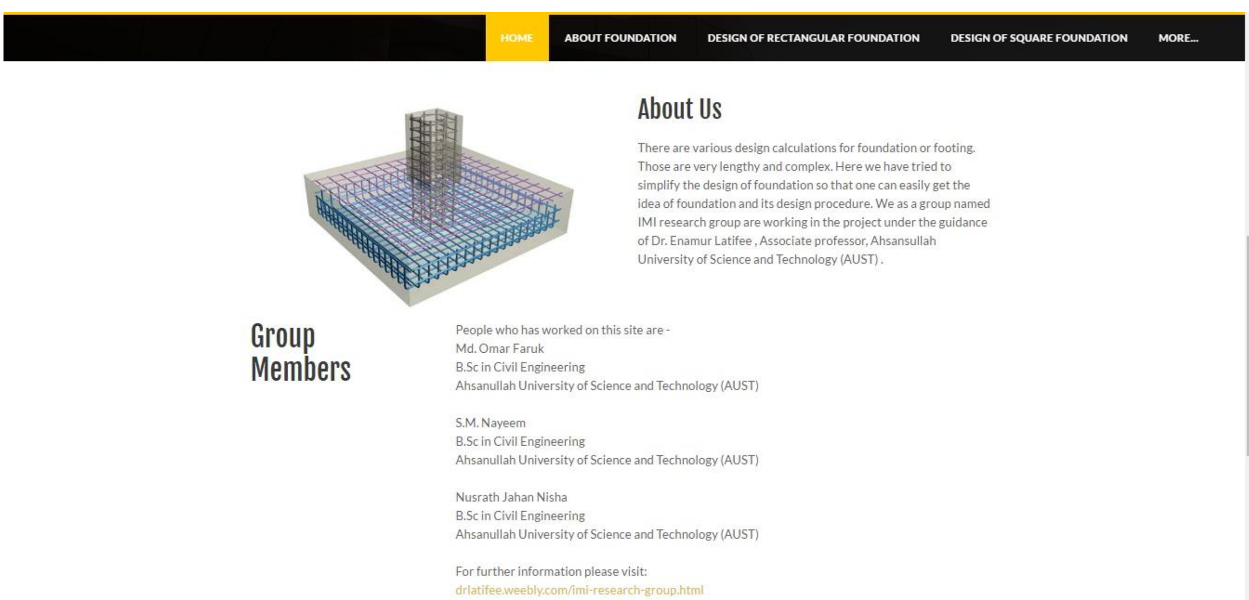


Figure 4.6 (b): Simplify the foundation design web page screenshot

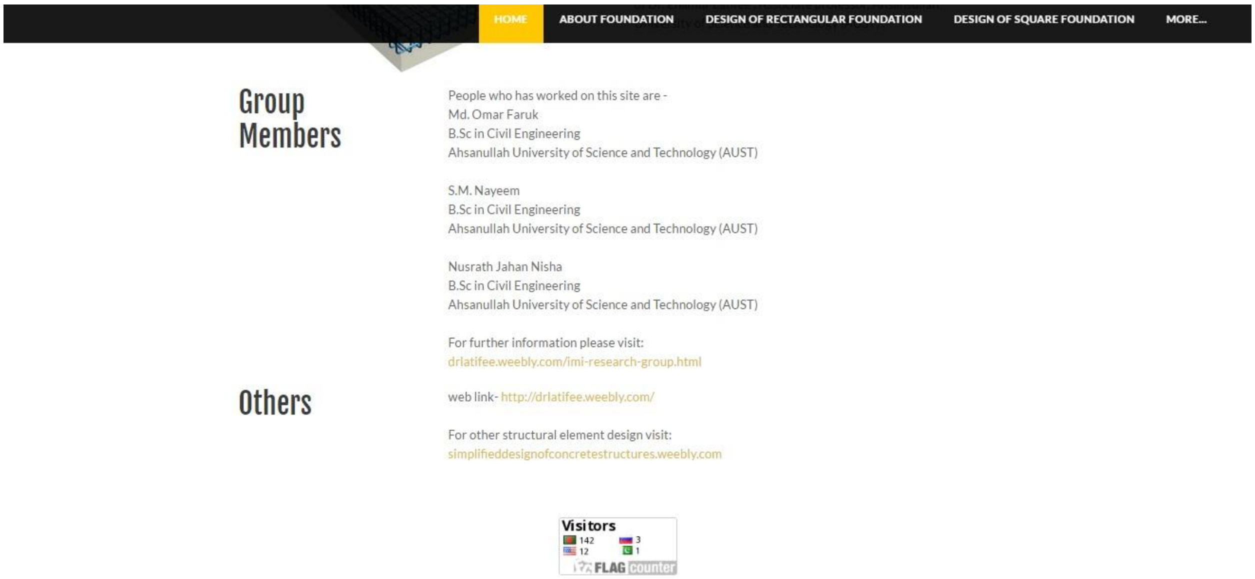


Figure 4.6 (c): Simplify the foundation design web page screenshot

Figure 4.6 (d): Simplify the foundation design web page screenshot

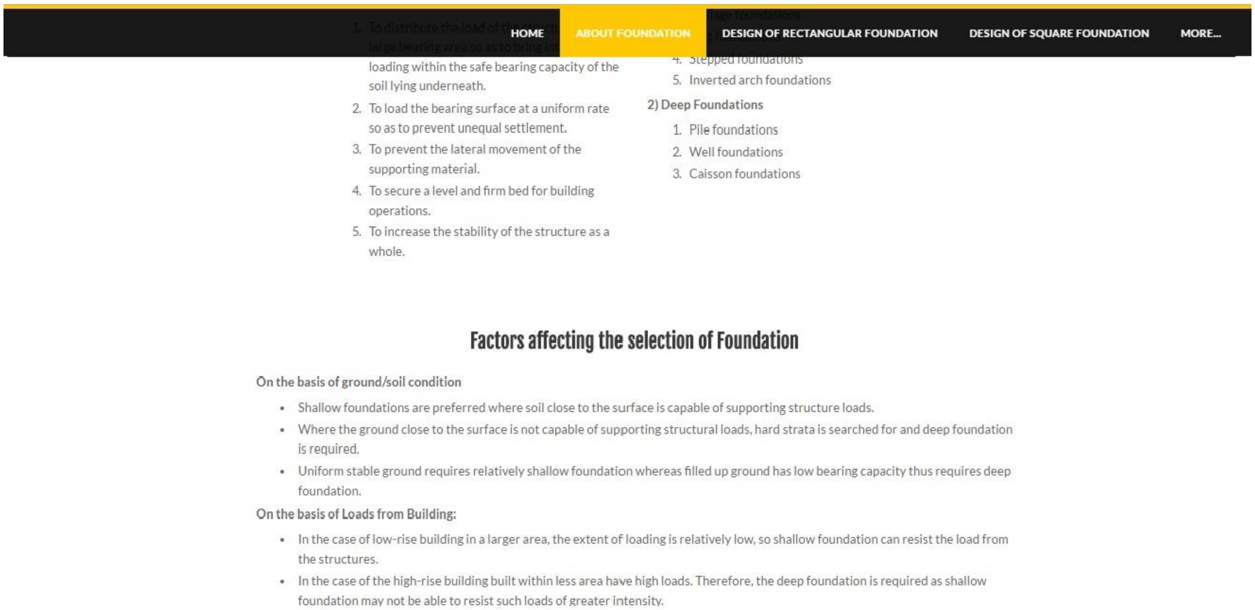


Figure 4.6 (e): Simplify the foundation design web page screenshot

Figure 4.6 (f): Simplify the foundation design web page screenshot

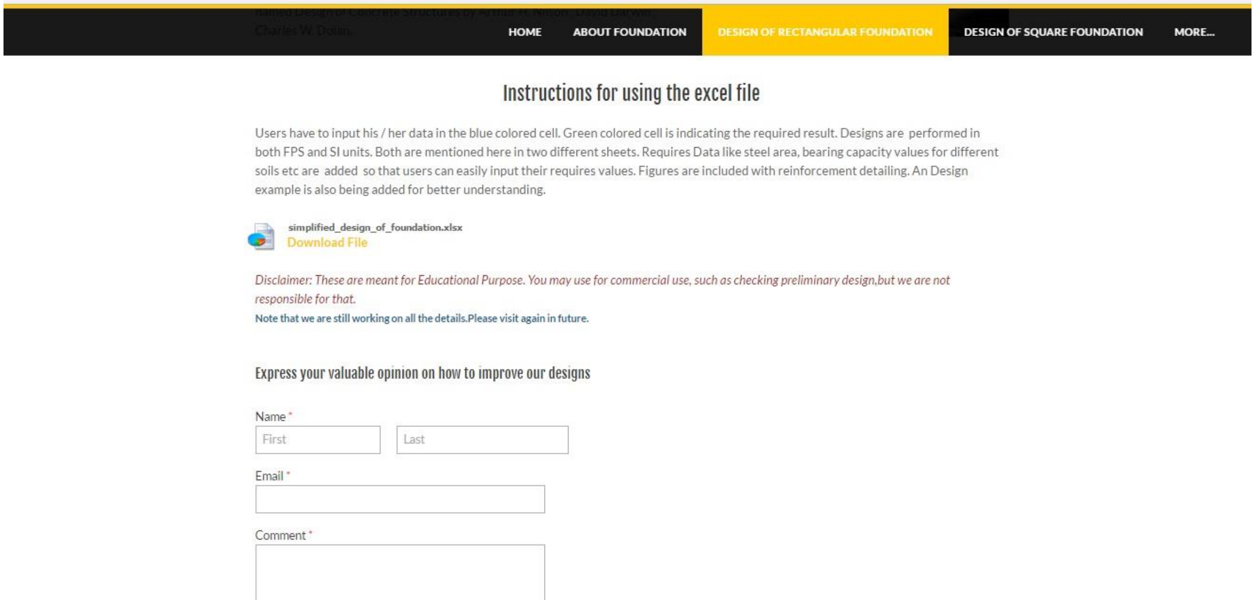


Figure 4.6 (g): Simplify the foundation design web page screenshot

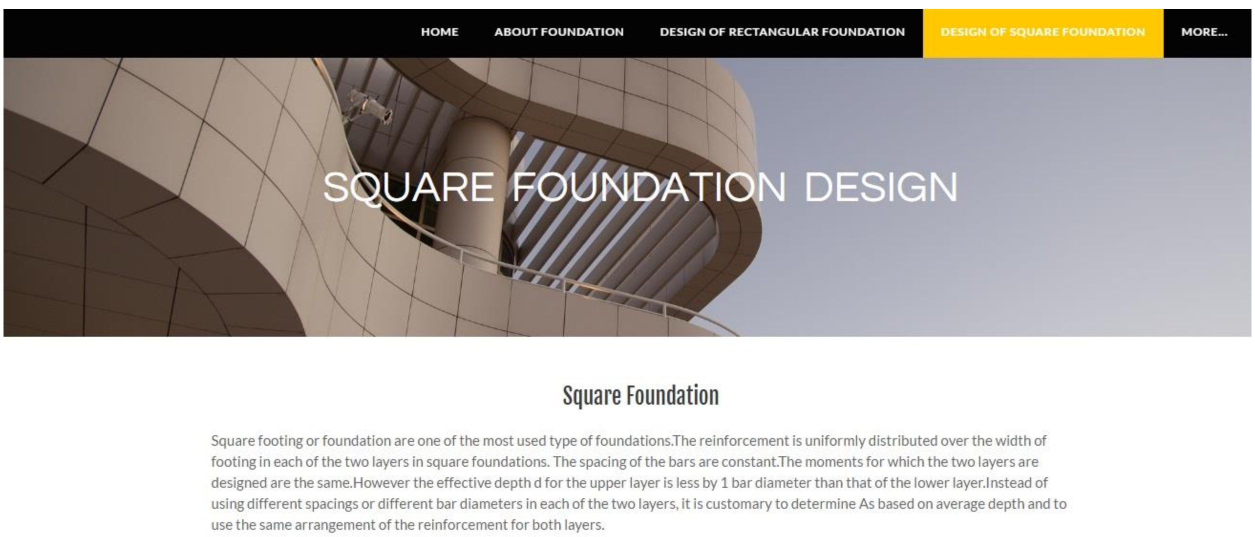


Figure 4.6 (h): Simplify the foundation design web page screenshot

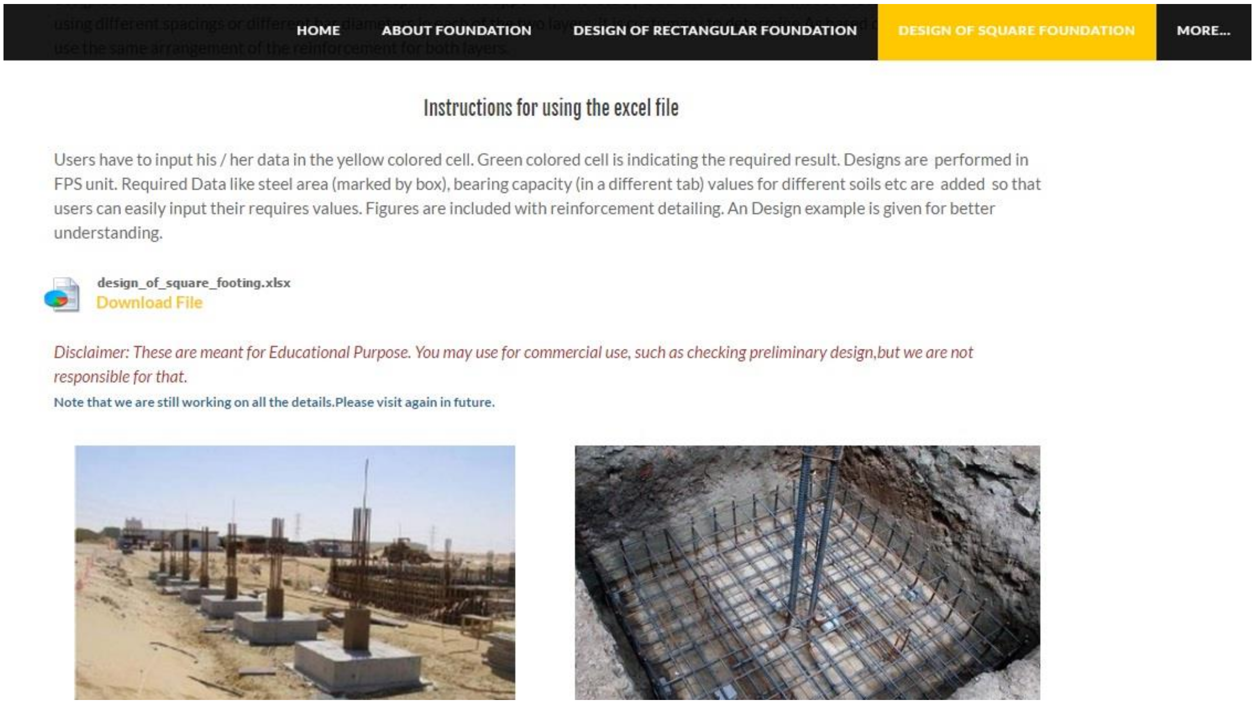


Figure 4.6 (i): Simplify the foundation design web page screenshot

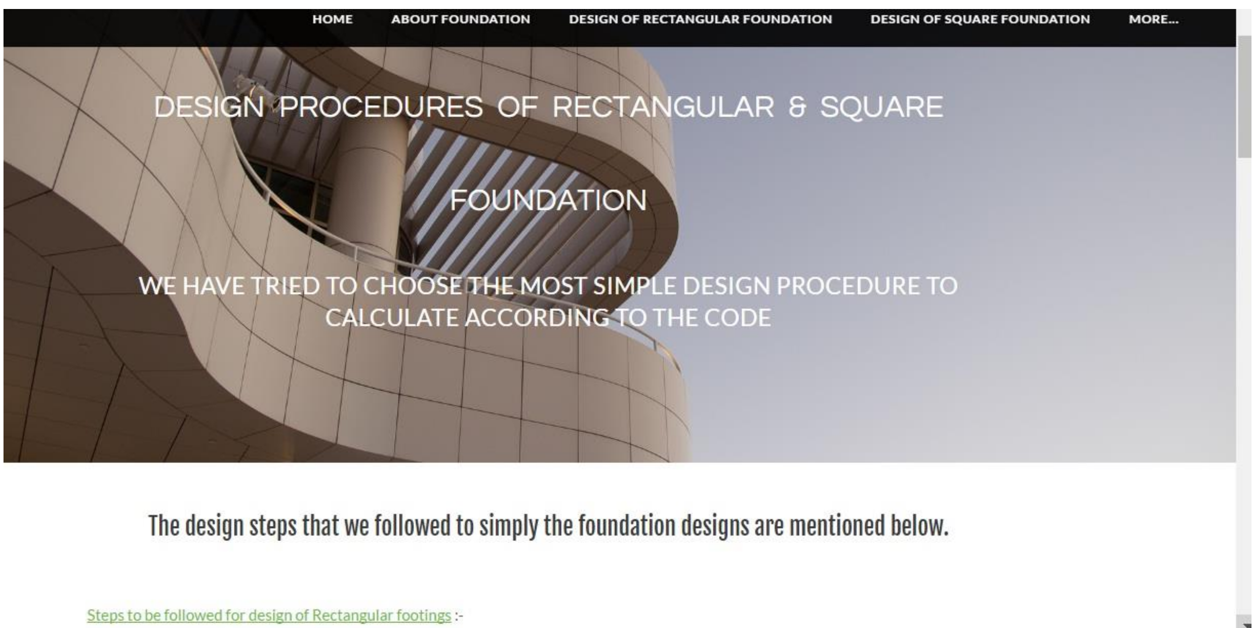
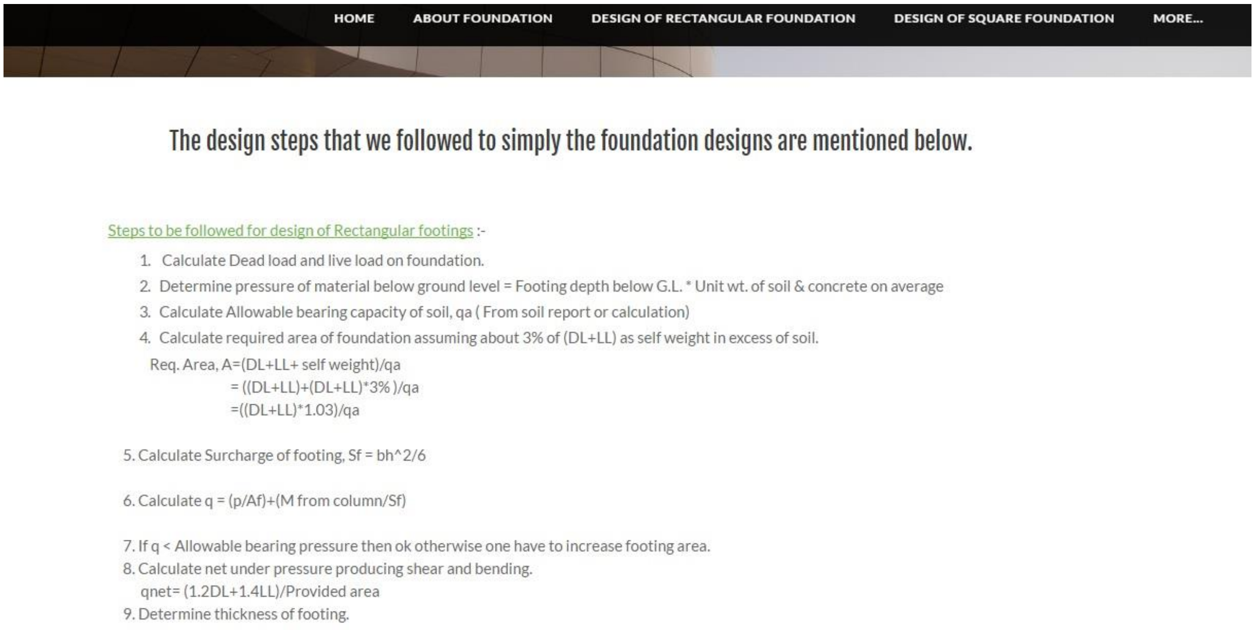


Figure 4.6 (j): Simplify the foundation design web page screenshot


