Prince Mohammad Bin Fahd University

College of Engineering

Civil Engineering Department

Structural design and analysis of 60-storey building constructed using ultra-lightweight floor

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List of Abbreviations:

RC	:	Reinforce Concrete
ULW	:	Ultra-Lightweight
CLT	:	Cross Laminated Timber
LL	:	Live Load
DL	:	Dead Load
EQ	:	Earthquake
GCC	:	Gulf Cooperation Countries
MRF	:	Moment Resisting Frame
ATMD	:	Auxiliary Tuner Mass Damper
LRFD	:	Load Resisting Factor Design
Ag	:	Area Gross

Abstract

The project is about redesigning and modeling a 60 story building, by creating four different models using two frame type, and two different floor systems. The two type of frames are reinforce concrete and a steel frame. Moreover, the project will implement new type of floor system which is the ultra-lightweight floor system. Basically, the project is going to compare the traditional reinforce concrete floor system with ultra-lightweight floor system in reinforce concrete and steel frames. A specific type of ultra-lightweight floor system will be used in the project which is cross laminated timber. The objective of this project is to redesign the 60 story building using hand calculation and computer programs, based on reinforce concrete slab and use the same conditions to compare the results with cross laminated timber slab. Also, one of the main objectives of the project is to check the overall structural performance of reinforce concrete frame with the different floor system, and the steel frame with the different floor system under gravity loads, and lateral loads. Furthermore, the project is going to investigate the foundation demand of the four models. In order to design the high-rise building, a literature review is conducted about the new technologies and methods that are used today for designing tall buildings, also an interview type survey is conducted with structural and architectural engineers in Saudi Arabia to check their awareness of the new ultra-lightweight floor systems. ETABS and SAP2000 is going to be used for the modeling to check the overall structural performance of the four models. CLT have significantly reduced the building the building weight and foundation demand. The combination of steel frame with CLT slab was the lightest and gave an opportunity for farther reduction in the material usage.

Chapter 1: Introduction

The general purpose of the project is to design and analyze a 60 story building for commercial uses, by creating four different models in term of the main framing systems, two with reinforce concrete frame and the other two with steel frame. Two types of floor systems will be used in the design and analysis. The first one is using the traditional reinforce concrete (R.C) slab, and the second one is using the ultra-lightweight (ULW) slab, the type of the ULW is going to be cross laminated timber (CLT). The floor that used traditional reinforce concrete slab will be used as a reference. Basically the project is designed using the hybrid structure concept in designing the 60 story building. The structural layout shown have been taken from paper for (M. Shin, T. Kang, J. Grossman, 2009) and the structural layout have been modified to simplify and ease the design process. The layout can be seen in figure 1 and in figure 2 shows the model.

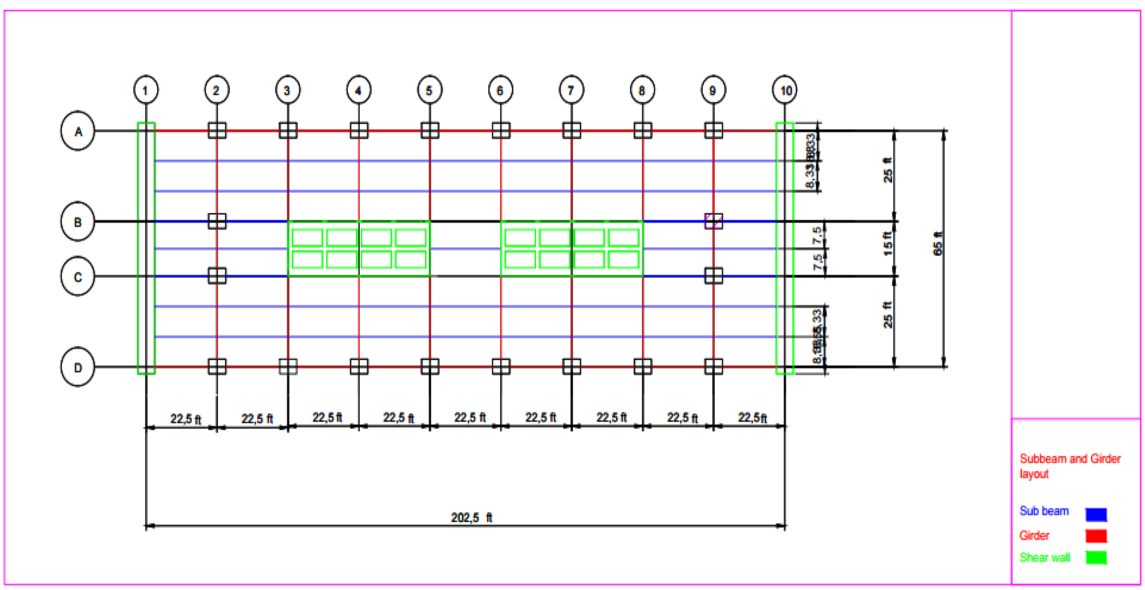


Figure 1 Typical Floor Layout

Construction of high-rise buildings is booming and becoming a trend in Asia and in the Middle-East, and structural and architectural engineers are seeking to develop new ways to optimize the high-rise building construction. For example, by trying to minimizing the cost and overcome some technical problems that could be faced during the construction that may delay the construction. The main project objective is to introduce an alternative way of floor system to be used in high-rise buildings, which has comparable stiffness and strength with reference to reinforce concrete slab, that it can significantly reduce the total weight of the building. The difference between the traditional reinforce concrete floor system and the new cross laminated timber floor system will be compared using the above four different models. Furthermore, the world of structural engineering is shifting to green buildings for the environment that enhances the life of the structures by using durable and sustainable construction material such as CLT slabs.

Well-known sophisticated computer programs were used in this study including AutoCAD for drawing, structural analysis program (SAP2000) for structure analysis and design, and extensional three-dimensional analysis of build system (ETABS). SAP 2000 and ETABS programs will be used to check the structural performance of the building under the gravitational and lateral forces, including lateral defamation (drift), inter-story drift, shear story distribution, base shear, and dynamic characteristics of the buildings. The Saudi Building Code (SBC) will be used as a major reference for all the design requirement and codes, also the project will use another supplement from the (SBC) reference for the design code and requirement is the American Concrete Institute (ACI), and American Institute of Steel Construction (AISC), hand calculation will be used based on SBC, ACI, and AISC in order to check the output of the software mentioned before. All the reinforce concrete and steel sections will be designed based on the concrete slab not on CLT to have a fair comparison.

Literature review will be discussed in chapter 2 and it includes; the properties of the CLT, high-rise building new technologies, and hybrid structure design. A survey is conducted in chapter 3 and completed by local structural and architectural engineers to study the current practice of ultra-lightweight floor systems in Saudi Arabia. Chapter 4 discusses the planer design, chapter 5 discusses the steel frame, chapter 6 discusses reinforce concrete frame, and chapter 7 discusses the foundation design that is going to be part of the project in order to see the foundation demand of the four different structural model. The final chapters wraps up the project by results in chapter 8, and conclusion in chapter 9.

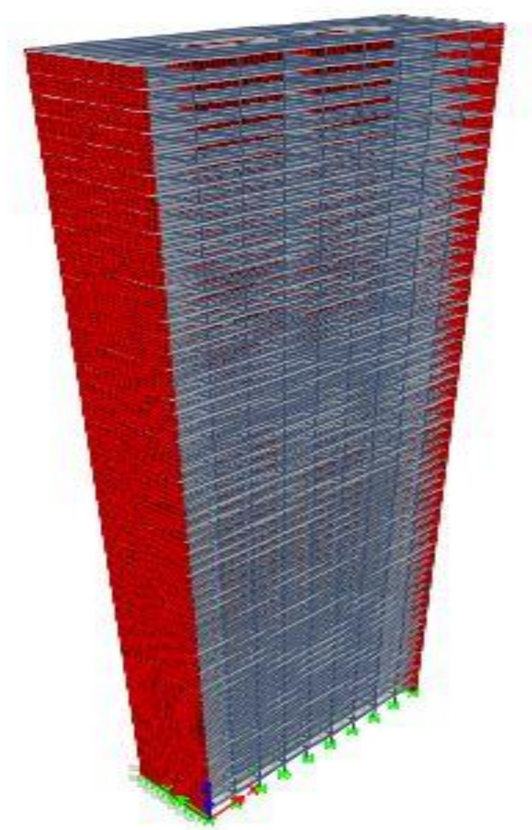


Figure 2 60 story building model

Chapter 2: Literature Review

2.1 High-rise building:

High-rise buildings can be defined as any building that have 12 story or more have emerged in late nineteenth century in the United States of America. Since then high-rise buildings were only located in the North American countries, but lately based on a statistic on 2006 most of the high-rise buildings are located in Asia, and the highest buildings nowadays are also located in Asia especially in the GCC countries. High-rise buildings traditionally have been constructed for commercial uses. High-rise buildings since it discovery have faced a lot of challenges, some of them are technical and some are economical challenges. The governing factor for any high-rise buildings is normally the economical factor. The major technical problems that is faced while designing the high-rise buildings is the foundation demand and the lateral deformation due to wind and earthquake. That's one of the reasons high-rise structures have undergone an intensive research and development by structural and architectural engineers.

Fazlur Khan in 1969 classified the structural system for high-rise buildings based on their heights with consideration for efficiency in the form of "Heights for Structural Systems". This system later has been updated to separate the concrete structural system from the steel structural systems. The classification in Figure 3 shows how Fazlur Khan introduced the three-dimensional analysis instead of series of planar system with the aid of computer to come up with this classification (Ali, Moon, 2007).

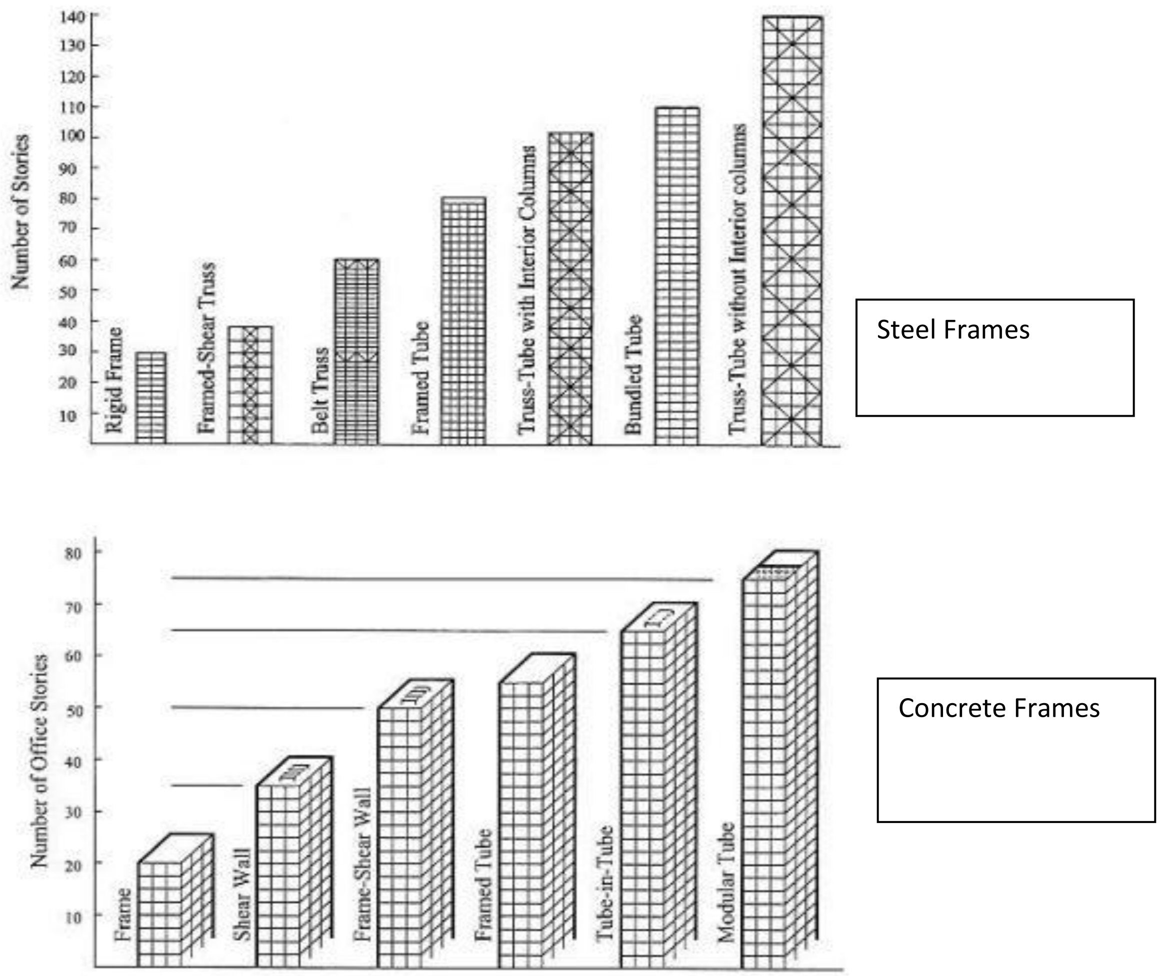


Figure 3 Classification of tall building stcrutral systems (Ali, Moon, 2007)

Basically, there are three main types of loads a high-rise structure must handle: 1- gravitational loads (live and dead loads), 2- Lateral load due to wind, 3- Seismic load due to earthquake. Usually, after the tenth story the lateral drift will be the governing criteria on the high-rise build structure. Structural systems of high-rise buildings are divided into two categories: 1- Interior system, 2- Exterior system. For the interior system there are two type of lateral load-resisting: 1- Moment resisting frame (MRF). 2- Reinforce concrete shear wall. The first type, which is the MRF, consists of a horizontal girder and a vertical column connected rigidly. This type resists the load through the flexural stiffness of the members. The second type, which is reinforce concrete shear wall, and it is the popular one, resists the lateral load primary through the axial stiffness of its members. The shear wall interaction system can be seen in Figure 4**.** The exterior structure depends on the nature of the building perimeter, because based on it the vulnerability of the lateral load will vary. The most common type of exterior structure is the tube, where many buildings in the United States have used the tabular concept or a variation of it to resist the wind load.

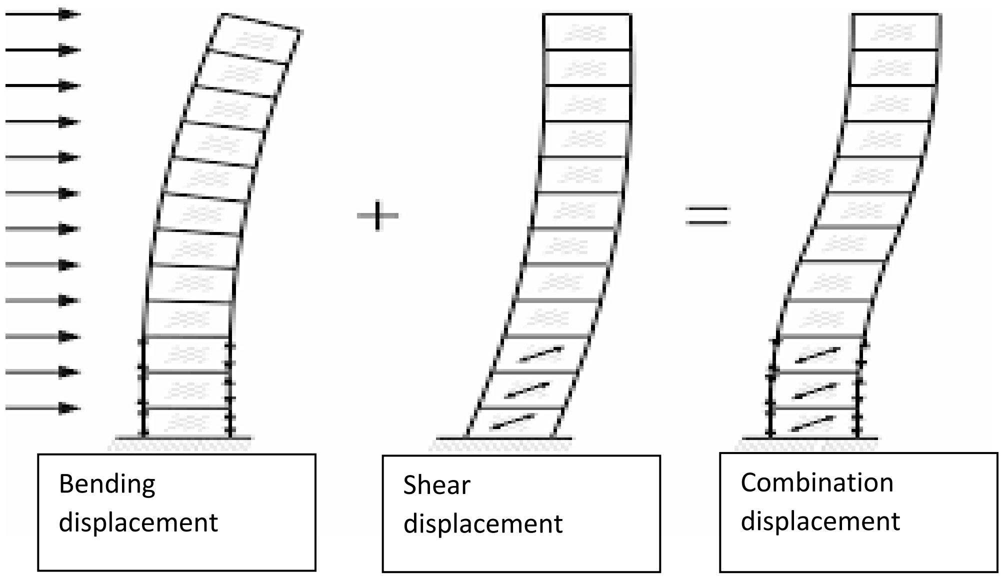


Figure 4 Deformation of building under lateral load (Ali, Moon, 2007)

The direction of evolution of the high-rise buildings structural systems, based on the new structural concepts with the newly discovered such as the high-strength materials and the newly developed construction methods, all these discoveries have been toward increase the efficiency of the high-rise buildings. Furthermore, structural and architectural engineers are constantly trying to make the structural systems lighter, in order to reduce the cost and the material consumption. However, because of the lightness a serious problem could arise primarily due to wind induced motion. These problems occurred because of the relationship between the high-strength of the material itself, for example if the strength of the material increase the modulus of elasticity of the material stay same or increase slightly not in the same rate of the strength. The control of this structural motion should be considered for static load as well as dynamic loads. For the static load, a stiffer columns and girders should produce less lateral drift. For the dynamic load which produce a vibration for the high-rise buildings, a dumping mechanism is required to dissipate and absorb the vibration that is caused by the dynamic load of the wind. The discussion of damping systems is important to for light material such as CLT when it is used in high-rise buildings There are two damping systems one is passive system, the second is active system.