HOME ABOUT FOUNDATION DESIGN OF RECTANGULAR FOUNDATION DESIGN OF SQUARE FOUNDATION MORE...

The design steps that we followed to simply the foundation designs are mentioned below.

Steps to be followed for design of Rectangular footings :-

1. Calculate Dead load and live load on foundation.
2. Determine pressure of material below ground level = Footing depth below G.L. * Unit wt. of soil & concrete on average
3. Calculate Allowable bearing capacity of soil, qa (From soil report or calculation)
4. Calculate required area of foundation assuming about 3% of (DL+LL) as self weight in excess of soil.

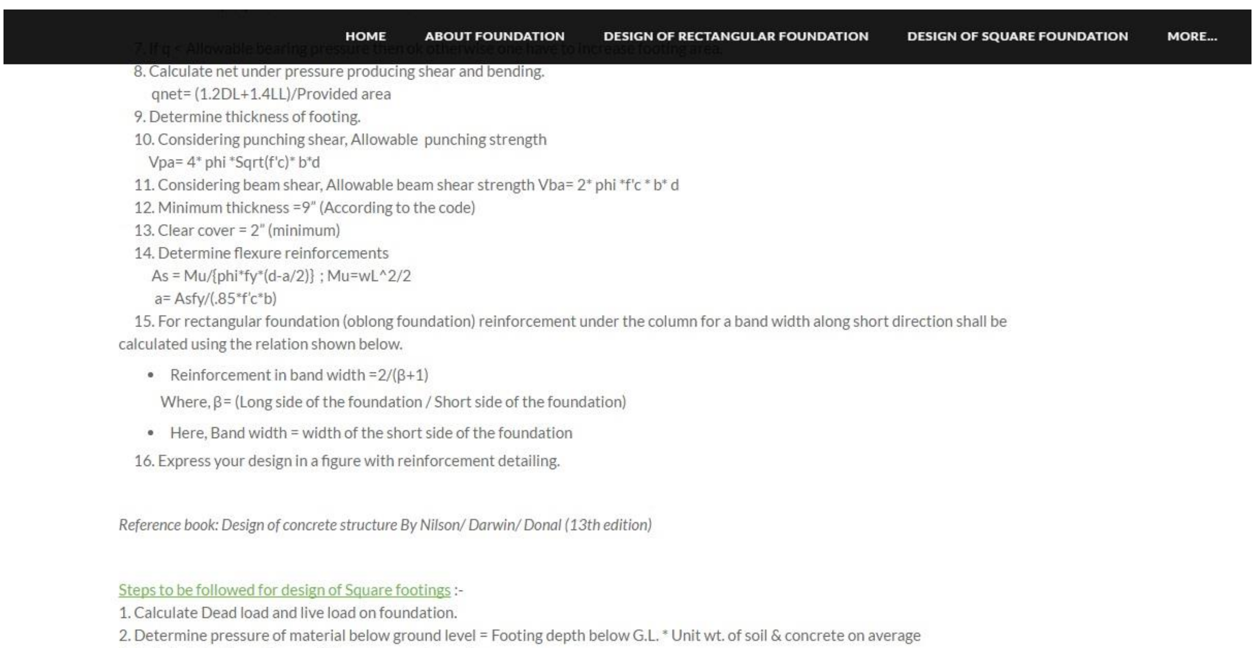
Req. Area, A=(DL+LL+ self weight)/qa
= ((DL+LL)+(DL+LL)*3%)/qa
=((DL+LL)*1.03)/qa

5. Calculate Surcharge of footing, Sf = bh^2/6

6. Calculate q = (p/Af)+(M from column/Sf)

7. If q < Allowable bearing pressure then ok otherwise one have to increase footing area.
8. Calculate net under pressure producing shear and bending.
qnet= (1.2DL+1.4LL)/Provided area
9. Determine thickness of footing.

Figure 4.6 (k): Simplify the foundation design web page screenshot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8. Calculate net under pressure producing shear and bending.
qnet= (1.2DL+1.4LL)/Provided area
9. Determine thickness of footing.
10. Considering punching shear, Allowable punching strength
Vpa= 4* phi *Sqrt(f'c)* b*d
11. Considering beam shear, Allowable beam shear strength Vba= 2* phi *f'c * b* d
12. Minimum thickness =9" (According to the code)
13. Clear cover = 2" (minimum)
14. Determine flexure reinforcements
As = Mu/{phi*fy*(d-a/2)} ; Mu=wL^2/2
a= Asfy/(.85*f'c*b)
15. For rectangular foundation (oblong foundation) reinforcement under the column for a band width along short direction shall be calculated using the relation shown below.

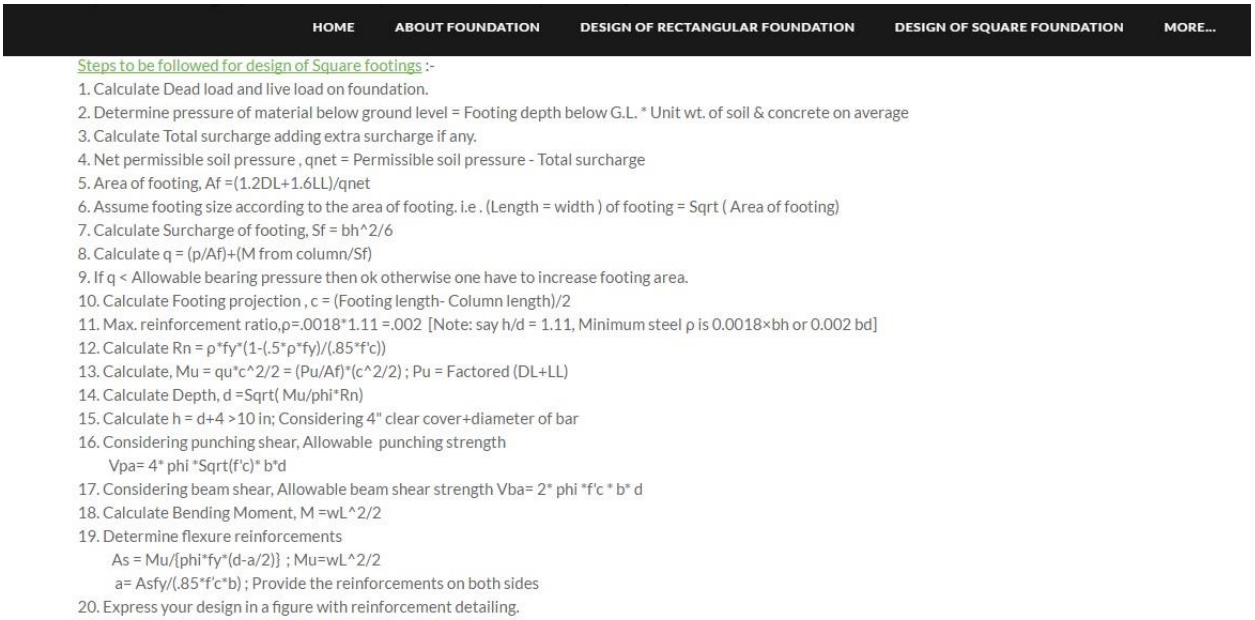
- Reinforcement in band width =2/(β+1)
  Where, β= (Long side of the foundation / Short side of the foundation)
- Here, Band width = width of the short side of the foundation

16. Express your design in a figure with reinforcement detailing.

Reference book: Design of concrete structure By Nilson/ Darwin/ Donal (13th edition)

Steps to be followed for design of Square footings :-
1. Calculate Dead load and live load on foundation.
2. Determine pressure of material below ground level = Footing depth below G.L. * Unit wt. of soil & concrete on average

Figure 4.6 (l): Simplify the foundation design web page screenshot



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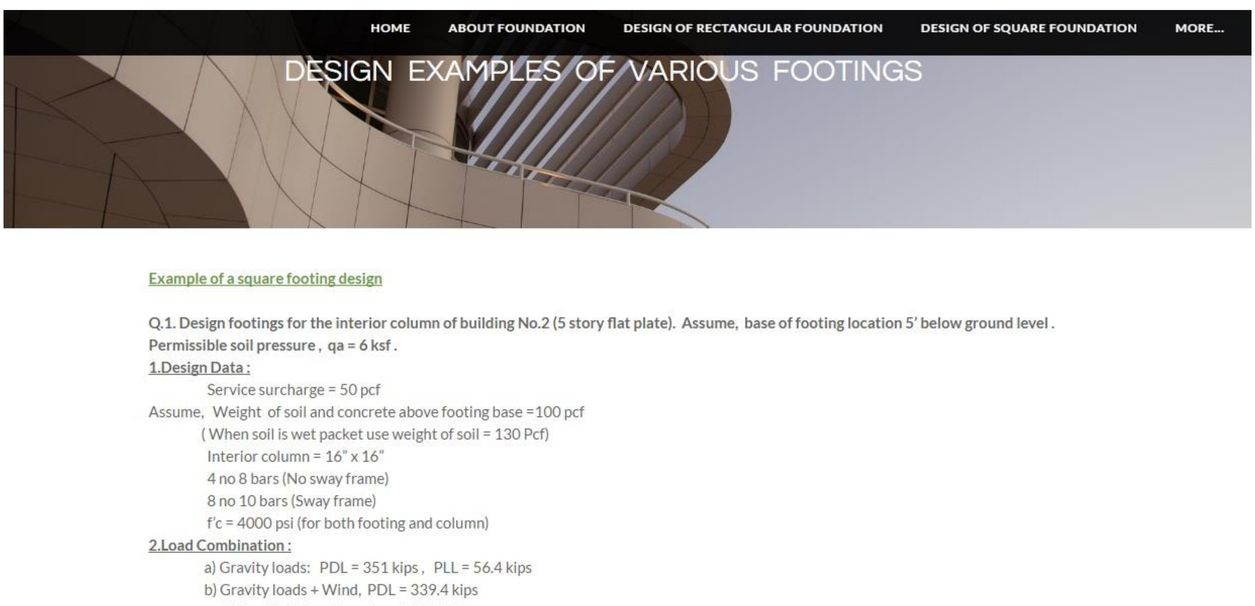
Steps to be followed for design of Square footings :-

1. Calculate Dead load and live load on foundation.
2. Determine pressure of material below ground level = Footing depth below G.L. * Unit wt. of soil & concrete on average
3. Calculate Total surcharge adding extra surcharge if any.
4. Net permissible soil pressure , qnet = Permissible soil pressure - Total surcharge
5. Area of footing, Af =(1.2DL+1.6LL)/qnet
6. Assume footing size according to the area of footing. i.e . (Length = width) of footing = Sqrt (Area of footing)
7. Calculate Surcharge of footing, Sf = bh^2/6
8. Calculate q = (p/Af)+(M from column/Sf)
9. If q < Allowable bearing pressure then ok otherwise one have to increase footing area.
10. Calculate Footing projection , c = (Footing length- Column length)/2
11. Max. reinforcement ratio,ρ=.0018*1.11 =.002 [Note: say h/d = 1.11, Minimum steel ρ is 0.0018×bh or 0.002 bd]
12. Calculate Rn = ρ*fy*(1-(.5*ρ*fy)/(.85*f'c))
13. Calculate, Mu = qu*c^2/2 = (Pu/Af)*(c^2/2) ; Pu = Factored (DL+LL)
14. Calculate Depth, d =Sqrt(Mu/phi*Rn)
15. Calculate h = d+4 >10 in; Considering 4" clear cover+diameter of bar
16. Considering punching shear, Allowable punching strength
    Vpa= 4* phi *Sqrt(f'c)* b*d
17. Considering beam shear, Allowable beam shear strength Vba= 2* phi *f'c * b* d
18. Calculate Bending Moment, M =wL^2/2
19. Determine flexure reinforcements
    As = Mu/{phi*fy*(d-a/2)} ; Mu=wL^2/2
    a= Asfy/(.85*f'c*b) ; Provide the reinforcements on both sides
20. Express your design in a figure with reinforcement detailing.

Figure 4.6 (m): Simplify the foundation design web page screenshot



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DESIGN EXAMPLES OF VARIOUS FOOTINGS

Example of a square footing design

Q.1. Design footings for the interior column of building No.2 (5 story flat plate). Assume, base of footing location 5' below ground level . Permissible soil pressure , qa = 6 ksf .

1.Design Data :

Service surcharge = 50 pcf

Assume, Weight of soil and concrete above footing base =100 pcf

(When soil is wet packet use weight of soil = 130 Pcf)

Interior column = 16" x 16"

4 no 8 bars (No sway frame)

8 no 10 bars (Sway frame)

f'c = 4000 psi (for both footing and column)

2.Load Combination :

a) Gravity loads: PDL = 351 kips , PLL = 56.4 kips

b) Gravity loads + Wind, PDL = 339.4 kips

PLL = 56.4 kips , Mservice = 75.4 k-ft

Figure 4.6 (n): Simplify the foundation design web page screenshot f'c = 4000 psi (for both footing and column)

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2.Load Combination :

a) Gravity loads: PDL = 351 kips , PLL = 56.4 kips

b) Gravity loads + Wind, PDL = 339.4 kips

PLL = 56.4 kips , Mservice = 75.4 k-ft

3. Base Area Footing :

weight of surcharge = (0.100 x 5) = 0.5 ksf

extra surcharge = 50 psf =0.05 ksf

[If there is no extra surcharge, ignore this term]

Total surcharge = (0.5+0.05) = 0.55 ksf

So, Net permissible soil pressure = (6 – 0.55) = 5.45 ksf

Area of footing , Af = (351+56.4)/5.45 = 74.75 sq. ft.

Try 9' x 9' square footing . (Af = 81 sq. ft.)

Now, we know , Sectional Modulus , S = I/C

or, S = I/C = (bh3/1 2) / (h/ 2)

so, **S = bh2/6**

S = (9*9^2)/6 = 121.5 ft3

As, Af = 81 ft2

Now, q = p/Af+M/Sf

=((351+56.4)/81)+(75.4/121.5)

= 5.65 > 5.45 (Not ok)

Try, 9.5' x 9.5' square footing (Af = 90.25 ft2)

q =((351+56.4)/90.25)+(75.4/142.2)

= 5.04 < 5.45 (Ok)

4. Footing Thickness :

Footing projection , c =(9.5-(16/12))/2

Now, ρ = 0.0018 x 1.11 = 0.002

Rn = ρ fy (1-(.5* ρ fy)/(.85f'c))

Figure 4.6 (o): Simplify the foundation design web page screenshot

As, Af = 81 ft2

Now, q = p/Af+M/Sf

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=((351+56.4)/81)+(75.4/121.5)

= 5.65 > 5.45 (Not ok)

Try, 9.5' x 9.5' square footing (Af = 90.25 ft2)

q =((351+56.4)/90.25)+(75.4/142.2)

= 5.04 < 5.45 (Ok)

4. Footing Thickness :

Footing projection , c =(9.5-(16/12))/2

Now, ρ = 0.0018 x 1.11 = 0.002

Rn = ρ fy (1 (.5* ρ fy)/(.85f'c))

= 0.002 x 60000 (1-(.5*.002*60000)/(.85*4000))

= 117.9 psi

d^2 required =Mu/(phi*Rn) =(Mu*1000)/(.9*117.9) .... (1)

Again, Mu = (p/Af)(c^2/2) .... (2) (as, (Pu / Af) = qu)

Now, from eqn. (1) , d^2req = 9.43 Mu

= 9.43x(p/Af)(c^2/2) ((from eqn. 2)

dreq =2.17c*Sqrt(p/Af)

so, **drequired = 2.2 c** * Sqrt(p/Af)

h = 2.2 c* Sqrt(p/Af) +4 (considering, 4" clear cover + dia of bar)

h = 2.2 *4.08*Sqrt(1.2*351+1.6*56.4/90.25) + 4

= 25.4 in > 10 in (Ok)

Try, h = 27 in.