There are two kind of passive damping system, 1- energy-dissipating-material-based damping system such as viscous dampers, and 2- auxiliary mass system to generate a counteracting inertia forces such as tuned mass dampers. The first type which is energy-dissipating-material-based damping systems is generally installed as integral part of the primary structural systems at vantage locations, reducing the dynamic motion of high-rise buildings. The second type which is auxiliary tuner mass damper (ATMD) systems to generate a counteracting inertia forces is relatively complicated mechanical devices that allow and support the intended performance of the mass. The frequency of the ATMD is usually modified to match the fundamentals frequency of the primary structure. Usually the ATMD is located near the top of the building to achieve the best performance as shown in figure 5.

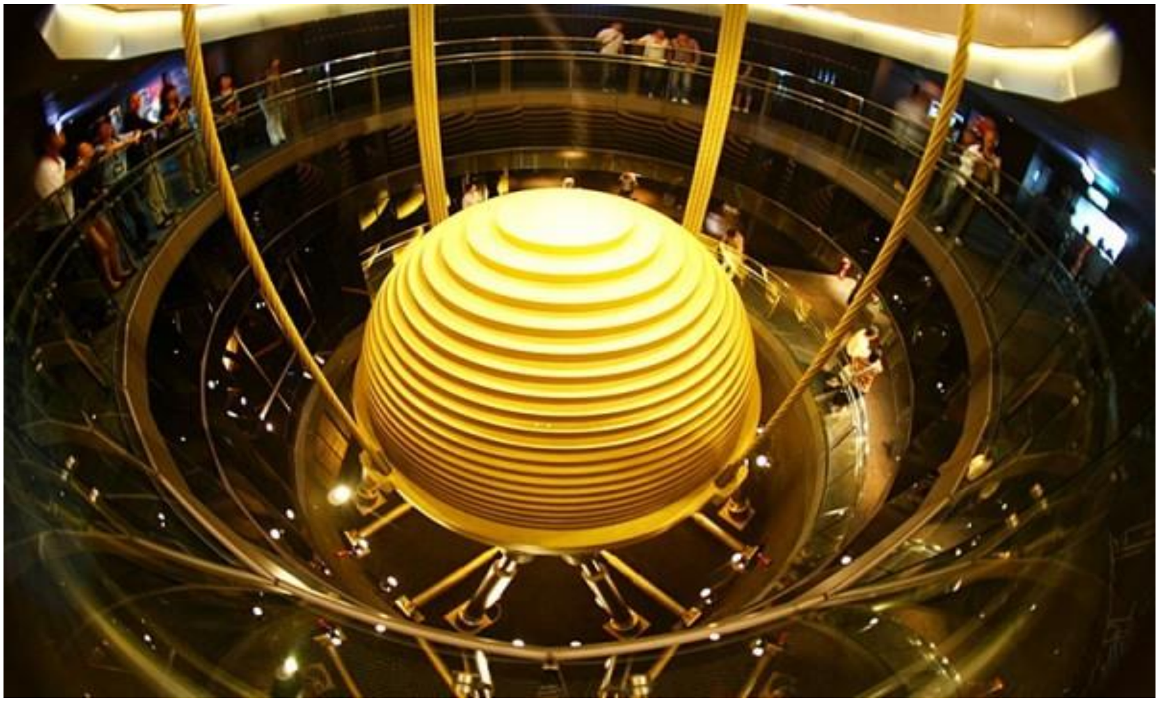


Figure 5 Example on passive damper system (8)

The second type of damping systems which is the active damping system. The active system is divided into two main category 1-Active mass damper (AMD). 2- Active various stiffness (AVS) devices. The active system is defined as “one that has the ability to determine the present state of the structure, decide on a set of actions that will change this state to a more desirable one, and carryout these actions in a controlled manner and in a short time” (Connor 2003). Since some passive systems are sometimes ineffective for certain loading condition, active systems can perform effectively over a much wider range and they are more advanced form of functional performance-driven technologies. The way that the active system work is basically is when the vibration is picked up by s sensor that is already installed, then the optimum vibration control is calculated by a computer, and then the movement of the building is reduce significantly by shifting a moveable mass with an actuator. While this technology is still in development stage, but it is expected to create an evolution in the high-rise buildings damping systems.

In designing a high-rise building many factors need to be taken into consideration in order to achieve high performance high-rise building such as site context, environmental impact, energy consumption, and uses of durable materials. A full integrating between structural and architectural engineers is necessarily.

2.2 Hybrid Structure:

Since the first high-rise building that have been constructed many developments have taken place in order to increase the efficiency of the high-rise buildings. The term hybrid means in construction context is a structure that is made by combining two different materials. This combination gives a variety of advantages because it enhances the material deficiency, for example a building that use steel column and timber beams, or a pre-cast unit for slab. Also composite materials is a very important to consider as an alternative materials in high-rise building like the fiber reinforcing for concrete, where the concrete is weak in tension, but the fiber reinforcement is good in it, so by combining the two material a new material has merged that contain the advantages of both of the materials. It is always better to use two or more different materials rather than one in order to get the maximum advantages of each material. Engineers recently have discovered how hybrid material is essential to achieve structural sustainability and rapid construction, not only that sometimes hybrid structure could reduce the cost. Hybrid structure is very important especially for high-rise buildings because of the different kind of loads that is acting on it. In figure 6 it is noticed that hybrid materials or as sometimes called composite material have proved to be an efficient material, that’s why it is now a strong competitor for steel and reinforce concrete.

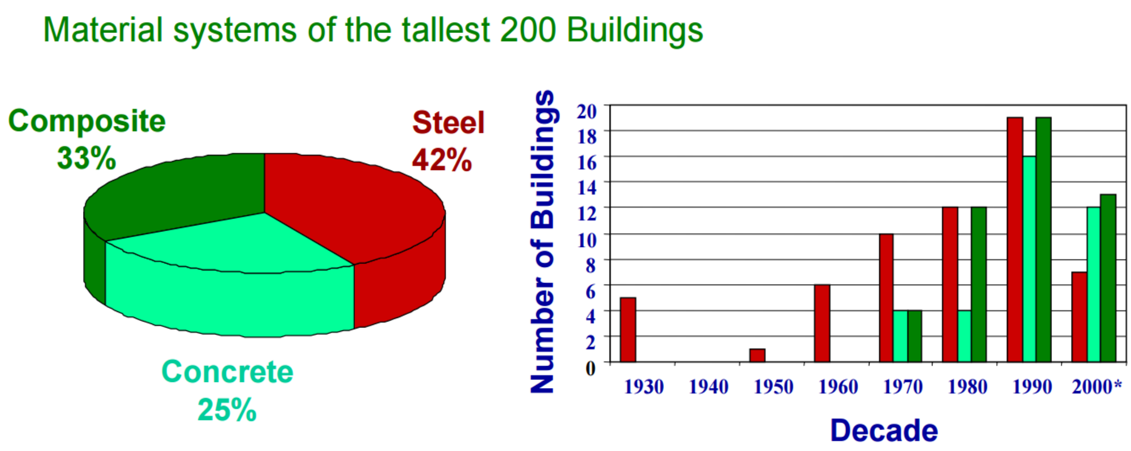


Figure 6 Statistics about material used in high-rise buildings (7)

2.3 ULW Floor:

Floor selection in high-rise buildings design is one of the important decision a structural engineers have to make (Asiz and Ahmed 2013), since it composes 20% of the total structure weight. Lateral load is created from wind that is transferred to the lateral load resisting system according to the stiffness of each floor. The material needed for the floor framing depends upon the span of the framing elements that is column to column distance, not based on the building height. There are two type of floor systems one is reinforce concrete slab which is the traditional one, the second type which is ultra-lightweight floor system which is new and recently developed type of floor systems. There are many new materials that are available to be used as an ultra-lightweight floor system such as: 1- Plastbau eDeck. 2- Lightweight autoclaved aerated concrete (AAC). 3- Cross laminated timber (CLT). These new materials have brought a lot of benefits to the construction field such as the ease in installation and assembly, improve in the safety measures on site, energy efficient, thermal efficiency, and workability because they can be modified on site. Plastbau is made of molds which are self-supported with metallic strips, and these molds contains ribs that accommodate the steel reinforcement as sheen in figure 7**.** Also Plastbau slabs are prepared to accommodate several types of floor finishing (Plastbau Arabia Co).

Figure 7 Plastbau slab

The AAC is a pre-cast concrete unit is a light weight material with a nominal dry density equals to 550 kg/m3 which make it very light, the raw materials that is required to make AAC is similar to the normal concrete materials such as water, sand, cement, and aluminum power (Siporex). This type of pre-cast unit is used in flooring and can be used as main construction material for 2 story house, a figure 8 can be seen below. Siporex panel comes with different thickness that vary from 7 to 20 inches (Siporex).

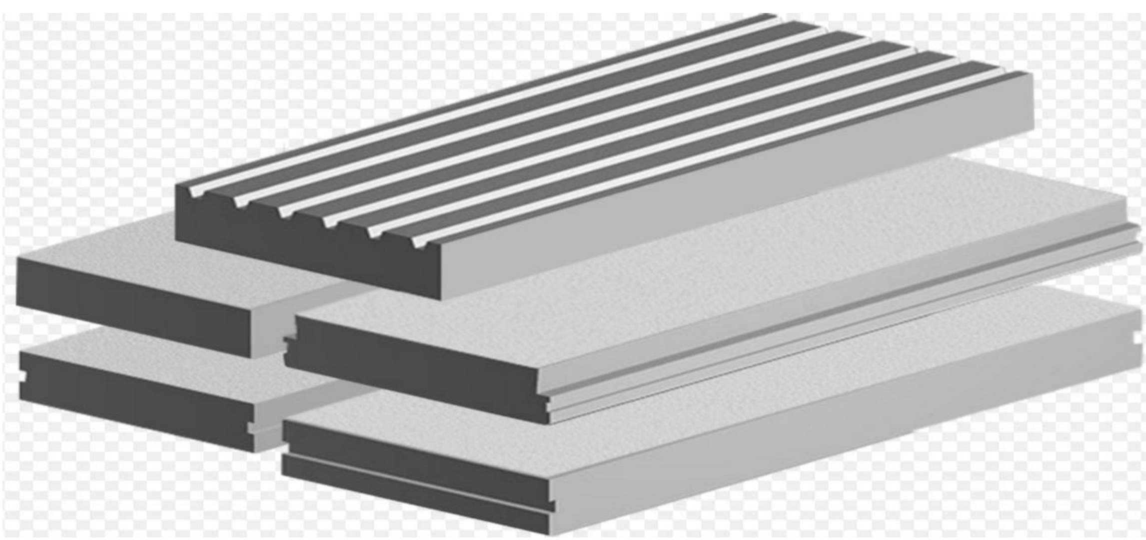


Figure 8 Siporex panel

CLT is planks of timber stacked crosswise on glued on top of each other. The connection between the CLT slab and the steel or reinforce concrete frame is very critical because it is important to get the intended rigidity or flexibility of the diaphragm as in Figure 9. As shown in the figure 9b below it's very easy to connect the beam to the CLT slab just by inserting fasteners.

(B) Reinforce concrete slab and steel beam

(A) CLT slab and steel beam

Figure 9 Floor system of multi-story buildings (Asiz, Ahmed, 2013)

Previous study has been done to check the workability of the CLT slab with the traditional reinforce concrete slab (Asiz, Smith, 2009; Asiz, Smith, 2011). CLT thickness ranges from 6 to 12 inches. CLT is a timber-based composite material that has been used in North America and Europe for low-rise buildings. The CLT is going to be used in this project.

Figure 10 CLT

The trend of the structural and architectural engineers nowadays to build green buildings with low carbon footprint and be LEED certified. However, some people consider green buildings as inefficient buildings which mean that the buildings are weak, but with CLT has the opportunity to be green building with a strong structural performance and high durability as it shown in the figure below. Also one of the CLT advantages is that it can accelerate the construction because it’s a pre-fabricated timber and easy to install (BSLC, 2014). Not only that CLT because of the cross lamination it minimizes the swelling and shrinkage in the board panel, also it has a strong strength and stiffness to resist lateral load such as wind and seismic loads. One of the problem people might think about using wood is the fire resistance, CLT and wood in general is very strong fire resistance material due to massiveness of its size and weight. in the figure below 11, 12 it shows a comparison of wood, steel, and reinforce concrete materials under fire, and how wood have strong resistance against fire than steel and concrete**.**

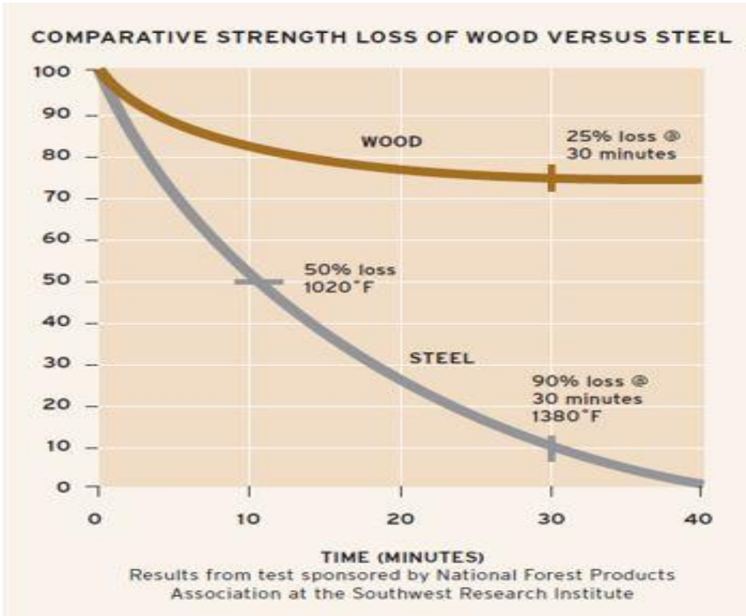


Figure 11 steel vs wood fire resistance (Sothwest Research Institute)

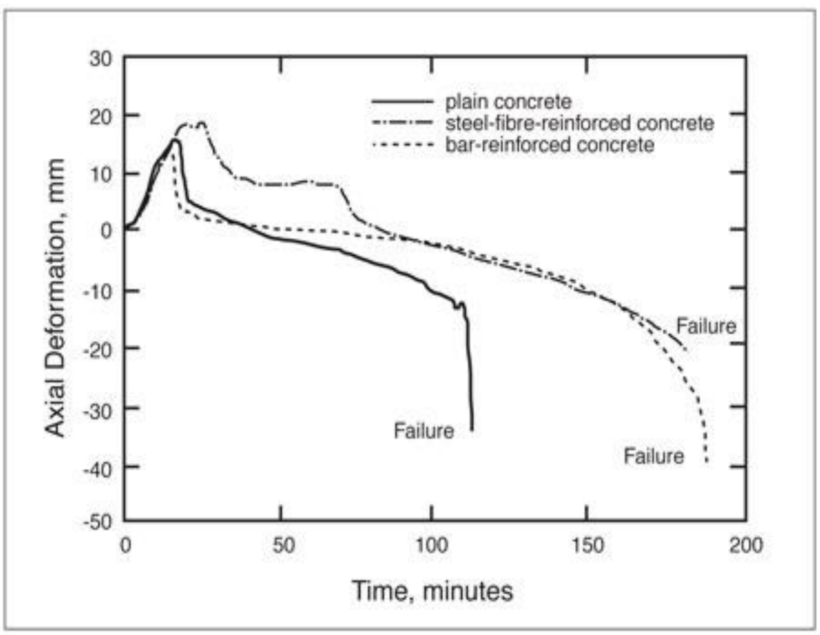


Figure 12 Concrete fire resistance (9)

Chapter 3: Survey

3.1 Objectives:

The objective of this survey is to assess the awareness level of the public and professionals about cross laminated timber (CLT) Technology, and the ultra-lightweight flooring system (ULW). Another objective is to obtain feedback to determine if hybrid towers are suitable for citizens In Saudi Arabia and GCC in general, and to find out what Influential Factors that effects making the decision to Use cross laminated timber (CLT) Technology, in addition to the effect of using cross laminated timber (CLT) Technology in structural would impact all perspectives such as environment, economy and community.

3.2 Methodology:

The survey will assess the level of public (Citizen, Resident) and professionals (engineers, business men and investing companies, owners and decision makers). The awareness of both genders males and females in different age categories, About cross laminated timber (CLT) Technology and the ultra-lightweight floor system (ULW). A questionnaire has been created as an interview survey which is consists of 15 main questions, the first 6 questions are directly related to cross laminated timber (CLT) Technology and the ultra-lightweight floor system (ULW) the other 6 questions focuses on the professionals side of the community (engineers, business men and investing companies, owners and decision makers). The last 3 questions are an interview type, where suggestions were taken and notify expectations and experience. The areas that this survey has been done is in the eastern region (Khobar, Dammam, Jubail) of Kingdom of Saudi Arabia and the Capital city (Riyadh) in add to the Kingdom of Bahrain. Result from different areas and ages were taken in order to have more different point of views in the results; Residents from many different areas are required to fill out the surveys.

All the cities has been visited one after the other. To get the surveys done, Recorders were used to record the people interviews. An appointment was taken. The surveys was emailed to whom could not have the time or the chance to meet with us, So they could answer on the survey questions and send it back. The questions were designed to scale the general people knowledge and determine the influence factors that would effect on public opinion, Also the missing factors that they required. All survey data is entered and analyzed with the use of Excel sheets, and charts have been prepared for the results, For the most significant questions in the survey.

3.3 Results:

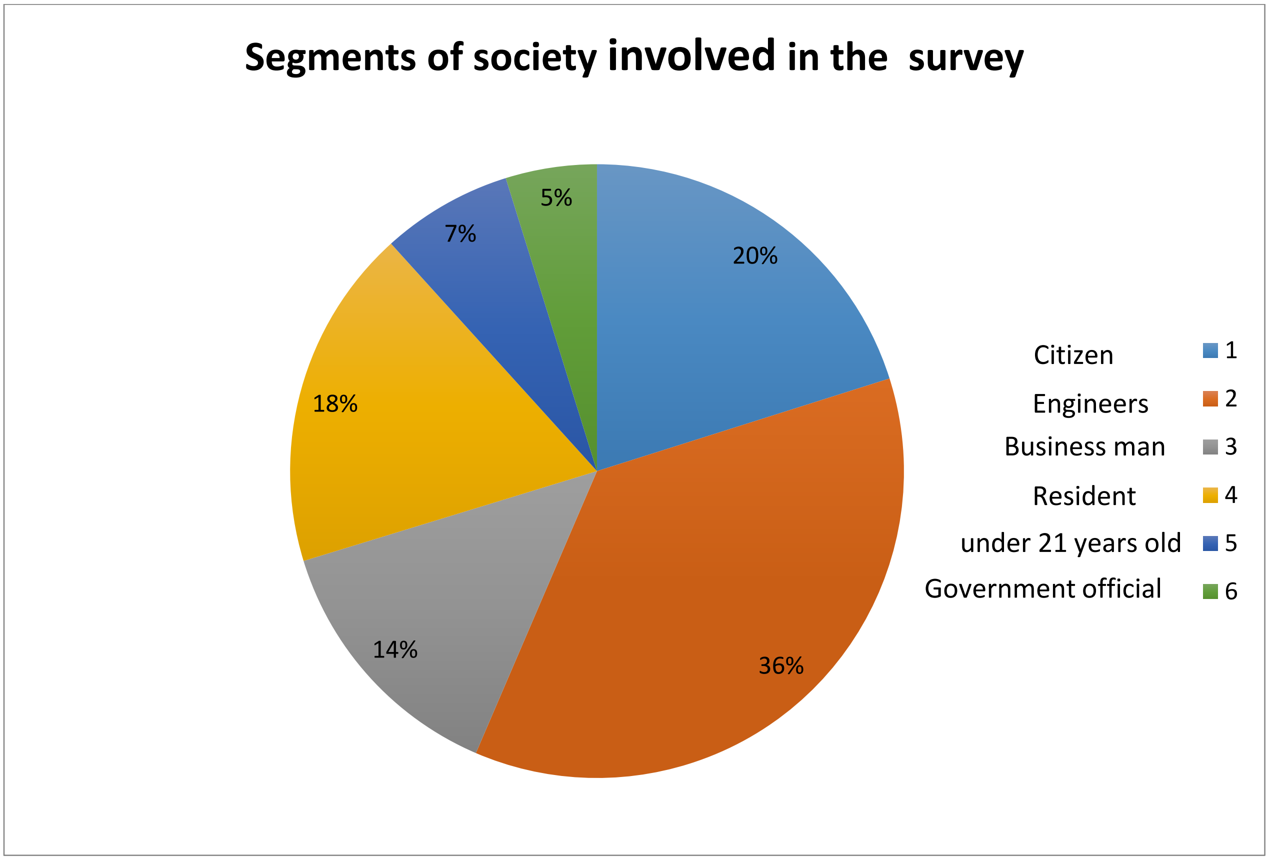


Figure 13 Segments of society involved in the survey

Public (Citizen, resident) and professionals (engineers, business man and investment company, owners and desirous makers)

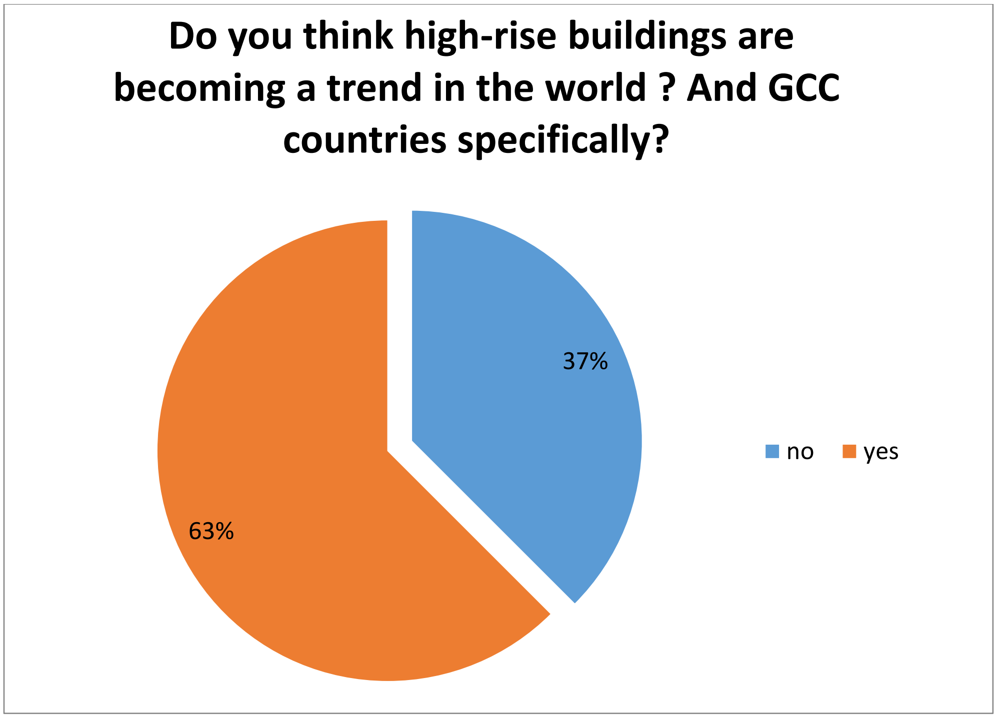


Figure 14 Do you think high-rise are becoming trend in the world

More than 60% of public (Citizen, resident) and professionals (engineers, business man and investment company, owners and desirous makers) think high-rise buildings are becoming a trend in the world And GCC countries specifically.

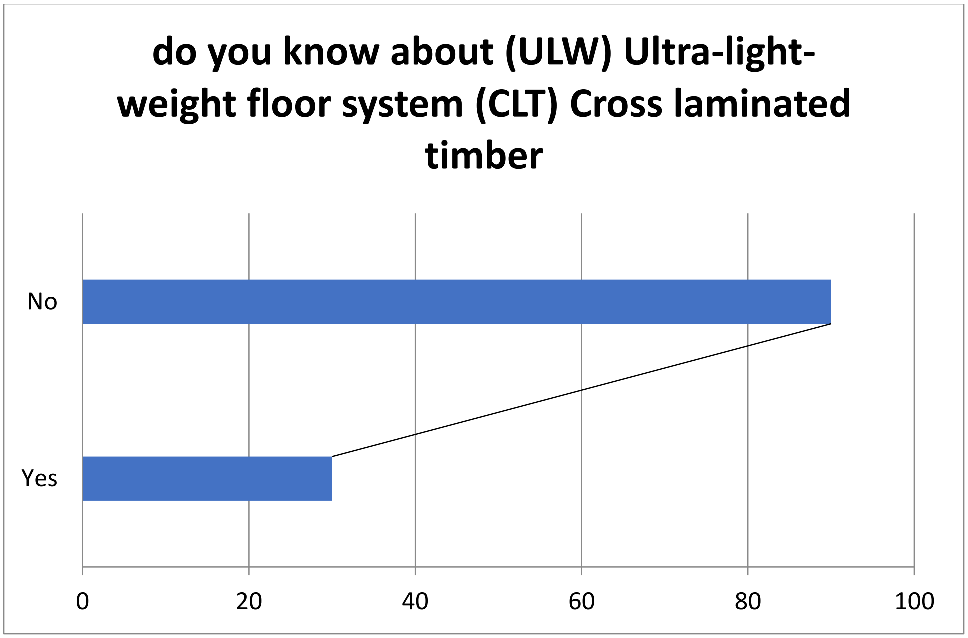


Figure 15 Do you know about ULW

Less than 30% of the public (Citizen, resident) and professionals (engineers, business man and investment company, owners and desirous makers) know about (ULW) Ultra-light-weight floor system (CLT) Cross laminated timber.

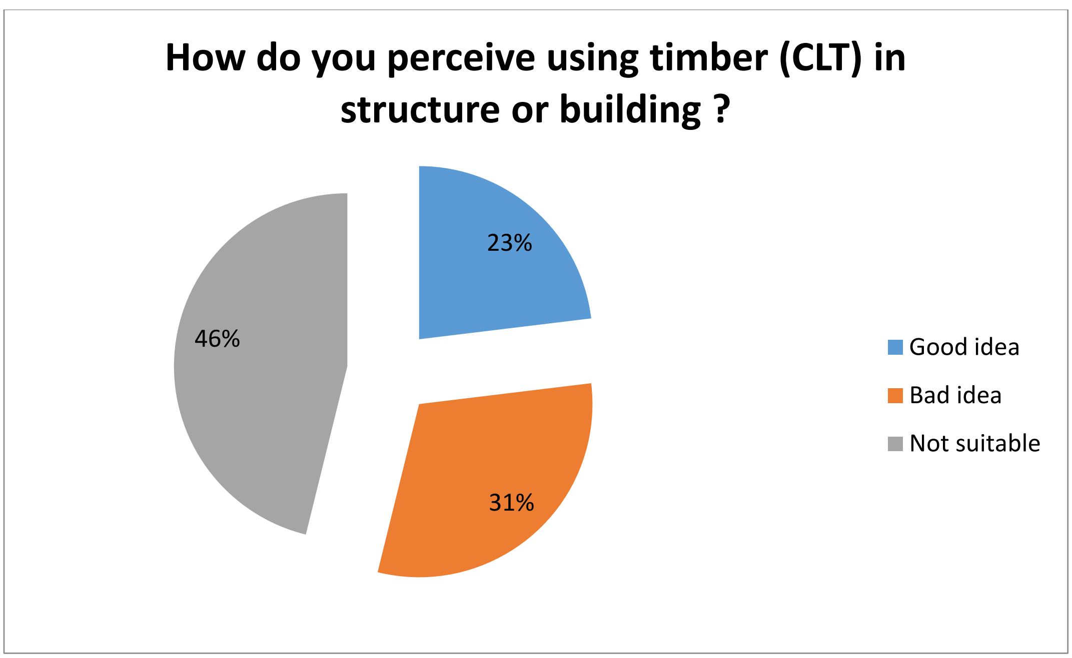


Figure 16 How do you perceive using timber in structure

More than 40% of the public (Citizen, resident) and professionals (engineers, business men and investment company, owners and desirous makers) interviewed perceive using timber (CLT) in structure or building is not suitable.