So, d = (27-4) in

= 23 in.

5.Qu net = Factored load/ Area of footing

=(1.2*351+1.6*56.4)/(9.5*9.5) =511.44/90.25 =5.67 ksf

6. Considering punching Shear or Two way shear :

Figure 4.6 (p): Simplify the foundation design web page screenshot

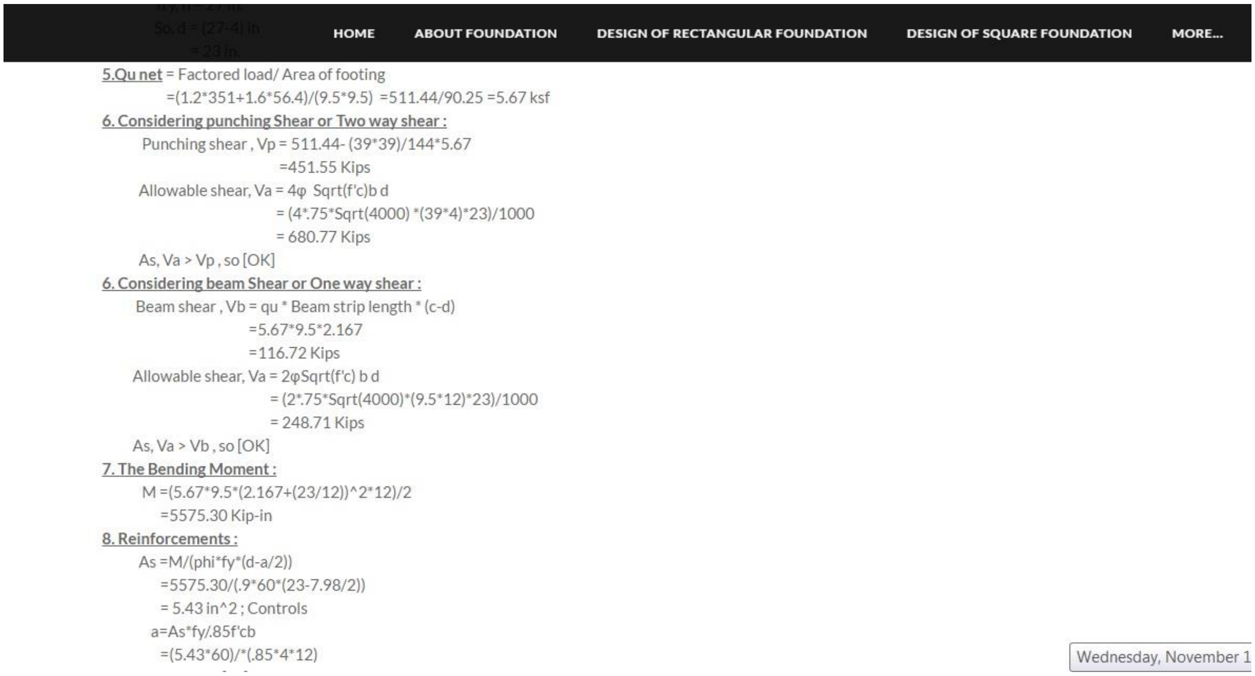


Figure 4.6 (q): Simplify the foundation design web page screenshot

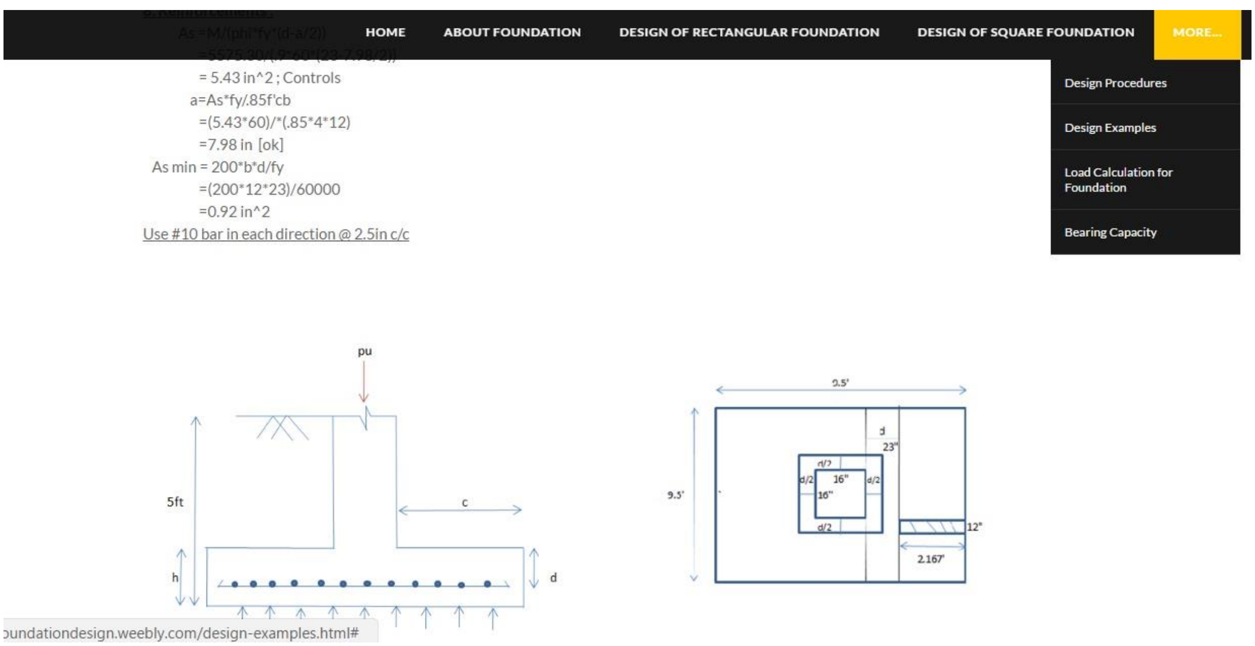


Figure 4.6 (r): Simplify the foundation design web page screenshot

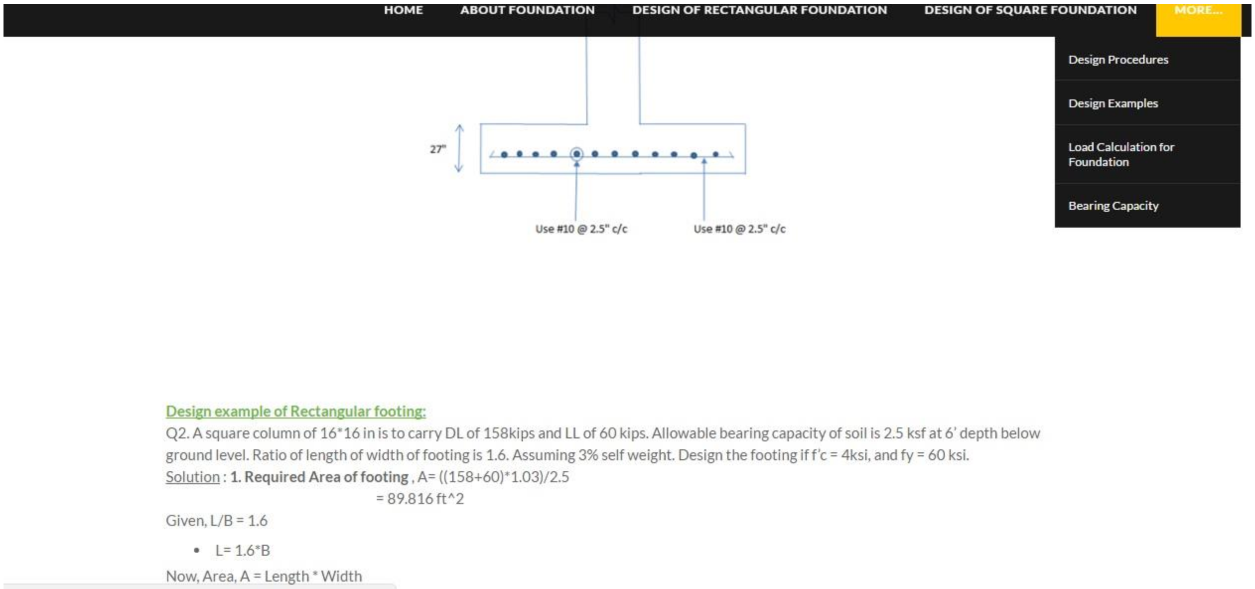


Figure 4.6 (s): Simplify the foundation design web page screenshot

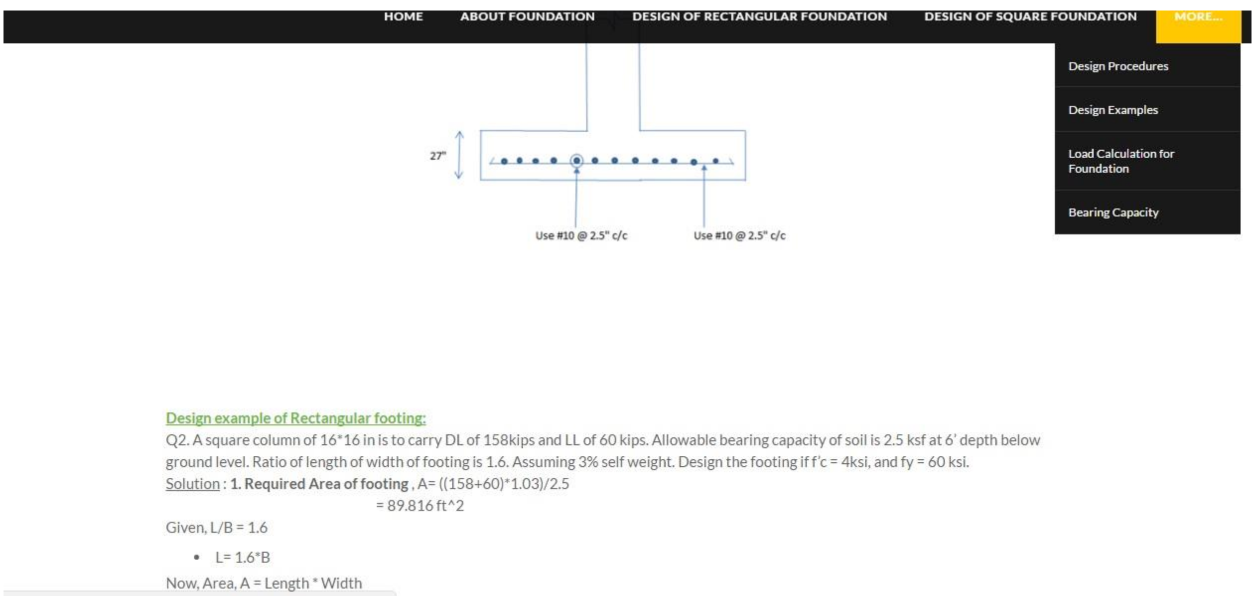
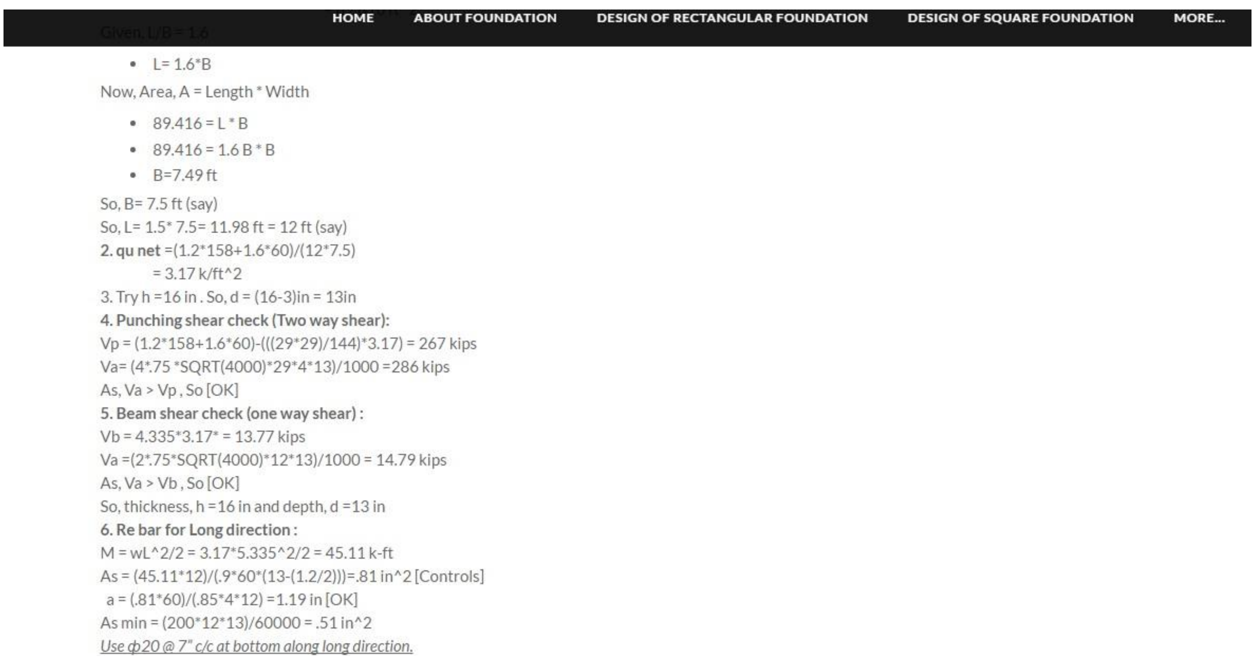


Figure 4.6 (t): Simplify the foundation design web page screenshot



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Given, L/B = 1.6

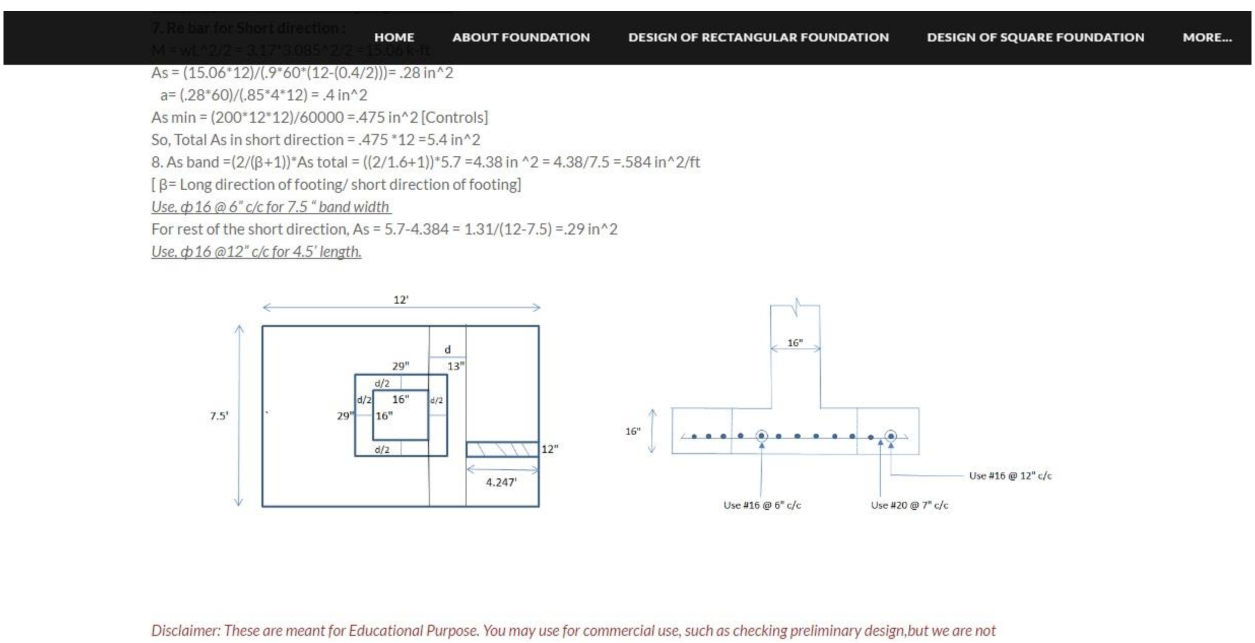
- L= 1.6*B

Now, Area, A = Length * Width

- 89.416 = L * B
- 89.416 = 1.6 B * B
- B=7.49 ft

So, B= 7.5 ft (say)
So, L= 1.5* 7.5= 11.98 ft = 12 ft (say)
2. qu net =(1.2*158+1.6*60)/(12*7.5)
= 3.17 k/ft^2
3. Try h =16 in . So, d = (16-3)in = 13in
4. Punching shear check (Two way shear):
Vp = (1.2*158+1.6*60)-(((29*29)/144)*3.17) = 267 kips
Va= (4*.75 *SQRT(4000)*29*4*13)/1000 =286 kips
As, Va > Vp , So [OK]
5. Beam shear check (one way shear) :
Vb = 4.335*3.17* = 13.77 kips
Va =(2*.75*SQRT(4000)*12*13)/1000 = 14.79 kips
As, Va > Vb , So [OK]
So, thickness, h =16 in and depth, d =13 in
6. Re bar for Long direction :
M = wL^2/2 = 3.17*5.335^2/2 = 45.11 k-ft
As = (45.11*12)/(.9*60*(13-(1.2/2)))=.81 in^2 [Controls]
a = (.81*60)/(.85*4*12) =1.19 in [OK]
As min = (200*12*13)/60000 = .51 in^2
Use ɸ20 @ 7" c/c at bottom along long direction.

Figure 4.6 (u): Simplify the foundation design web page screenshot



7. Re bar for Short direction :
HOME ABOUT FOUNDATION DESIGN OF RECTANGULAR FOUNDATION DESIGN OF SQUARE FOUNDATION MORE...
M = wL^2/2 = 3.17*3.085^2/2 =15.06 k-ft
As = (15.06*12)/(.9*60*(12-(0.4/2)))= .28 in^2
a= (.28*60)/(.85*4*12) = .4 in^2
As min = (200*12*12)/60000 =.475 in^2 [Controls]
So, Total As in short direction = .475 *12 =5.4 in^2
8. As band =(2/(β+1))*As total = ((2/1.6+1))*5.7 =4.38 in ^2 = 4.38/7.5 =.584 in^2/ft
[β= Long direction of footing/ short direction of footing]
Use, ɸ16 @ 6" c/c for 7.5 " band width
For rest of the short direction, As = 5.7-4.384 = 1.31/(12-7.5) =.29 in^2
Use, ɸ16 @12" c/c for 4.5' length.

Disclaimer: These are meant for Educational Purpose. You may use for commercial use, such as checking preliminary design,but we are not

Figure 4.6 (v): Simplify the foundation design web page screenshot

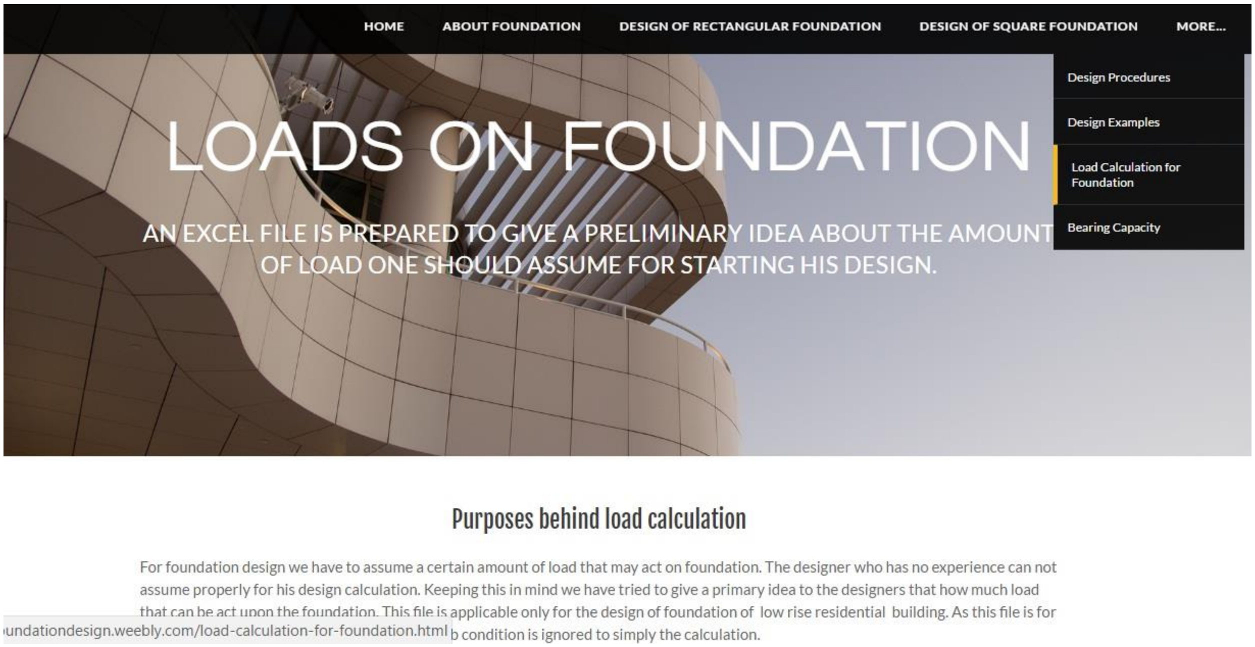


Figure 4.6 (w): Simplify the foundation design web page screenshot

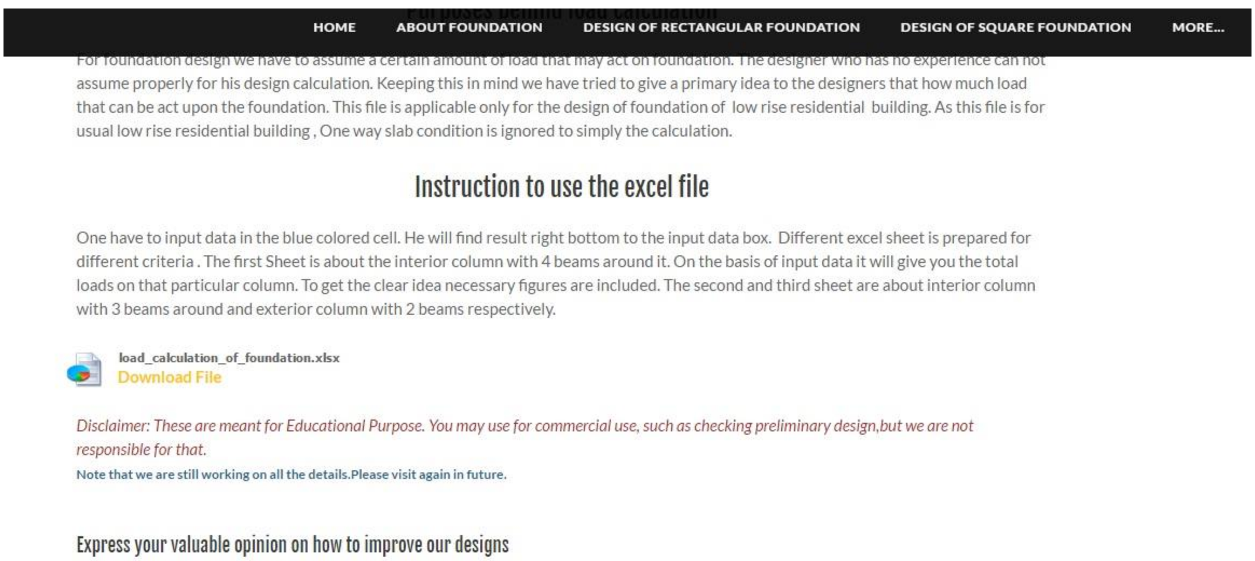
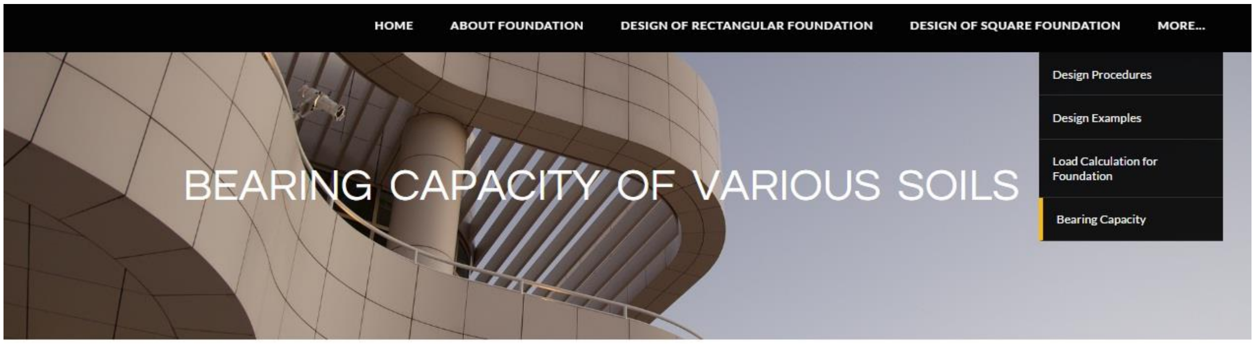