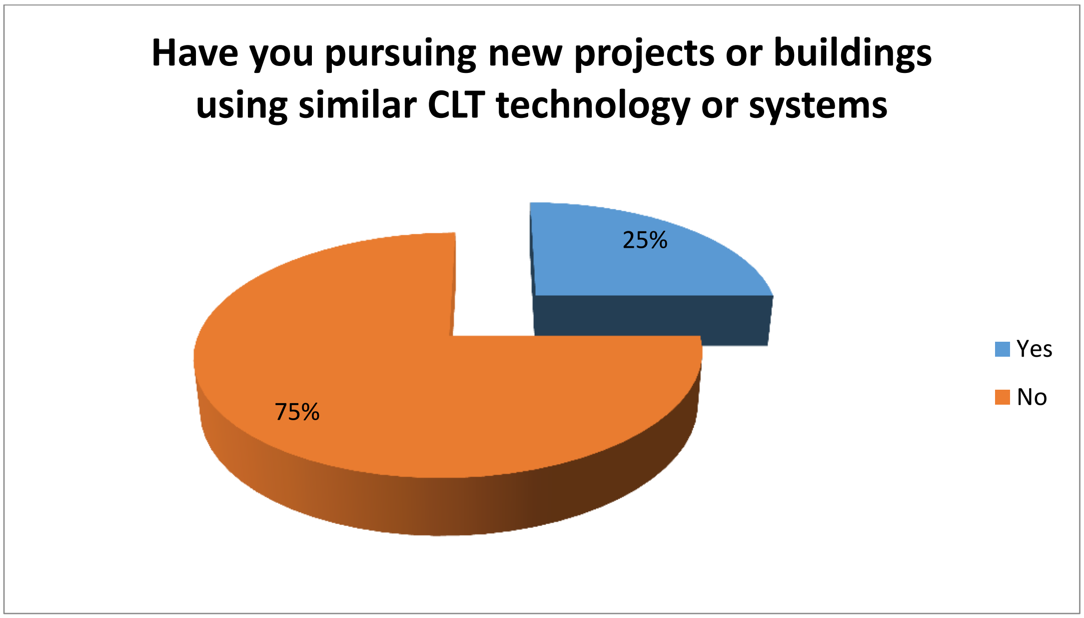


Figure 17have you pursuing new projects or buildings using CLT

Almost 80% of the public (Citizen, resident) and professionals (engineers, business man and investment company, owners and desirous makers) did not pursue new projects or buildings using similar CLT technology or systems

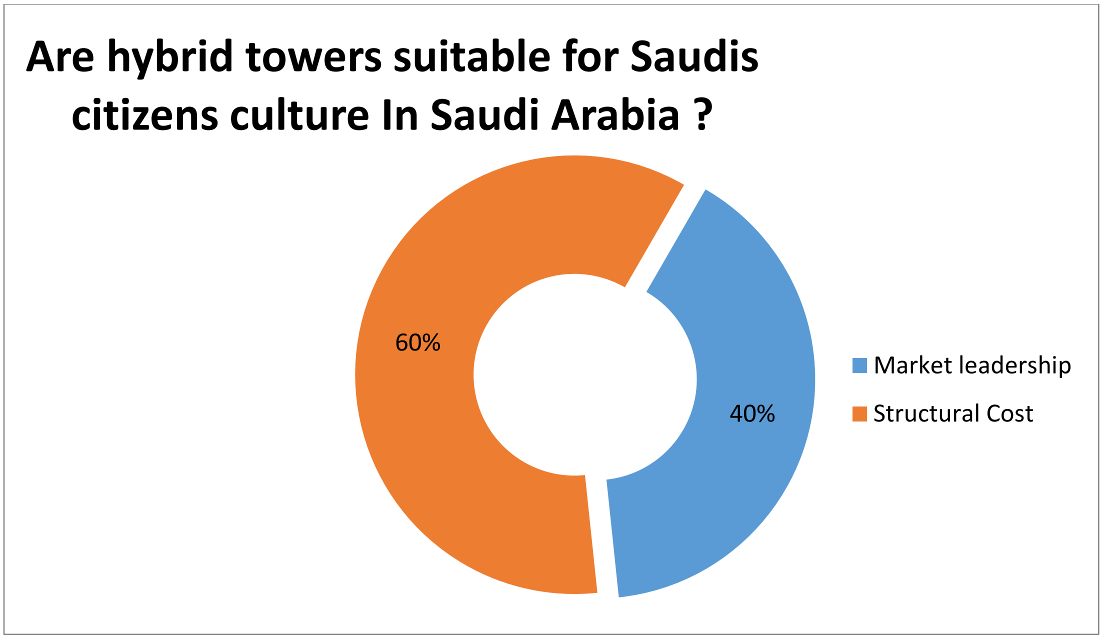


Figure 18 Are hybrid towers suitable for Saudis

Less than 40% of public (Citizen, resident) and professionals (engineers, business man and investment company, owners and desirous makers) think that hybrid towers suitable for Saudis citizens culture In Saudi Arabia.

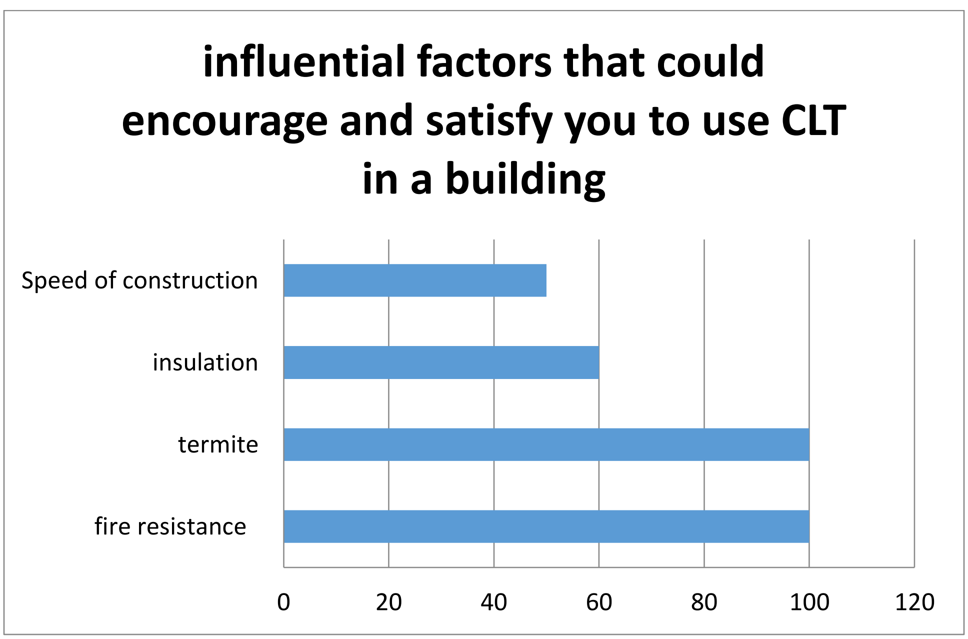


Figure 19 Influential factors that could encourage you to use CLT

Almost 100% of the public (Citizen, resident) and professionals (engineers, business man and investment company, owners and desirous makers) care fire resistance and termite if they want to use (CLT) technology.

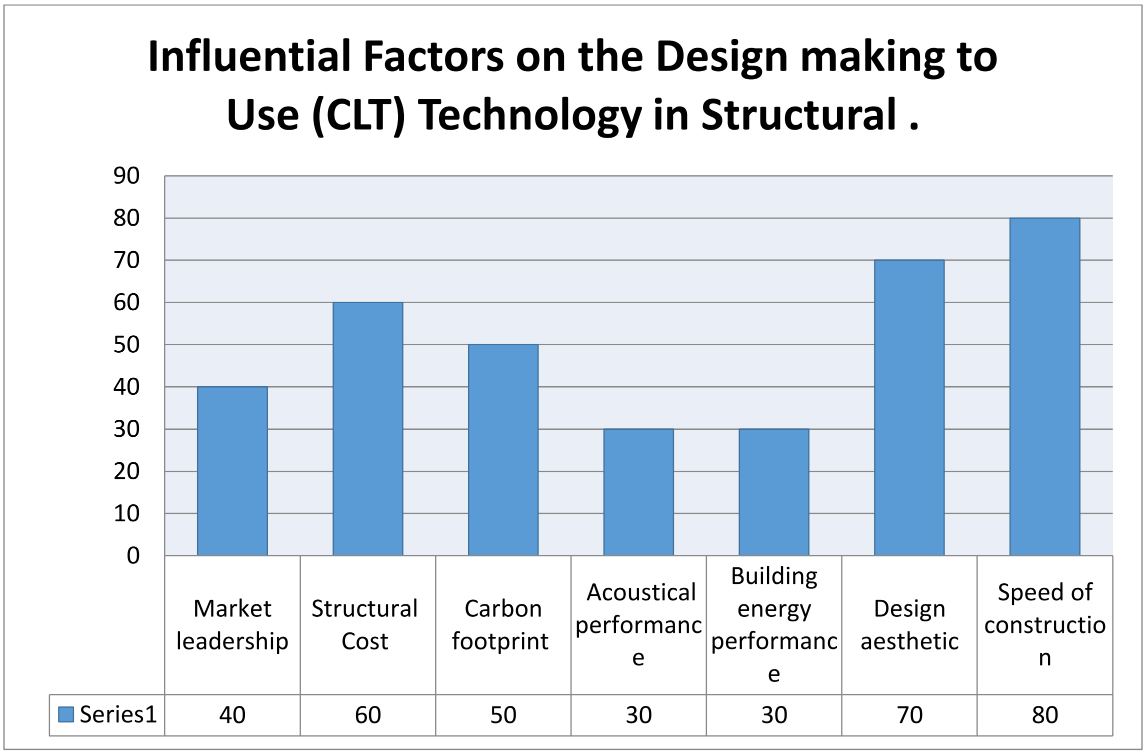


Figure 20 Influential factors on the design making to use CLT in structure

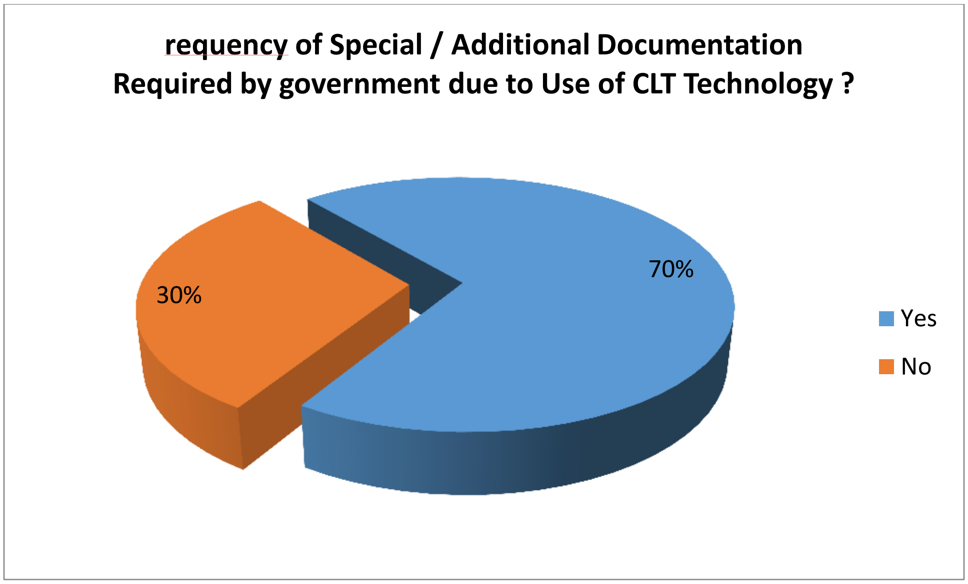


Figure 21 Requency of special documentation by government to use CLT

A majority of interviewed public and professionals about 70% believes that there will be request of Special / Additional Documentation by government due to Use of CLT Technology.

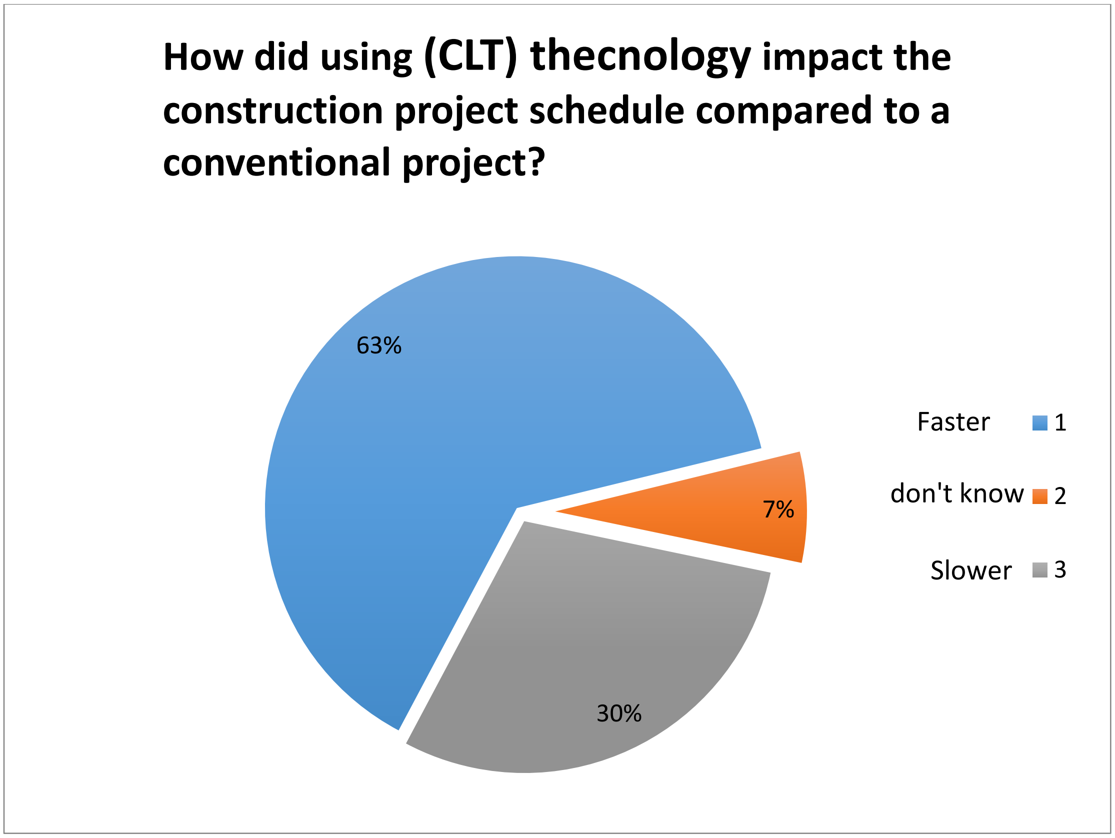


Figure 22 How did using CLT impact the construction project schedule compared to conventional project

More than 60% of public (Citizen, resident) and professionals (engineers, business man and investment company, owners and desirous makers) think that using (CLT) technology would effect on project schedule that would make it faster compared to a conventional project

Chapter 4: Planer Design

4.1 Concrete Slab:

The first stage of the structural design in a building is the Slab; it is the stage that controls the number of sub beams by deflection. To begin with; The type of slab must be known by dividing the width of the slab over the shortest span from one sub beam to another, this formula is taken from the ACI code.

4.2 Concrete Sub Beam and Slab Design:

From the calculations the type of slab is one way slab. Next step is to check the minimum slab thickness, This is done by using the formula from the ACI code 9.5.2.2 table 9.5(a), The width of the slab over 28, The result was 9.5in slab thickness. The second stage is to design the sub beam that will carry the load of slab and prevent deflection. Sub beams are used to transfer the load from the slabs to the main beams (Girders). The design of the sub beam is done based on the most critical sub beam that will take the maximum load from all side acting on the sub beam. Figure 23 shows the critical sub beam in the layout.