Figure 4.6 (x): Simplify the foundation design web page screenshot



Bearing capacity is the **capacity of soil** to support the loads applied to the ground. The **bearing capacity of soil** is the maximum average contact **pressure** between the foundation and the **soil** which should not produce shear failure in the **soil**.*Ultimate bearing capacity* is the theoretical maximum pressure which can be supported without failure; *allowable bearing capacity* is the ultimate bearing capacity divided by a factor of safety. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing capacity is based on the maximum allowable settlement. Bearing Capacity of soil varies with the types of soil and places.

A word file is added to pick up the bearing capacity values for using in the design as bearing capacity of soil plays an important role in foundation design.

Figure 4.6 (y): Simplify the foundation design web page screenshot

VALUES OF SAFE BEARING CAPACITY

RECOMMENDED VALUES OF SAFE BEARING CAPACITY FOR PRELIMINARY ANALYSIS

Sl. No	TYPE OF ROCK OR SOIL	SAFE BEARING CAPACITY (kN/m^2)	(kg/cm^2)
	ROCKS		
1	Rocks (hard) without lamination and defects, for example granite, trap and diorite	3300	33
2	Laminated rocks, for example sand stone and lime stone in sound condition	1650	16.5
3	Residual deposits of shattered and broken bed rock and hard shale, cemented material	900	9
4	Soft rock	450	4.5

	NON-COHESIVE SOILS		
5	Gravel, sand and gravel mixture, compact and offering high resistance to penetration when excavated by tools. (Refer Note 5)	450	4.5
6	Coarse sand, compact and dry (with ground water level at a depth greater than width of foundation below the base of footing)	450	4.5
7	Medium sand, compact and dry	250	2.5
8	Fine sand, silt (dry lumps easily pulverized by fingers)	150	1.5
9	Loose gravel or sand gravel mixture; loose coarse to medium sand, dry (Refer Note 5)	250	2.5
10	Fine sand, loose and dry	100	1
	COHESIVE SOILS		
11	Soft shale, hard or stiff clay in deep bed, dry	450	4.5
12	Medium clay, readily indented with thumb nail	250	2.5

Figure 4.6 (z): Simplify the foundation design web page screenshot

4.3 Column design result and analysis

Excel calculations has been created on simplified design of concentrated loading square and column of reinforced concrete buildings of moderate size and height. The users including the engineers, the architects, and common non-technical person can give very simple inputs, e.g. Loads, percentage of longitudinal steel, size of longitudinal bar to be use etc. in this excel sheet and instantly get the visual results there. It can be used for initial structural design, verifying existing design and to get rough idea on the design and check the assumptions.

4.3.1 Simplified design of Concentric loading square column

User needs to input data in the green colored cell. He will find final result at bottom. User has to give the following information about the column i.e. loads, percentage of steel, reinforcement bar to be use as main bar etc. This analysis includes determination of column size, spacing of tie bar etc. Reinforcement detailing of column has shown in the excel file to better understand the position and spacing of reinforcement of column.

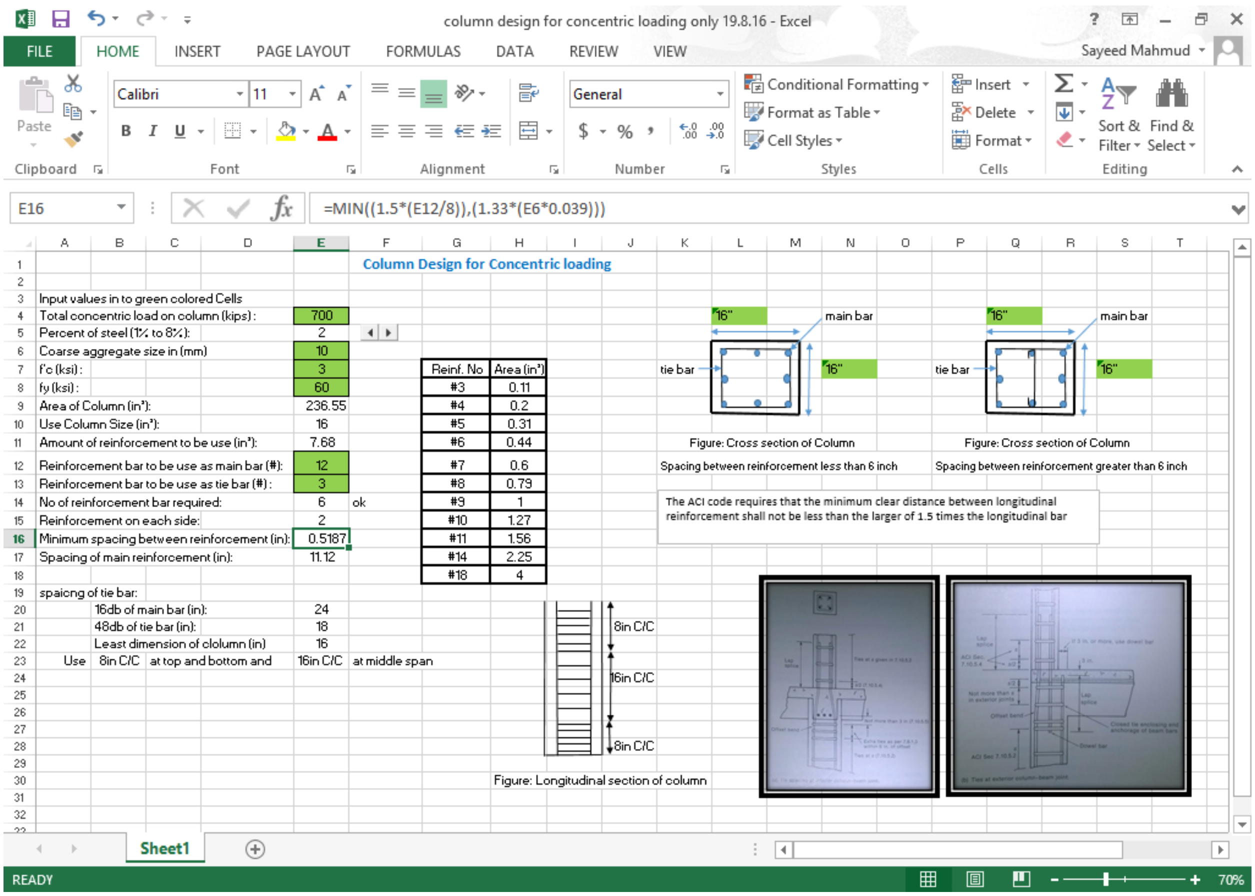


Figure 4.7 (a): Design of square column excel file screenshot

4.3.2 Simplified design of Concentric loading circular column

User needs to input data in the green colored cell. He will find final result at bottom. User has to give the following information about the column i.e. loads, percentage of steel, reinforcement bar to be use as main bar etc. This analysis includes determination of column size, spacing of tie bar etc.

Reinforcement detailing of column has shown in the excel file to better understand the position and spacing of reinforcement of column.

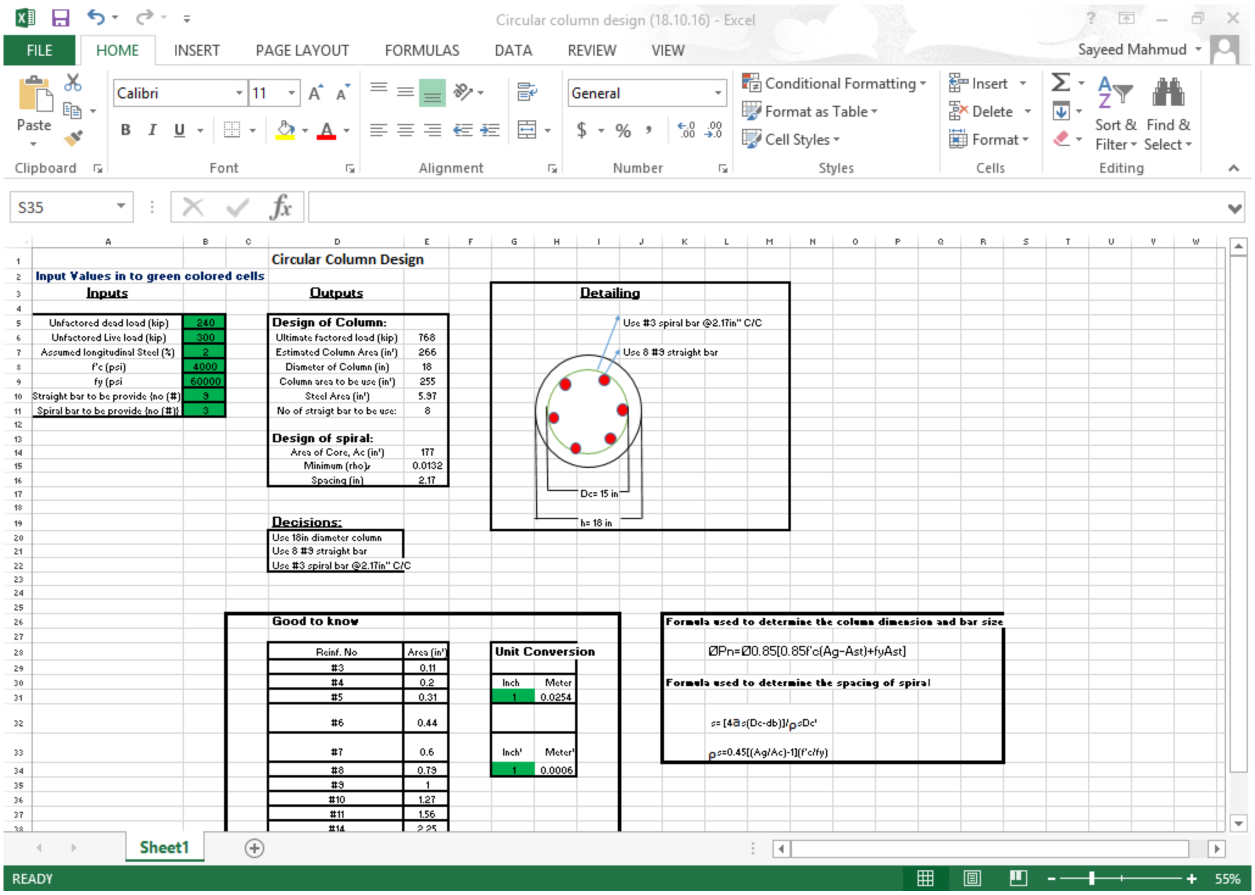


Figure 4.8 (a): Design of circular column excel file screenshot

4.3.3 Preliminary Column Sizing

It is necessary to select a preliminary column size for cost estimating and/or frame analysis. The initial selection can be very important when considering overall design time. In general, a preliminary column size should be determined using a low percentage of reinforcement; it is then possible to provide any additional reinforcement required for the final design (including applicable slenderness effects) without having to change the column size. Columns which have reinforcement ratios in the range of 1% to 2% will usually be the most economical.

The design charts presented in Figures are based on ACI Eq. (10-2). These charts can be used for no slender tied square columns loaded at an eccentricity of no more than 0.1h, where h is the size of the column. Design axial load strengths for column sizes from 10 in to 24 in with reinforcement ratios between 1 and 8% are presented in figures.

These design charts will provide quick estimates for a column size required to support a factored load within the allowable limits of the reinforcement ratio. Using the total tributary factored load for the lowest story of multistory column stack, a column size should be selected with a low percentage of reinforcement. This will allow some leeway to increase the amount of steel for the final design, if required.

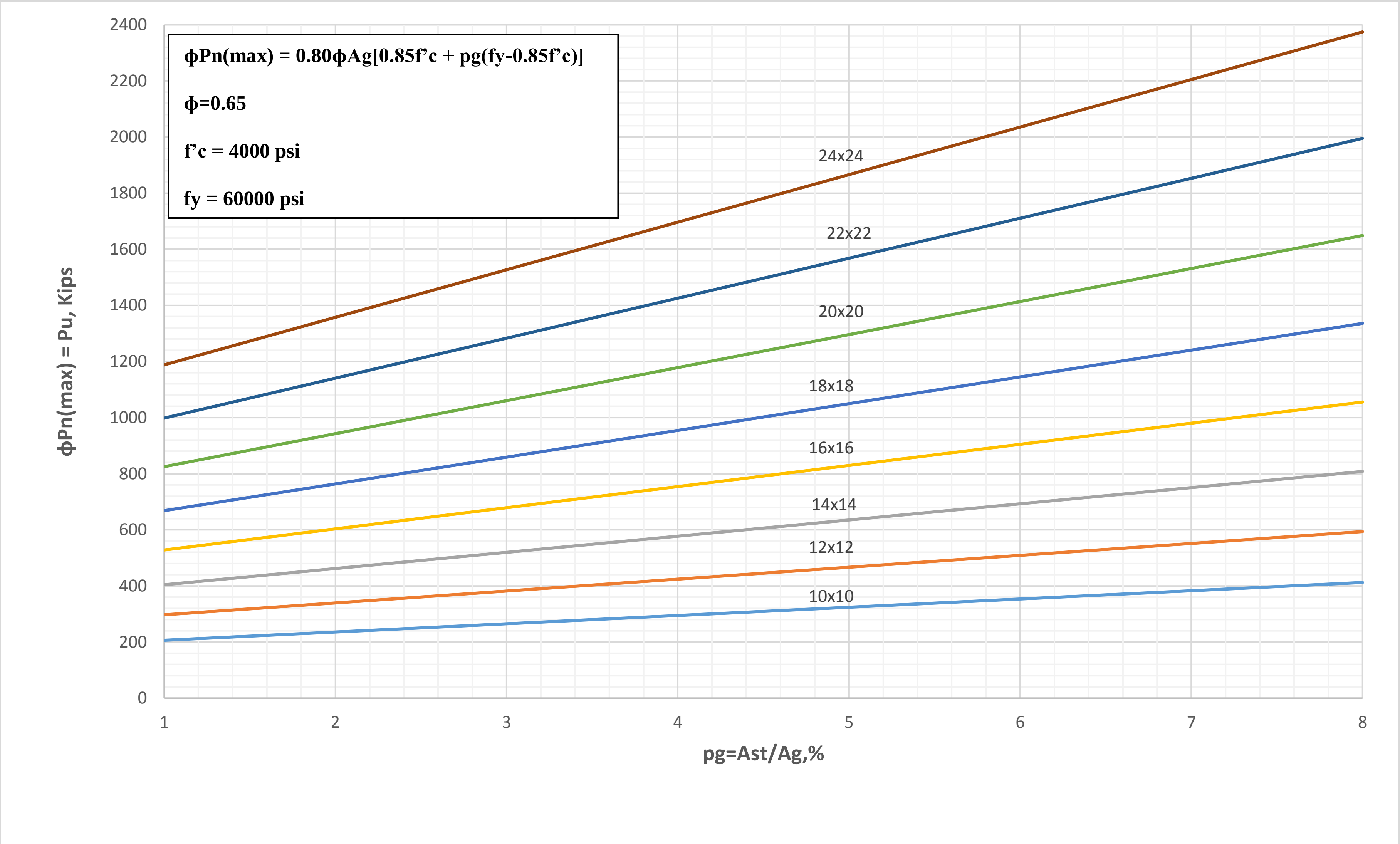


Figure 4.9 (a): Design Chart for Non-slender, Square Tied Columns (in inch²)

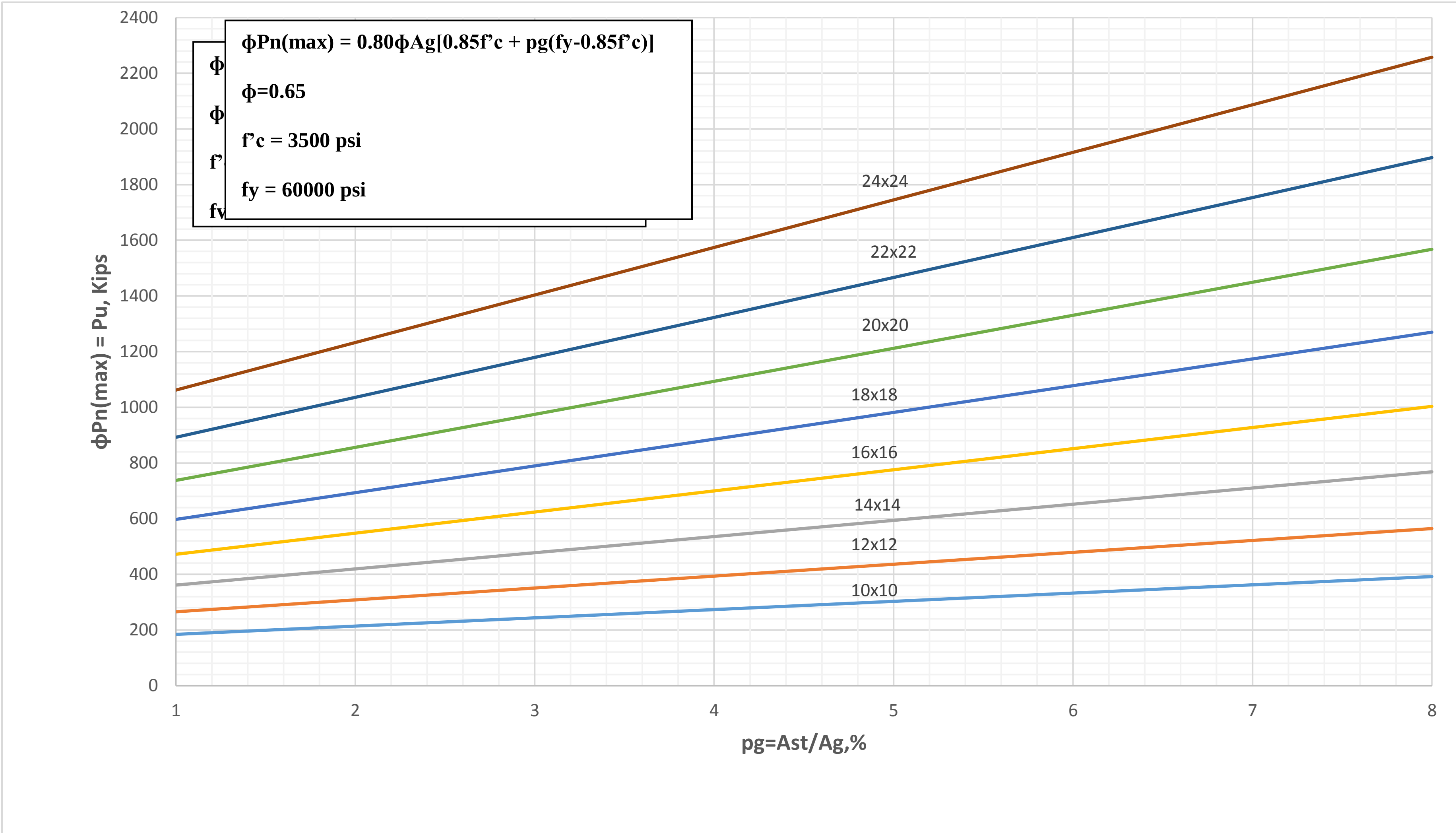


Figure 4.9 (b): Design Chart for Nonslender, Square Tied Columns (in inch²)

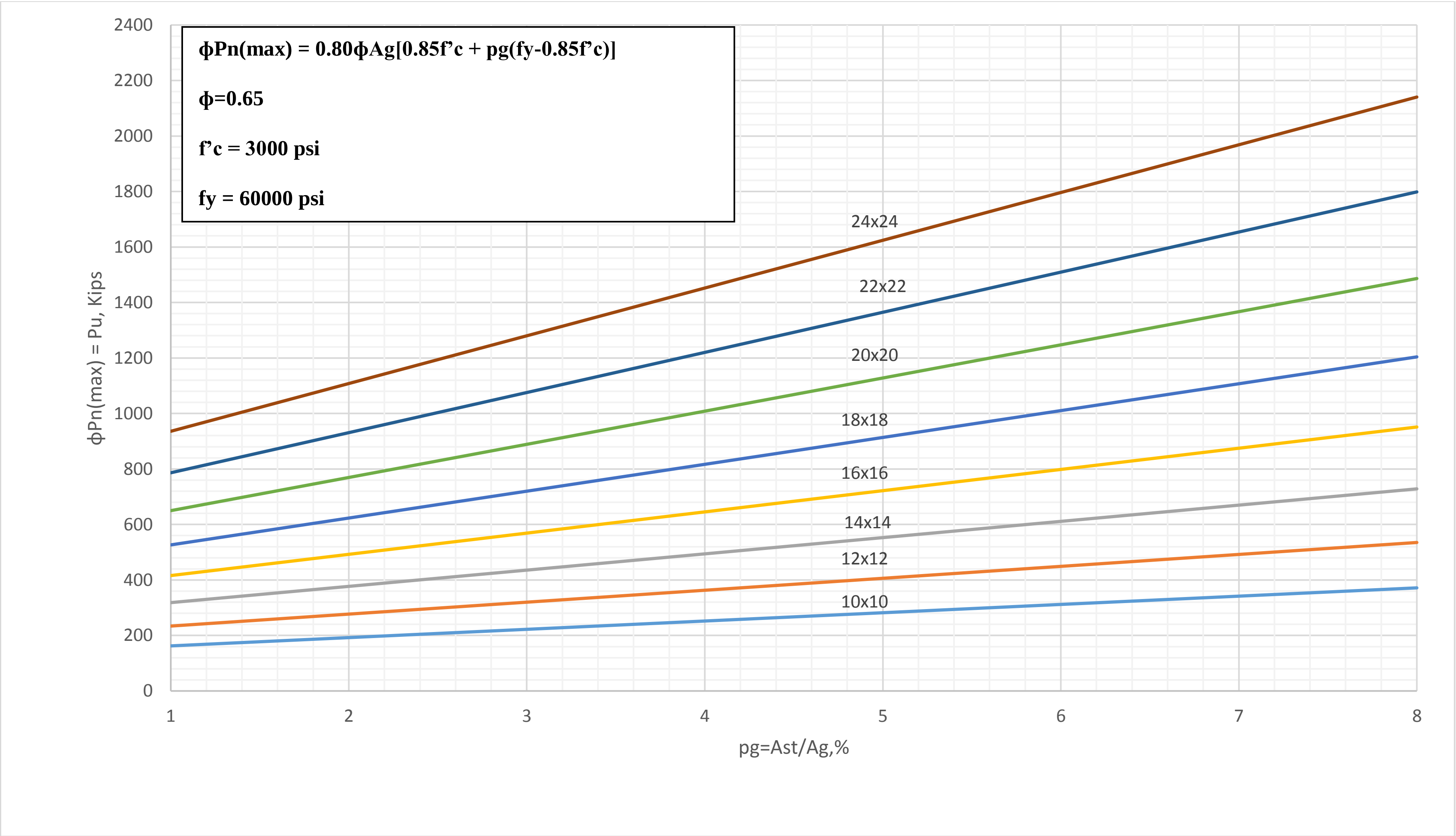


Figure 4.9 (c): Design Chart for Non slender, Square Tied Columns (in inch²)