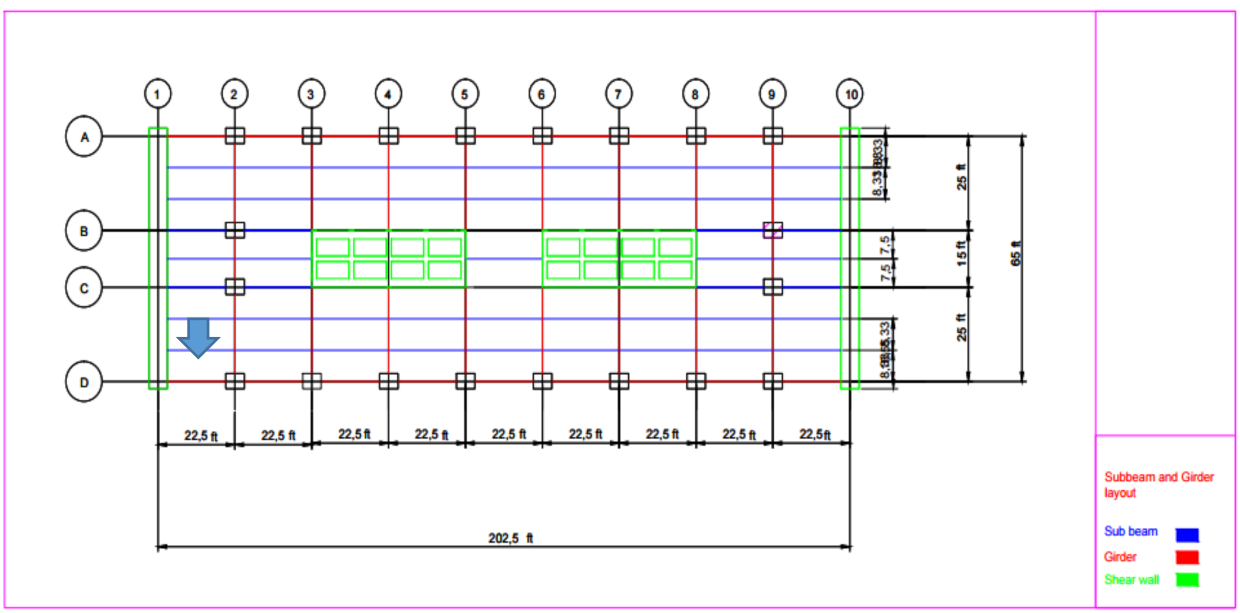


Figure 23 Layout with critical sub beam

This is done by subjecting the Sub beam with three sources of loads acting on the Girder, the sources are: first- Live load which is taken from the Saudi building code (SBC) chapter 4 table (4-1) commercial use tower, office type second- Superimposed load that comes from many sources, from the interior partitions, exterior wall and the flooring finishing. The interior partitions used are glass. The exterior walls are double glazed glass, the flooring finishing used is ceramic tiles, and therefore there is mortar to hold the ceramic tile with the floor. Third- Slab self-weight. Basically the summation of these loads will give the total gravity load that is acting on the sub beam as a uniform load which helps determine the cross section of the sub beam through the maximum moment.

$$M_B\,(\text{max}) = 181.18\ kips.ft$$

The calculated cross section of the sub beam is: b=8.5in, d=17in, h=20in

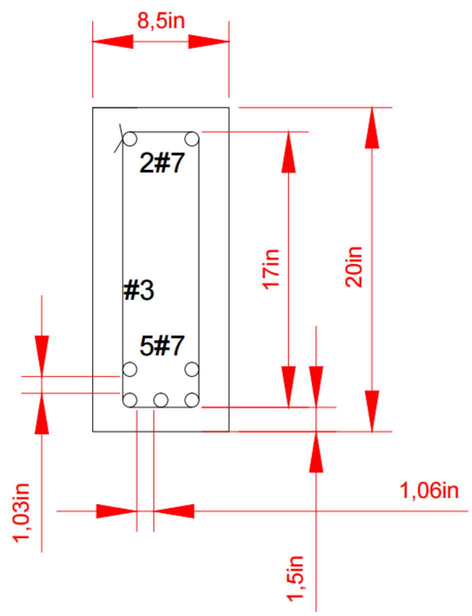


Figure 24 Sub beam cross section

Therefore the weight of the sub beam can be calculated. Total concrete weight of sub beam = $150\frac{\text{lb}}{\text{ft}^3}\left(\frac{8.5\times20-5\times0.6}{144}\right)=184.18\frac{\text{lb}}{\text{ft}}$. …………………….. eq (1)

To be able to figure out the total deflection of the sub beam including the self-weight of the sub beam. The area of steel is then calculated to figure the amount of steel needed to hold the tension forces in the sub beam. Based on (McCormac, Brown 2009 chapter 4) the following equation the area of steel is calculated.

AS, req = ρ × b × d

ρ = permissible steel ratio.

b= width of beam.

d= depth of beam.

ρ is calculated from another equation based on (McCormac, Brown 2009 chapter 4)

$$\frac{0.85\times fc\prime}{fy}\times 1-\sqrt{\left(1-\frac{2\times Mu}{0.85(fc\prime)}\right)}$$ ………………………………………eq (2)

After calculating the area of steel, 2.9in^2 . A match from the steel bars table in the figure below must be found that matches with the area of steel required. From the area of steel tables and number of bars 5#7 has area of 3.0in^2 which is larger than the steel minimum needed.

Checking the compatibility of steel area with available width

b min = 2(1.5)+2(0.375)+ 3(0.875)=6.375in

Spacing between bars = 8.5in - 6.375in = 2.125in

2.125/2=1.0625in

2 layer in the bottom, reinforcing steel of #7 which of those 3 in lower layer and 2 in upper layer.

Referring to figure 24 the area of steel is chosen from the table 1

Table 1 Area of steel table American A706 A1035 Steel Rebar Sizes & Rebar Stock

Imperial Bar size	"Soft" Metric size	Weight unit length (lb/ft)	Mass per unit Length (Kg/m)	Nominal Diameter (in)	Nominal Area (in^2)
#5	#16	1.043	1.556	0.625	0.31
#6	#19	2.044	3.049	0.750	0.44
#7	#22	2.67	3.982	0.875	0.6

4.3 Concrete Main Beams (Girder) design:

The last stage in designing the flooring systems is to design the Main beams or the girders. Girders transfer all the loads from the sub beams and the slab to the main system columns. The design of the girder is done based on the most critical girder in the system; if the most critical one is safe then the whole system is safe. Figure 25 below will identify the most critical Girder in the layout.

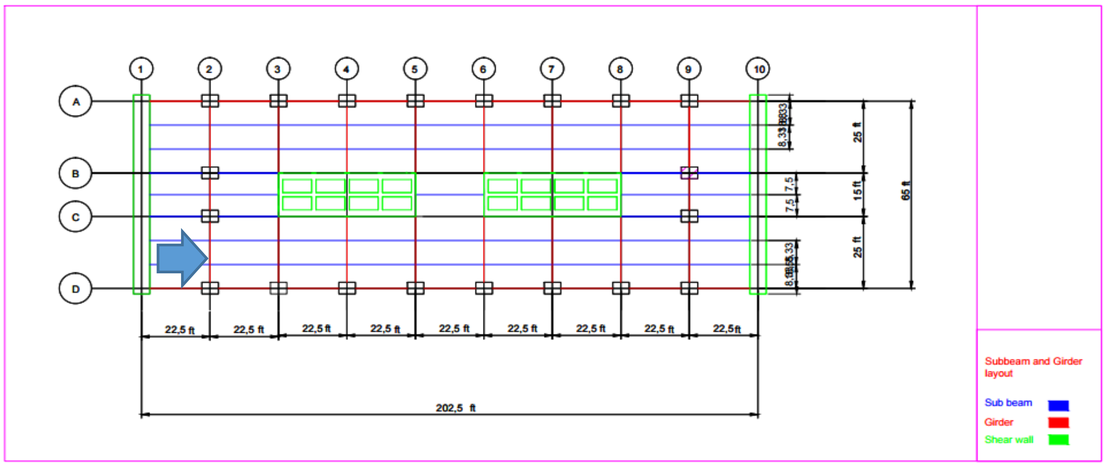


Figure 25 layout for critical Girder

The working concept of the girder is that, it takes all the loads as point load as the sub beams are sitting on the girder at different spans. The method for calculating the girder moment is same as the sub beam, but the only difference is the loads acting on the sub beam are uniform loads while the girder loads are point loads. The max moment is then calculated. Max Moment $=339.8 \text{ kips} - \text{ft}$.

Moment is the main aspect in calculating the cross section of any reinforced concrete beam, calculating the dimensions, b=9.5in, d=19in, h=22in. as shown in

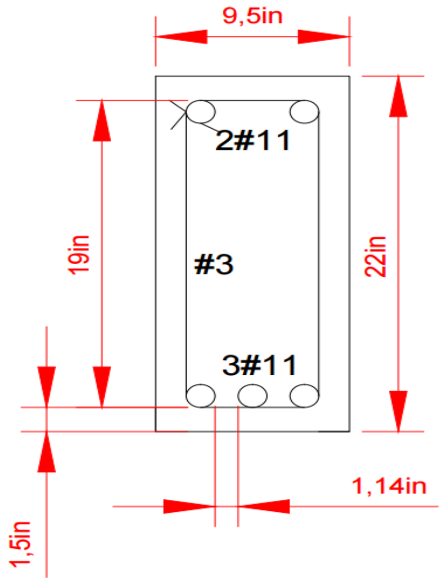


Figure 26 Girder cross section

in figure 16The total weight of the girder is then calculated. Total weight of sub beam = $284.2\frac{\text{lb}}{\text{ft}}$. After checking the deflection with the weight of sub beam is done. The area of steel is then calculated Based on (McCormac, Brown 2009 chapter 4) the following equation the area of steel is calculated.

AS, req = ρ × b × d

ρ = permissible steel ratio.

b= width of beam.

d= depth of beam.

ρ is calculated from another equation based on (McCormac, Brown 2009 chapter 4)

$$\frac{0.85\times fc\prime}{fy}\times 1-\sqrt{\left(1-\frac{2\times Mu}{0.85(fc\prime)}\right)} \text{ ....eq (2)}$$

AS req = 0.0197 × 10.5 × 21 = 4.35 in^2 Roundup to 4.5in^2

From the area of steel tables and number of bars 3#11 has area of 4.68in^2 which is larger than the steel minimum needed.

Checking the compatibility of steel area with available width

b min = 2(1.5)+2(0.375)+ 3(1.41)=7.98in

Spacing between bars = 10.5in - 7.98in = 2.52in   2.52/2=1.26in

Referring to figure 26 the area of steel is chosen from the table 2

Table 2 Area of steel for grider (American A706 A1035 Steel Rebar Sizes & Rebar Stock)

Imperial Bar size	"Soft" Metric size	Weight unit length (lb/ft)	Mass per unit Length (Kg/m)	Nominal Diameter (in)	Nominal Area (in^2)
#10	#32	4.303	6.418	1.27	1.27
#11	#36	5.313	7.924	1.41	1.56
#14	#43	7.65	11.41	1.693	2.25

4.4 Steel Sub Beam Design:

The design of the steel beams has the same concept of concrete sub beam, As both are designed based on the critical sub beam. But the properties of the material is different, As a result the criteria of designing is different. There are several steps and criteria that should be taken into consideration in order to design a preliminary steel section, The steel sections that are going to be used are W-shape. The first criteria is the local rapture of the sub beam. Second criteria is the sub beam slenderness. Third criteria is the sub beam effective length.

Table 3 Steel sub beam calculation

Subbeam	
Length(ft.)	22.5
Deflection limit	1.125
Unfactored UDL (kip/ft.)	2.088
moment(kip.ft)	132.1313
Minimum moment of inertia (in^4)	369.3109
Factored UDL (kip/ft.)	2.863
moment(kip.ft)	181.1742
Minimum moment of inertia(in^4)	506.3876
Reaction forces (kip)	32.20875
unfactored UDL include self-weight	2.119
factored UDL include self-weight	2.9002
moment(kip.ft)	134.093
moment(kip.ft)	183.5283
Check for deflection	1.124382
Check for deflection	
Check reaction	32.62725
section property	W14x38
Self-weight (kip/ft.)	0.038
moment of inertia (in^4)	385
Mpx(kip.ft)	231
Vx(kip)	131

4.5 Steel Girder Design:

The design of the steel girder is the same, Moment is calculated and from the moment, the effective section is selected; check the rapture, slenderness and deflection of the section from the moment acting from the weight of the slab, weight of sub beam, live load, dead load and weight of the girder.

Table 4 steel Girder Calculation

Girder	
Length(ft.)	25
Deflection limit	1.25
moment(kip.ft)	271.86
Minimum moment of inertia (in^4)	860.316
unfactored UDL include self-weight	0.065
factored UDL include self-weight	0.078
reaction without factor	33.44875
reaction with factor	33.61225
moment(kip.ft) without factor due self-weight	5.078125
moment(kip.ft) without factor due point load	277.6246
moment(kip.ft) with factor	285.0671
Check for deflection	1.026
Section property	w18x65
self-weight (kip/ft)	0.065
moment of inertia (in^4)	1070
Mpx(kip.ft)	499
Vx(kip)	248

Chapter 5: Steel Column Design & Modeling

5.1 Column Design:

One of the important stages in structural design of a building is the column, it is the stage that comes after the beam design and before the foundation design. Columns or compression members as some books says are designed to resist the compression forces that are acting on it. There are four sources of loads that are acting on the column, 1- Live load. 2- Dead load. 3- Slab self-weight. 4- Beam self-weight. Basically the summation of these loads will give the total compression force that is acting on the column as a point load. In this project the design will be in compliance with the Saudi Building Code (SBC), the American Institute of Steel Construction, and the LRFD design equations will be used.

The column steel sections that will be used are W-shape. There are several steps and criteria that should be taken into consideration in order to design a preliminary steel section. The first criteria is the local buckling of the column. Second criteria is the column slenderness. Third criteria is the column effective length. There are couple of steps to design steel column, the first step is to identify the critical column which will be designed for, and in order to locate the critical column the total factorized load acting on a column must be calculated. This step must be done several time to check which column is the critical one. In the table below is one example of calculating the point load that is acting on the critical column, also the tributary area can be seen with orange square in figure 27. The full excel sheet can be found in the appendix C.

Table 5 (Example of Point Load Calculation)

Load	Length (ft)	Length (ft)	Area (ft^2)	Thick-ness(ft)	Pressure force (kip/ft^2)	Density (kip/ft^3)	Factor	Pu(kip)= Area*Pressure force or Area*thickness*density
Live	22.5	20	450	0	0.1044	0	1.6	75.168
Dead	22.5	20	450	0	0.0285	0	1.2	15.372
Slab	22.5	20	450	0.791	0	0.150	1.2	64.125
Sub-beam	0	22.5	0.0778	0	0	0.490	1.2	1.029
Girder	0	20	0.133	0	0	0.490	1.2	1.564
Total								157.258

The second step after the converting the distributed loads into point load acting on the column, and after locating the critical column which is shown in the figure 27 below where the blue arrow pointing, is to start the steel design process using LRFD method in compliance with the SBC and AISC. Also the design process will consider several criteria such as column slenderness, stiffness, and local buckling. From First of all K constant will be assumed as 1 time been based on the value in figure 28 below, and after getting the steel sections. The accurate effective length will be calculated. In the column design there will be 6 different variations in the column size, the purpose of these variations is to reduce the column size in top floors due to lower gravity load acting on it.

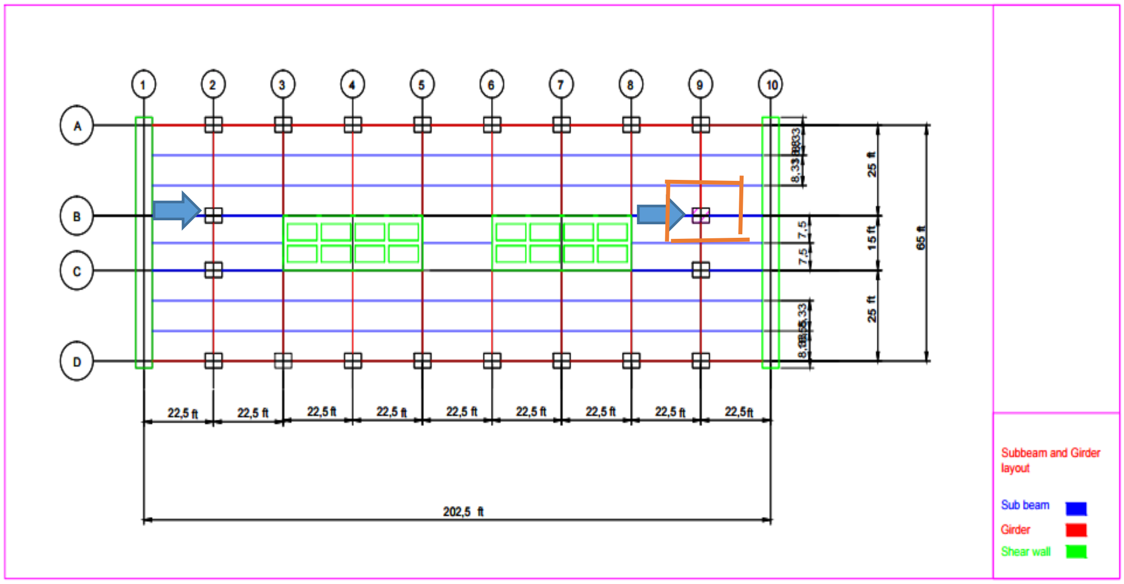


Figure 27 Typical floor layout with critical column

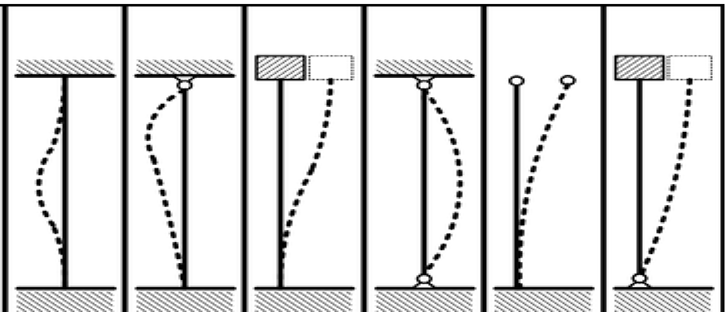
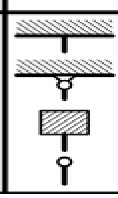
Buckled shape of column shown by dashed line						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value K	0.65	0.80	1.2	1.0	2.10	2.0
End condition key		Rotation fixed and translation fixed Rotation free and translation fixed Rotation fixed and translation free Rotation free and translation free				

Figure 28 K value (McCormak, Csrenak, 2012)

The equation used to design steel column and compression is

$$\emptyset Pn = \emptyset \times Fcr \times Ag \text{ (AISC Equation E3-1)} \emptyset = 0.9.$$

And in order to find Fcr which is the flexural buckling stress of a column the ratio $\frac{K \times L}{R}$ must be calculated first, where K is a constant, L is the column length, and R is the radius of gyration. After finding this ratio the required steel column section can be either found directly from table 4-1 from AISC Manuel or indirectly by going to table 4-22. Since K is assumed to be equal to 1 and the length of the column is 13 ft. for the first 3 stories and 10 ft. for the rest of the building, a section can be found directly from the AISC table 4, this case only applicable for the top floors since they carry less loads, however for the lower floors the indirect method is going to be implanted in order to get the required steel section. In following table is a summary of the total load obtained for each variation.

Table 6 Total Pu for floors

Floor Group	Pu (Kip)
1-3	9435
4-23	8806
24-33	5661
34-43	4088
44-53	2516
54-60	943.52

From the 60 story to the 4 story the direct design method is going to be used since the force relatively small and it is available in the AISC Manuel. To use the table 4-1 in the AISC Manuel for W-shape two things must be known, which are: 1- K value which assumed to be 1. 2- The length which is 10 ft. By entering the table 4-1 for W-shapes and Fy-50 ksi will find the required steel sections. In the table below is the selection of steel column section for each floor group, and the property of the section. (The section have been selected with tolerance added)

Table 7 Preliminary steel column section

Floor Group	PU (kip)	Steel Section	ϕcPn (kip)	Area Gross (in^2)	Ry (in)
1-3	9435	W14X800	10124.2	227	4.72
4-23	8806	W14X730	9130	215	4.69
24-33	5661	W14X550	6840	162	4.49
34-43	4088	W14X398	4920	117	4.31
44-53	2516	W14X233	2900	68.5	4.1
54-60	943.52	W14X120	1470	35.3	3.74

This part for indirect design for the first three stories. First the ratio $\frac{KL}{r}$ will be considered equal to 30, then for fy= 50 ksi ϕcFcr from AISC table 4-22 equal to 42.1 Ksi, the gross area required is equal to $\frac{9435}{42.1} = 224.64\ in^2$. After getting the required area, going to the ETABS software where section is going to be designed with following dimension:

Table 8 Dimensions for a manually designed steel section

Depth (in)	Web thickness (in)	Flange width (in)	Flange thickness (in)	Moment of inertia x-x (in4)	Moment of inertia y-y (in4)	Radius of Gyration (in)
22.6	3.4	18.1	5.1	15108	5084	4.72

After the designed steel columns have been preliminary designed, and the beams already been designed. It is possible now to get the accurate K value for the column that have been preliminary designed. In order to get the accurate K Value G factor must be calculated first through this equation:

$$\frac{\sum(\frac{Ec\times Ic}{Lc})}{\sum(\frac{Eg\times Ig}{Lg})}$$ AISC equation (C-A-7-2). E: modulus of elasticity, I: moment of inertia (inch4), L: Length (in).

It is important to calculate the true K value because assuming is K value as 1 is so conservative sometimes, and sometimes it might be not, but it is also safe because it is recommended by the SBC and AISC codes. The importance of calculating the accurate K value is to know the true effective length of the column, and in order to do that the columns and the beams section must be known. There are two type graphs that are going to be used in order to get the K value, these two graphs depend on the G factor and on the sideway. The two type of graphs can be seen in figure 2 9 below**.**

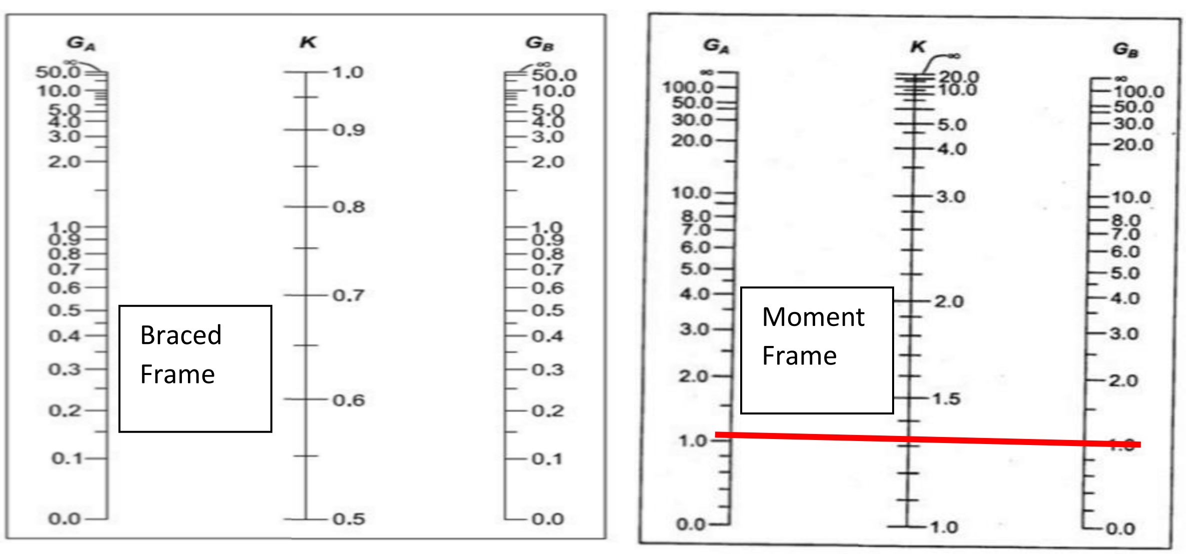


Figure 29 Jackson and Moreland Alignment Chart (McCormac, Csernak, 2012)

In the table below an example is shown on how to calculate the G factor and the new K value.

Table 9 G factor

Floor group	Shape	Moment of inertia (in)	Length (in)	I/L	G	K
1-3	W14X800	15108	156	N/A	0	1
4-23	W14X730	14300	120	N/A	0	1.1
24-33	W14X550	9430	120	78.58	6.61	2.4
34-43	W14X398	6000	120	50	4.2	2
44-53	W14X233	3010	120	25.08	2.1	1.6
54-60	W14X120	1380	120	11.5	0.96	1.25
Girder	W18X65	1070	180	5.944	N/A	N/A

After calculating the new K value, a new stiffness reduction factor tau will be calculated to get more accurate design instead of overly designed sections. The tau factor depends on the column and girder. The equation for calculating tau is:

$\tau = 4\left(\alpha \frac{Pu}{Py}\right) \times [1 - \left(\alpha \frac{\mathrm{Pu}}{\mathrm{Py}}\right)]$ AISC equation C2-2b. Where α =1, Py=Fy*Ag

Or stiffness reduction factor tau can be found directly from the table 4-21 (AISC, 2013) by dividing the total load by the total area of the steel section. In the table 10 below is the tau stiffness factor with the new K factor.

Table 10 K based on Tau

Floor group	Shape	Pu (kips)	Ag(in^2)	Pu/Ag	Tau	New K
1-3	W14X800	9435	227	N/A	N/A	1
4-23	W14X730	8806	215	N/A	N/A	1.1
24-33	W14X550	5661	162	34	0.9	2.1
34-43	W14X398	4088	117	35	0.84	1.7
44-53	W14X233	2516	68.5	36	0.8	1.3
54-60	W14X120	943.52	35.3	26	0.9	1.1

After finding the last modified K factor based on tau stiffness reduction factor, it is needed now to check if the section with new K value is safe and can handle the loads on it, after checking the sections, the next step would be the modeling. In the table below is the new ϕcPn which is based on the new K.

Table 11 New ϕcPn for steel sections

Floor Group	PU (kip)	Steel Section	KL	ϕcPn (kip)
1-3	9435	W14X800	13	10124.2
4-23	8806	W14X730	11	9130
24-33	5661	W14X550	21	5790
34-43	4088	W14X398	17	4470
44-53	2516	W14X233	13	2770
54-60	943.52	W14X120	11	1450

5.2 Modeling:

After finalizing all the preliminary designs starting by slab and beams and finishing by columns. This step very important because using the software mentioned in chapter 1 that will be used for the analysis is extensional three dimensional analyses for building systems (ETABS) will help to check a lot of parameters such as the steel stress/strain ratio, story drift, floor deflection, and a lot of parameters that are important to check the structural performance. First step in the modeling is to create a two steel frame model one using typical reinforce concrete slab, and the other model will use the cross laminated timber slab, however the first three stories for the CLT model will be concrete slab. Second step is to draw the floor layout on the grid with moment connections with the shear wall openings, after that the steel sections must be defined using the data in table 4 before, and the data mentioned in chapter four for the beams. After defining all the steel sections, the slab must be defined. For the first model the slab will be reinforce concrete slab with 9.5 in. thickness, and for the second model a CLT slab will be used and the mechanical properties for the CLT that will be entered can be found in table 12 below. A wall section will be defined using a 5000psi concrete material with a wall thickness 30 inch.

Table 12 Mechanical Properties (Asiz, Ahmed. 2013)

Property	Steel	Concrete	CLT
Directional Properties	Isotropic	Isotropic	Orthotropic
Density	7200	2400	400
Elastic modulus	200	25	E1=9 E2=4.5 G12=0.5
Poisson's ratio	0.3	0.25	V12=0.3
Strength	250	27.5	Ft-1=20, ft-2=15 Fc-1=30, fc-2=25 F-shear=5
Notation: E=elastic modulus; G= modulus of rigidity; 1= CLT major direction; 2=CLT minor direction; t=tension; c=compression			

After defined all the required sections. The load cases and patterns must be defined in order to check the structural performance under gravity loads, wind loads, and seismic load. First things will be defined is the gravity loads (dead and live) and then applying these loads on the slabs. The other two cases which are wind and seismic will be defined as linear static using lateral load definition of ASCE 7-10 and according to the Saudi Building Code (SBC 301). Since the wind and seismic loads doesn't act only on one axis, they will be defined separately in x and y directions. The wind load is going to be assigned for the highest registered wind speed in the SBC occurred in Saudi Arabia for exposure B which means that the building will be located inside a urban area with an frame exposure, the highest wind speed is located in Qaseem with a speed of 190 km/h as located in figure 6.4-1 (SBC 301, 2007). For the seismic load the pattern will be seismic drift, and the load definition is spectral acceleration will be equal to 0.33 based on the figure 9.4-1(SBC 301, 2007) and the exposure type is D because the soil type isn't fixed for a certain location. After that Load cases will be defined. The load cases are according to the SBC 301 and can be found in the table 13 below.

Table 13 Load cases

Load case	Load pattern	Safety factor
DL+LL	Dead load Live load	1.2 1.6 Eq2.3.2-2(SBC 301)
DL+Windy	Dead load Windy	0.9 1.6 Eq2.3.2-6(SBC 301)
DL+Windx	Dead load Windx	0.9 1.6Eq2.3.2-6(SBC 301)
DL+EQy	Dead load EQY	0.9 1.6 Eq2.3.2-6 (SBC 301)
DL+EQx	Dead load EQX	0.9 1.6 Eq2.3.2-6 (SBC 301)

After defining all the steel, slab, wall sections the two model is ready for analysis by ETABS based on the load cases which also have been defined. As mentioned before this is the last step but it's also a very important step because this analysis is going to check the structural performance to make sure that the structure is safe, then a comparison will be happening between the two floor systems. The results will be discussed in the following chapters, and to compare between the models also will be discussed on the last chapter.

Chapter 6 Concrete Column Design & Modeling

6.1 Column Design:

Designing concrete columns will follow the same initial steps mentioned in chapter 5.Converting all loads on critical column into a point load. Since concrete is heavier than CLT, concrete slab was used in calculating the point loads. The table below shows calculation of point loads using concrete slab. Calculations for several column locations are available in the appendix.

Table 14 Point load calculation for RC frame

Load	Length (ft)	Length (ft)	Area (ft^2)	Volume (ft^3)	Thickness(ft)	Pressure force (kip/ft^2)	Density (kip/ft^3)	Factor	Pu(kip)= Area*Pressure force or Area*thickness*density
Live	22.5	20	450	0	0	0.1044	0	1.6	75.168
Dead	22.5	20	450	0	0	0.0285	0	1.2	15.372
Slab	22.5	20	450	0	0.792	0	0.15	1.2	64.125
Sub-beam	0	22.5	1.181	26.562	0	0	0.15	1.2	3.9843
Girder	0	20	1.451	29.027	0	0	0.15	1.2	4.35416
Total									163

The building floors were divided into several groups. The design of the columns for each group was based on the most bottom column in each group. In order to find the total point load on each column, we multiply point load calculated earlier by the number of floors above the desired column. The table below shows the calculations.

Table 15 PU for floors groups

Floor Group	Pu (kip)
1-3	9780.1909
4-13	9291.18135
14-23	7661.14953
24-33	6031.11772
34-43	4401.0859
44-53	2771.05408
54-60	1141.02227

To calculate the cross sectional area of the columns for each group this equation was used.

$$Pu = 0.8\phi \times 0.85\, fc'\, Ag$$

The equation have been taken from (Wong, Salmon, 1992).

The table 16 below shows the calculations of cross sectional areas. However for certain groups the area was huge. Therefore it was modified to use reasonable dimensions.

Table 16 Columns dimensions

Floor Group	Ag(in²)	dimension (in)	used (in)
1-3	5136.65488	72x72	60x60
4-13	4879.82214	70x70	60x60
14-23	4023.71299	64x64	60x60
24-33	3167.60384	57x57	57x57
34-43	2311.49469	49x49	49x49
44-53	1455.38555	39x39	39x39
54-60	599.276403	25x25	25x25

6.2 modeling:

After obtaining the preliminary design of slabs, sub beams, beams, and columns, it was important to verify the design complies with SBC and ACI. The program used for the analysis is (ETABS) as mentioned earlier in the first chapter. The ETABS allows us to check slab deflection, members passing or not, and story drift. The first step was modeling one floor for two different slabs materials with all structural elements. The two slabs are concrete and CLT. (The properties of the materials used are mentioned in table 12). The elements include slabs, beams, columns, and shear walls. The second step was defining the materials that will be used in the modeling. The concrete used for slab, beams and columns is 4000psi concrete. The shear walls concrete however is 5000psi concrete. The dimensions of all structural members were used as per the preliminary design. However, wall thickness was used as 30in. Third step was applying loads on the frame. The loads include dead, live, wind and seismic loads. Dead and live load were applied to the slab, while wind and seismic loads were assigned to the frame. The last step was defining the load cases. The values for the loads and load cases were mentioned earlier in the chapter 5. By the end of this step, the model was ready to check the performance of the building against the load cases.