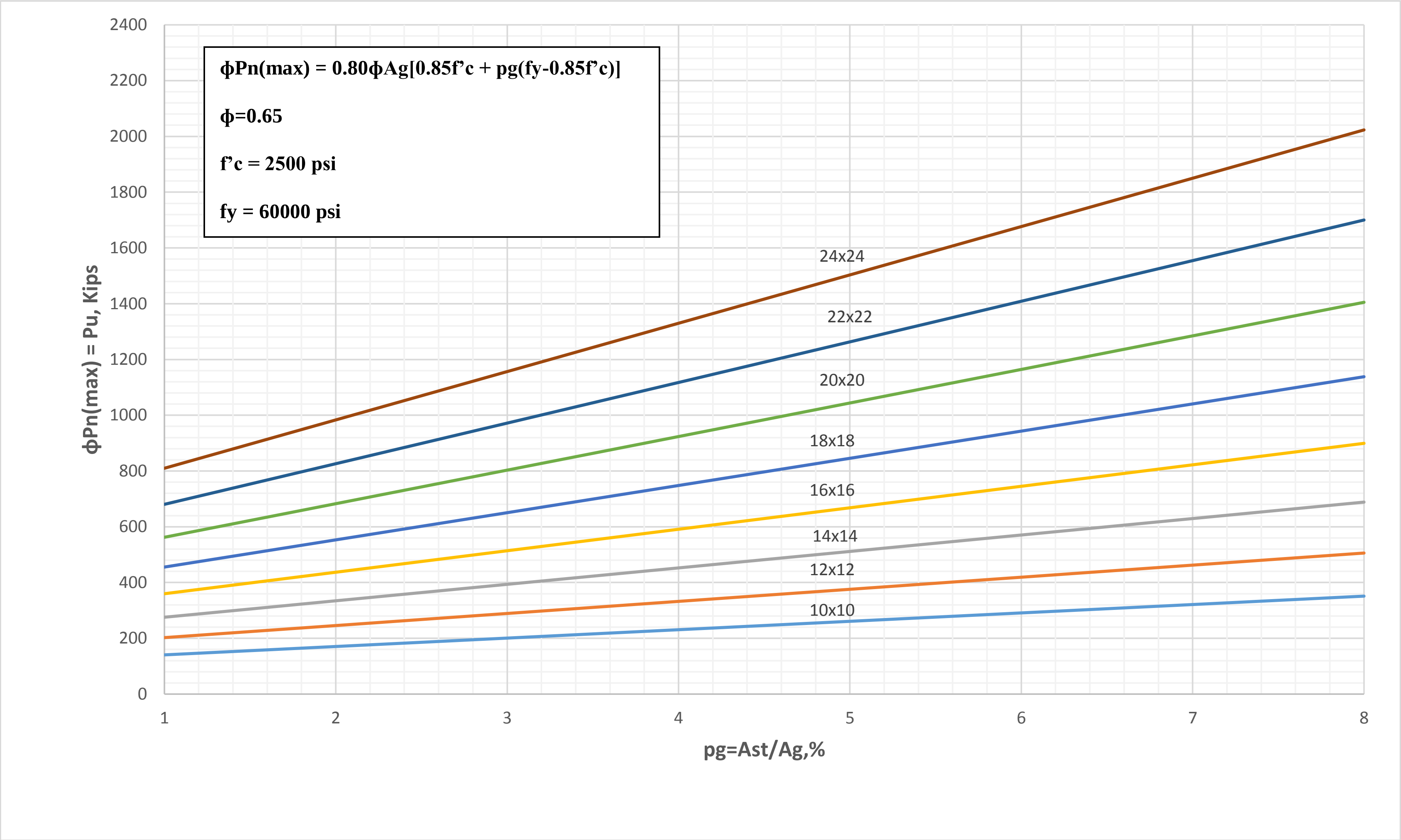


Figure 4.9 (d): Design Chart for Non slender, Square Tied Columns (in inch²)

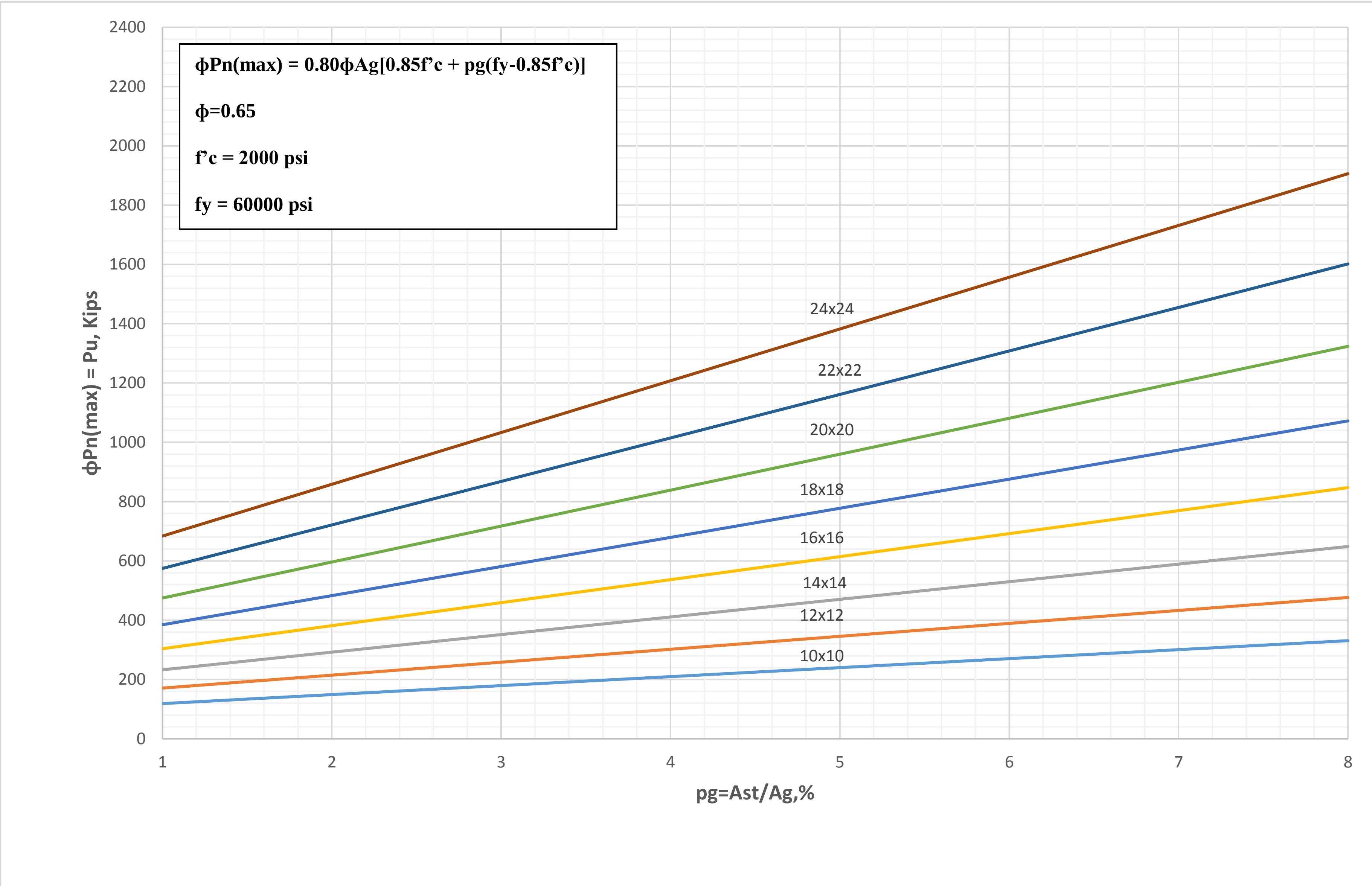


Figure 4.9 (e): Design Chart for Nonslender, Square Tied Columns (in inch²)

Chapter 5

Conclusion and Recommendation

5.1 Conclusion

The purpose of this paper is to give the idea of simplifying design of reinforced concrete components like foundation, column, stair. It will help practicing engineers to give idea about their assumption data in design, further checking abilities, and some way of reducing the design time required for smaller projects. We have tried to follow the the ACI Standard 318, Building Code Requirements for Structural Concrete, Bangladesh national building code and others code. Here for design, dead load & live load are considered in accordance of the code. If wind load, resistance to earthquake, induced forces, earth or liquid pressure, impact effects or structural effects of differential settlement need to be included in the design, such effects should be considered separately. They are not included within the scope of simplified design techniques presented here.

This simplified design approach can be used for conventionally reinforced concrete buildings of moderate size & height with usual spans & story height. This paper was prepared for the purpose of suggesting the design of Foundation (Rectangular footing, Square footing), Column (Short square and circular column), Stair. Here most numbers of parameter in design procedure are taken as a constant value. The main reason behind this is to shorten the time & effort of the designer. Simplified design procedures comply with the provisions of Building Code Requirements for Structural Concrete (ACI 318) using appropriate load factors & strength reduction factors.

The design is formulated in excel which would help the designers & those who are interested in designing the foundation, column, stair in shortest possible time, with minimum amount of effort. Simplified design of other units of structure will be carry forward in future.

5.2 Recommendations

1. This paper contains simplified design of reinforced concrete foundation, column and stair. In order to complete the full building, simplified design of other structural units of building i.e. slab, beam, shear wall, over head tank, underground reservoir etc. have to be calculated whose designs are added in our websites.

2. One should not fully depend on these calculations in practical purposes because for simplifying the calculation some effecting factors are ignored, but in practical many different factors will be in considerations. *These are only meant for educational purposes and checking designs.*

3. During load calculation of foundation, all slabs are considered as two way slab but in practical there may be one way slab in some cases. In that case loads from one way slab portion must be calculated separately.

4. Some unit conversions must be done manually during inputting data or getting results according one's requirements.

5. The design can be simplified if the parameters like strength of rebar and concrete can be made constant (i.e. fy = 60,000 psi, f'c = 4000 psi).

6. Here for design purpose only dead load and live load are considered. But if other loads i.e. wind load and earthquake loads are to be considered, then this loads are taken into account separately in design procedure.

7. Analysis of Stair design for various strengths are done only for 16 feet span and for 6inch slab thickness. It can be done for other span too.

8. Both BNBC and ACI code are being followed together during stair design. Separate design can also be done for specific code.

9. Columns which have reinforcement ratios in the range of 1% to 2% will usually be the most economical.

10. Design charts for various concrete strengths are being prepared for non slender square tied columns only, for circular column one can try to develop same kind staffs.

11. In design charts of column the ultimate strength of steel assumed to be constant (fy=60ksi), It may be different, in that case the charts will be invalid.

12. Ultimately, In simplified designs some of the parameters are made constant (like strength of reinforcement, ultimate strength of concrete, properties of cement etc. are made constant depending on availability of the material) in order to shorten the design procedure and to make the design easy plus time efficient as well as for learning purposes, but in practical they may have considered.

APPENDIX

1. http://simplifythefoundationdesign.weebly.com/
   [Note: This website contains relevant knowledge regarding Foundation, its types, purposes, influencing factors, bearing capacity, load calculation, various design, its procedures, examples and diagrams about foundations.]

2. http://designofstair.weebly.com/
   [Note: This website is all about stair, its types, its design with examples and procedures and diagrams.]

3. http://drlatifee.weebly.com/student-corner.html
   [Note: Dr. Enamur Rahim Latifee is a well-known person in Bangladesh and abroad. He is currently an Associate Professor in the Department of Civil Engineering at Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh. This is his website's student's corner link where he has mentioned various helpful materials about design of Structural elements, about materials and so on.]

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