Chapter 7: Foundation Design

Foundation is an essential part of any structural building because it holds the structure, and it is the last stage of the building design. There are mainly three type of foundation: 1- Shallow foundation. 2- Deep foundation. 3- Mixed Foundation. For the first type shallow foundation it comes with three different type either individual footing, strip footing, or raft or mat foundation. Shallow foundation is basically considered as surface foundation because of its relatively short depth, the material used for the shallow foundation is reinforce concrete, Shallow foundation is usually used for small buildings because it can't carry a lot of weight, also its considered cheap because it requires less excavation.

The second type which is the deep foundation it comes with one type which is pile foundation, it called deep foundation because it requires a very deep exaction in order to place the pile, usually it made from steel, but sometimes it can be made out of reinforce concrete. The deep foundation is usually used for heavy-weight structure that require a very strong, also it used when there is a weak soil layers near the surface. The pile foundation comes in two type either end bearing pile, or friction pile. The deep foundation most of the time require a solid rock layer to place the piles because of the settling time, rarely it can be placed in a weak soil but the friction pile must be used in this case. The deep foundation is considered expansive because it requires a very deep excavation

The third type which is the mixed foundation is basically a mix between the shallow foundation, and the deep one. For this type engineers usually mix the raft or mat shallow foundation with the end bearing pile foundation, the mix is very beneficial and it usually used for high-rise buildings. This is the type that is going to be implanted in the report. Further discussion about the design process for this project will be in the next pages. Also one example will be shown in chapter 7 the rest can be found in appendix D**.**

7.1 Raft or Mat Foundation Design:

As mentioned before the type of the foundation is mixed, so the first design step would the raft foundation, the following example is for steel frame with a concrete slab. The first step of designing the raft foundation is to calculate the ultimate bearing capacity of the soil will considered as 35kips/ft2

After calculating the ultimate bearing capacity of the soil, the next step is to calculate the depth of the raft foundation. The design method that is going to be used is the conventional rigid method. The first step is to identify the highest total base reaction force from the load cases that have been mentioned in the previous chapter, and the total base reaction was as expected dead and live load combo. After identifying the critical load case, second step is to calculate the pressure from the column or joints on the soil using the following relation:

$q = \frac{Q}{A} + \frac{My*x}{Iy} + \frac{Mx*y}{Ix}$ Where: q=pressure (kip/ft2), Q= total reaction forces (kips), A= area of the building (ft2), M= moment (kip.ft), x or y= distance from the joint to the center of the building (ft.), I= moment of inertia (ft4)

To simplify the design process well-distributed joints with high reaction forces have been taken, the following table is summary of the calculation:

Table 17 joint pressure on soil calculation

label	X	y	Q Total	My	Mx	Ix	Iy	A	q
			kips	kip.ft	kip.ft	ft^4	ft^4	ft²	kips/ft²
1	-101.25	32.5	399294	-33677.2	-37863.3	4627431	44978730	13162.5	30.14566
23	101.25	32.5	399294	-33677.2	-37863.3	4627431	44978730	13162.5	29.99404
11	-101.25	-32.5	399294	-33677.2	-37863.3	4627431	44978730	13162.5	30.67752
20	101.25	-32.5	399294	-33677.2	-37863.3	4627431	44978730	13162.5	30.5259
29	-33.75	32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.09512
26	33.75	32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.04458
14	-33.75	-32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.62698
17	33.75	-32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.57644
75	101.25	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.25997
7	-101.25	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.41159
325	-36	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.36273
337	36	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.30883
			399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.33578

After getting several pressure forces on the soil, the next step is to choose one critical strip of joints with high reaction forces to obtain the shear, and moment diagram to calculate the area of steel later. The strip of joint that have been selected can be seen in the figures 30, 31, 32 below.

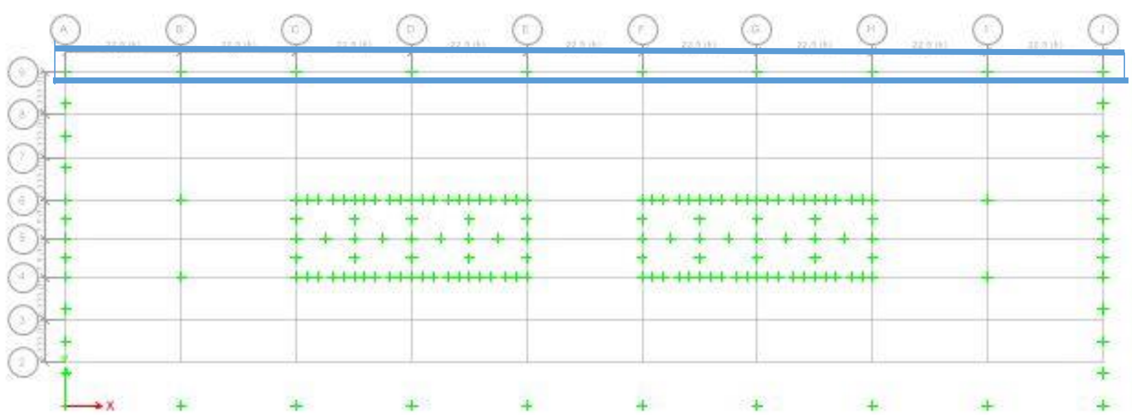


Figure 30 Joint layout

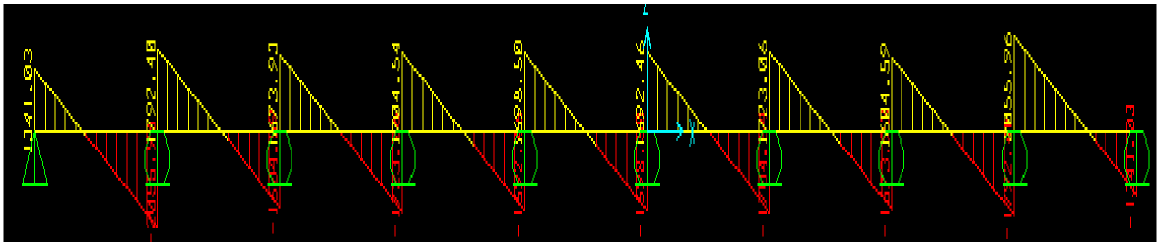


Figure 31 shear diagram

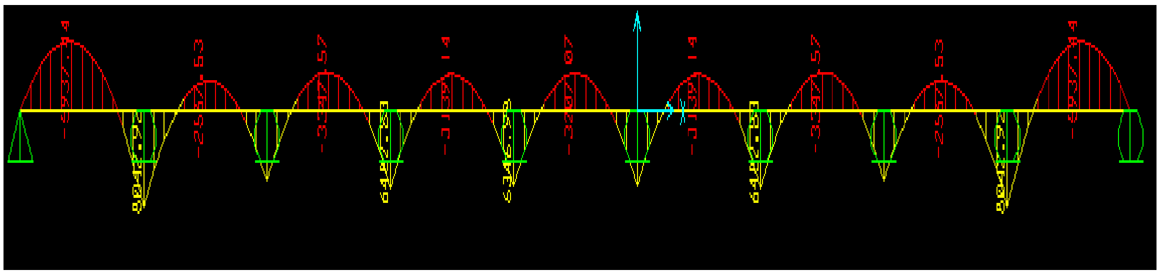


Figure 32 Moment diagram

The next step is to calculate the raft foundation depth using the following equation:

$U = bo \times d \times (\Phi \times 0.34 \times \sqrt{fc'})$ Where: U= highest reaction force (MN), bo= tributary perimeter around the column (m), d= depth (m), $= 0.85$, fc'= 27.5 MN/m^2

Following table shows the calculation:

Table 18 Foundation depth

u	u	fc'	d
kips	MN	MN/m^2	m
4184.91	18.615	27.5	2.5

The last stage of the raft foundation design is to calculate the required area of steel for the raft. In order to calculate the area of steel, the first thing needed is the ultimate moment that can be seen in figure 32 above, after that the following equation will be used:

$Mu = \Phi \times As \times fy \times (d - \frac{a}{2})$ Where Mu= ultimate moment (kip.ft), $\Phi = 0.85$, As= area of steel (ft^2), fy= 50 (ksi), d= depth (ft)

The rest of the calculation for the other buildings can be found in appendix D

7.2 Pile foundation design:

The pile foundation design will consist of one part which is calculating the elastic settlement because the pile will be piled on a rock bed. In order to calculate the elastic settlement, a several diameters of steel piles will be assumed in order to check which one gave an appropriate time of settlement.

To calculate the elastic settlement of the pile the following equation is going to be used:

$$S1 = \frac{Q \times L}{A \times E}$$

Where Q= point load (KN), L= pile length (m), A= pile cross section area (m^2), E= elastic modulus (pa)

The following table has an example of pile foundation calculation:

Table 19 Pile foundation calculation

Pile foundation	Raft depth (m)	L(m)	diameter pile(m)	area of pile (m^2)	Q(kN)	elastic (Gpa)	Elastic settlement (m)
1	2.5	7.5	0.03	0.0007065	24349.56	2E+11	0.001292439
2	2.5	7.5	0.04	0.001256	24349.56	2E+11	0.000726997
3	2.5	7.5	0.05	0.0019625	24349.56	2E+11	0.000465278
4	2.5	7.5	0.06	0.002826	24349.56	2E+11	0.00032311

The rest of the calculation can be found in appendix D. The raft and pile cross section can be found in the figure 33 below.

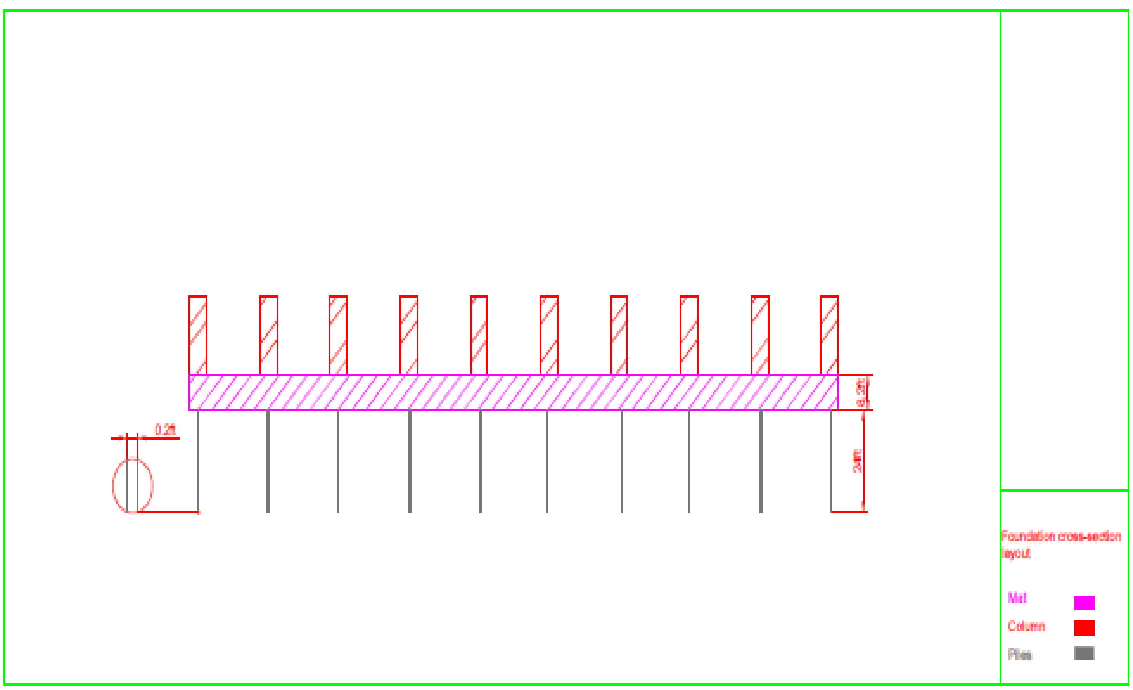


Figure 33 foundation cross section

Chapter 8: Results

After all four models have been run using all the cases mentioned before. In this chapter a comparison between reinforce concrete slab with CLT slab in a reinforce concrete frame, and reinforce concrete slab with CLT slab in a steel frame will going to be conducted in order to check the buildings performance under the gravity loads and the lateral loads, and to come up with a conclusion in chapter 9.

8.1 Steel Buildings:

As anticipated the wind load in general and specifically in the y direction was the governing load for the drift, and the gravity load was the governing for the base reaction as mentioned in chapter 6 in the steel frame both for reinforce concrete slab and CLT slab, that is due of the building height which is 600 ft., also since the building have a rectangular layout. The comparison between the two slabs will consider several criteria, the first one is the building drift in y and x axis due to wind, as seen in figure 34, 35 below. As seen the maximum drift due to wind and dead load combinations in the steel frame with CLT slab is higher by approximately 5 inches in total comparing it with the steel building with reinforce concrete slab. The detailed drift and the inter-story drift can be seen in appendix E**.** However, both steel frames drifts are less than the maximum allowable drift mentioned in the Saudi building code for occupation category 2 (SBC301, 2005).

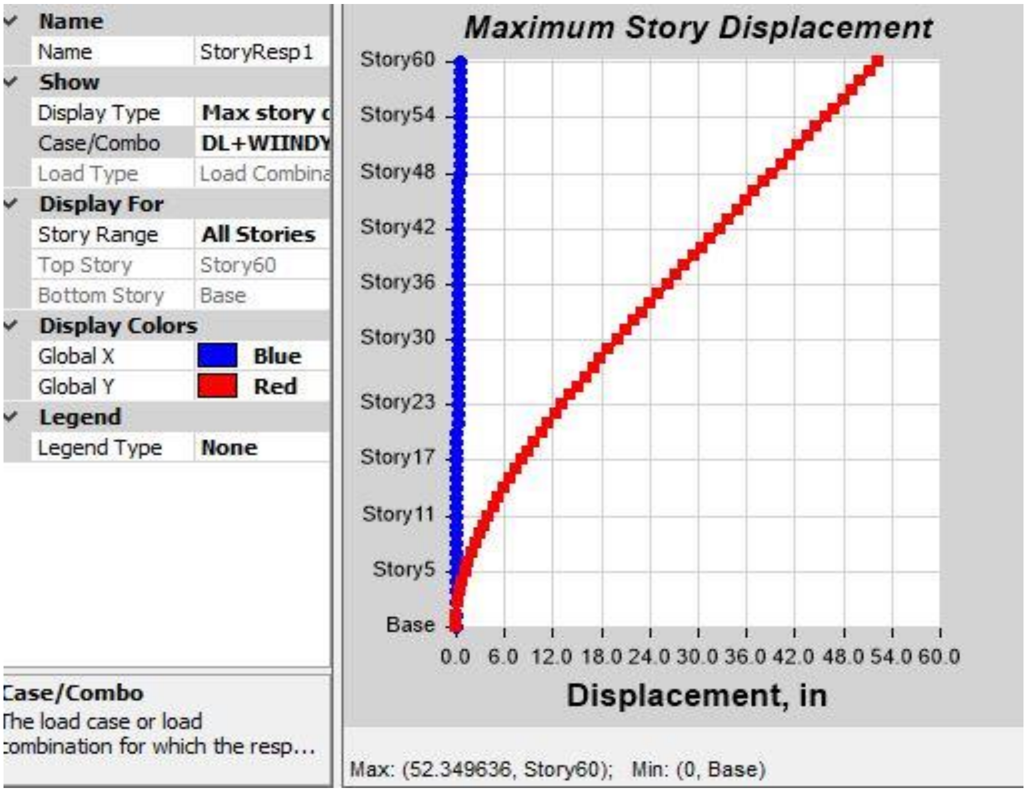


Figure 34 Steel frame with RC slab displacement

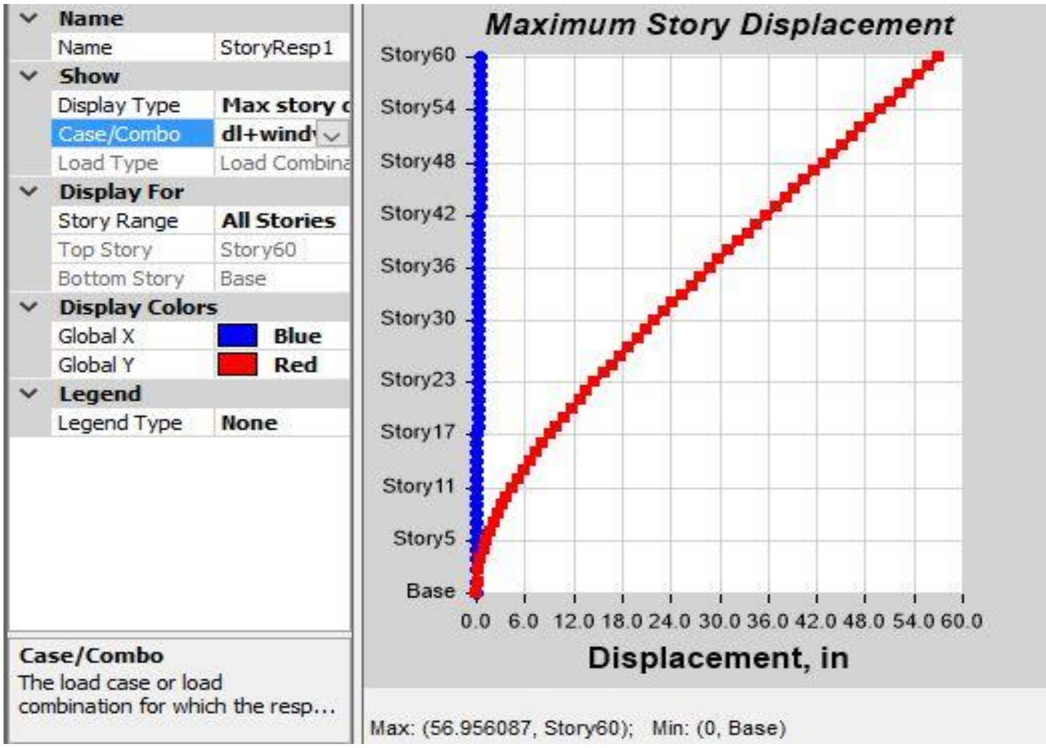


Figure 35 Steel frame with CLT slab displacement

Second criteria is the slab deflection. Slab deflection have been checked only under gravity load which have the dead and live load combination, since slab or floor system are designed to carry gravity loads only. It has been noted that reinforce concrete slab have a maximum deflection of 0.7 in. comparing to 0.8 in reinforce CLT slab. That comes from the stiffness and the high modulus of elasticity of reinforce concrete slab comparing it to the CLT slab. The floor deflection can be seen in figure 36, 37**.**

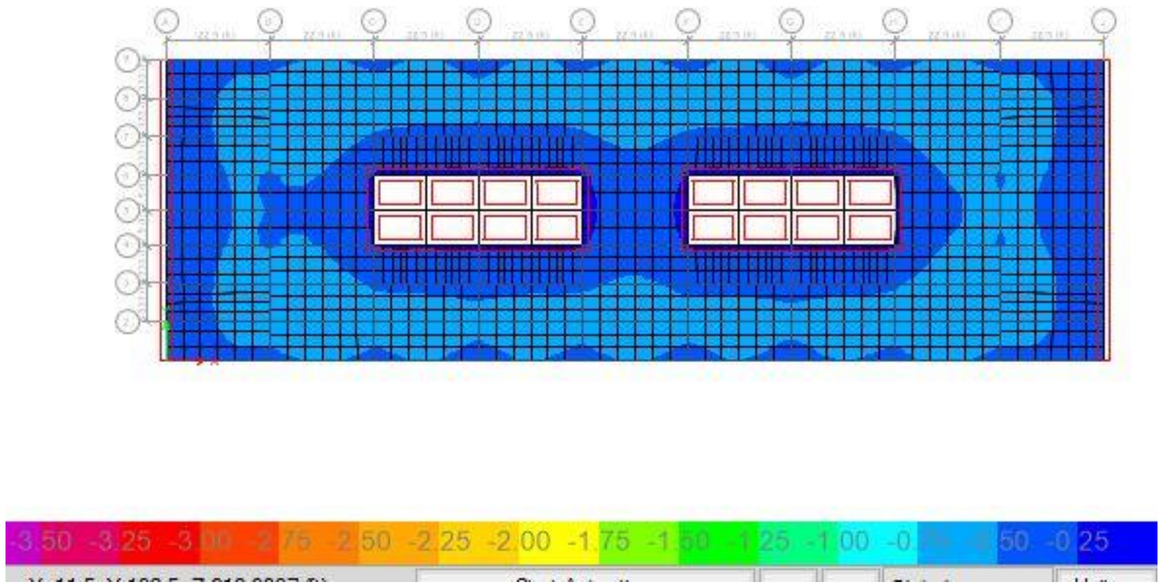


Figure 36 RC slab deflciton

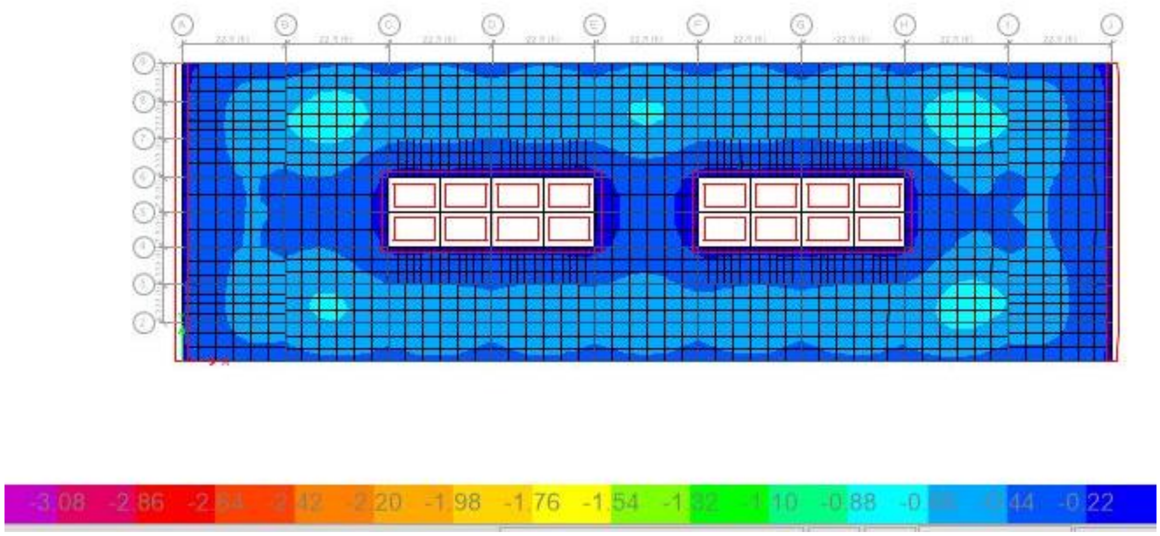


Figure 37 CLT slab deflection

Third criteria is the stress/strain ratio. The stress/strain ration is an indication for how safe is the steel member based on its capacity, and how much is the deformation based on the stress applied on the member, the stress/strain ratio should be less than 1 if it is more than 1 it means that the steel member is going to fail under the stress acting on it. It has been noted that most of the stress/strain ratio for the steel frame with reinforce concrete is higher than the one with CLT slab in all load cased, that's due of the heaviness of reinforce concrete slab that is causing higher stress and moment on the steel members.

Fourth criteria is the reaction forces in the base floor. It is important to check the reactions because as mentioned in chapter 6 it will help in designing the foundation. As mentioned before that the governed force was the gravity load as mentioned in chapter 6, and in table 19 and 20 below total reactions forces obtained from steel frame with reinforce concrete slab and the steel frame with CLT slab.

Table 20 Steel frame, R.C slab reaction forces

R.C						
load case	FX(kips)	FY(kips)	FZ(kips)	MX(kips.ft)	MY(kips.ft)	MZ(kips.ft)
DL+LL	0	0	399294.707	12939157	-40394830	-0.00002351
DL+EQx	-1656.854	0	234090.972	7576454	-24416428	53605.3443
DL+EQy	0	-1152.539	234090.972	8093194	-23673579	-116544
DL+wind x	-6774.504	0	210681.875	6818809	-23595734	195441.5796
DL+wind y	0	-16733.522	210681.875	12483985	-21306221	-1632149

Table 21 Steel frame, CLT slab reaction forces

CLT						
load case	FX (kips)	FY(kips)	FZ(kips)	MX(kips.ft)	MY(kips.ft)	MZ(kips.ft)
DL+LL	0	0	319247.433	10337700	-32290044	-0.00002786
DL+EQx	-1259.747	0	167384.91	5408574	-17482088	40664.5863
DL+EQy	0	-1259.747	167384.91	5971072	-16919590	-127302
DL+wind x	-6774.504	0	150646.419	4867716	-17517144	195441.5791
DL+wind y	0	-16733.522	150646.419	10532893	-15227631	-1632149

Fifth criteria is the foundation demand. The foundation demand have been designed in chapter 7 because it is one of the essential criteria in comparison since is a very critical element in any structural building. The results that have been obtained and can be seen in table 22 below shows that the steel building with CLT floor systems require less foundation than the RC floor system, and that comes from the lightness of the CLT slab compared to the RC slab, also that means that less excavation and civil works are required. For the pile foundation in order to have reasonable comparison the length of the piles will be equal and the diameter of the pipe also will be equal.

Table 22 Foundation Demand for steel building

Building type	Steel building with RC slab	Steel building with CLT slab
Raft foundation depth (m)	2.5	2
Raft foundation As (ft^2/ft	0.12 for negative moment 0.022 for positive moment	0.1 for negative moment 0.018 for positive moment
Pile foundation settlement (mm)	0.3	0.2

8.2 Reinforce Concrete Buildings:

For reinforce concrete building almost the same criteria that have been used before in the steel building will be used for reinforce concrete building in order to get the results and to check the structural performance of the two building that have different type of slabs.

First criteria is the building drift. The building displacement will be checked under wind with dead load in the y direction since it was the highest, as shown in the figure 38 ,39 below, the reinforce concrete frame with reinforce concrete slab have less displacement than the reinforce concrete building with CLT slab almost 10 in.

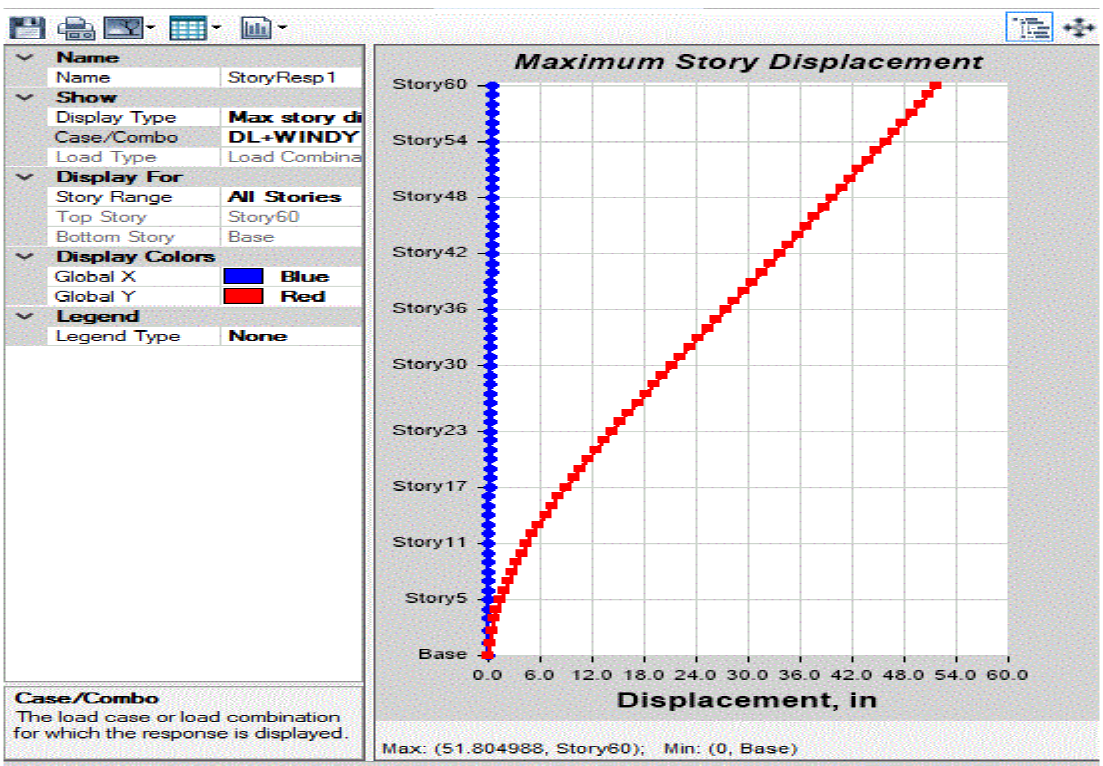


Figure 38 RC frame with RC slab displacement

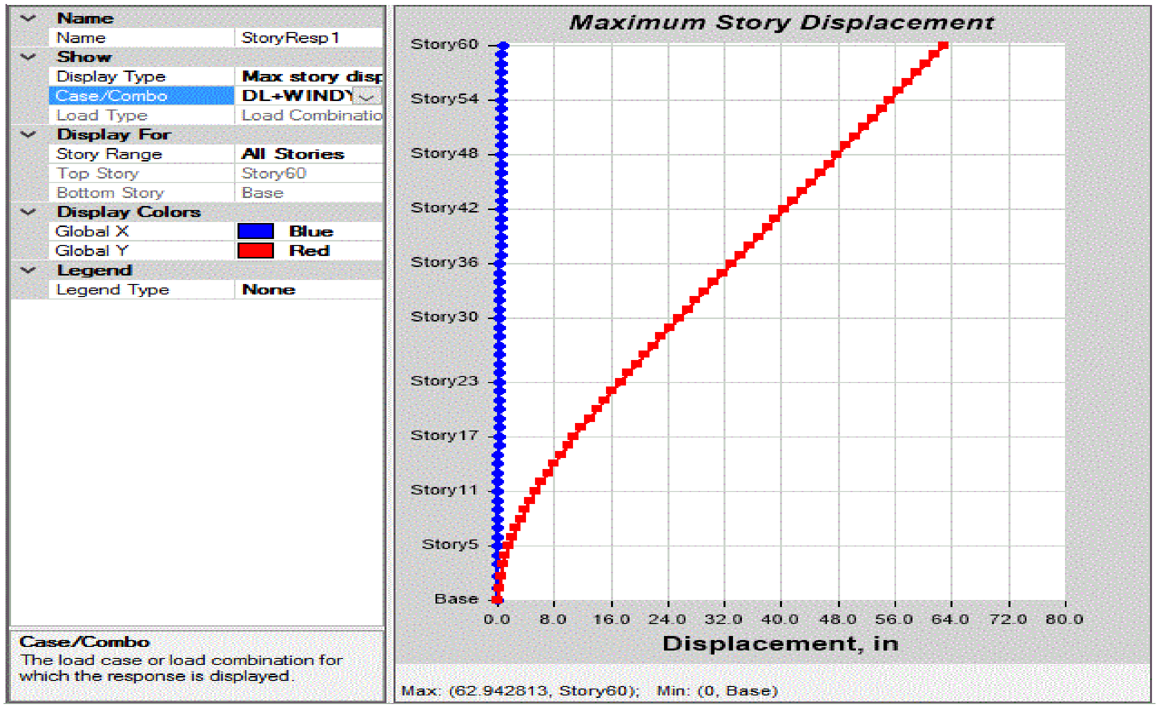


Figure 39 RC frame with CLT slab displacement

Second criteria is the slab deflection. The slab deflection will be checked under gravity loads only, and as shown in figure 40, 41 below the concrete slab deflection had a deflection of 0.65 in less than the CLT slab which had a 0.75 in.

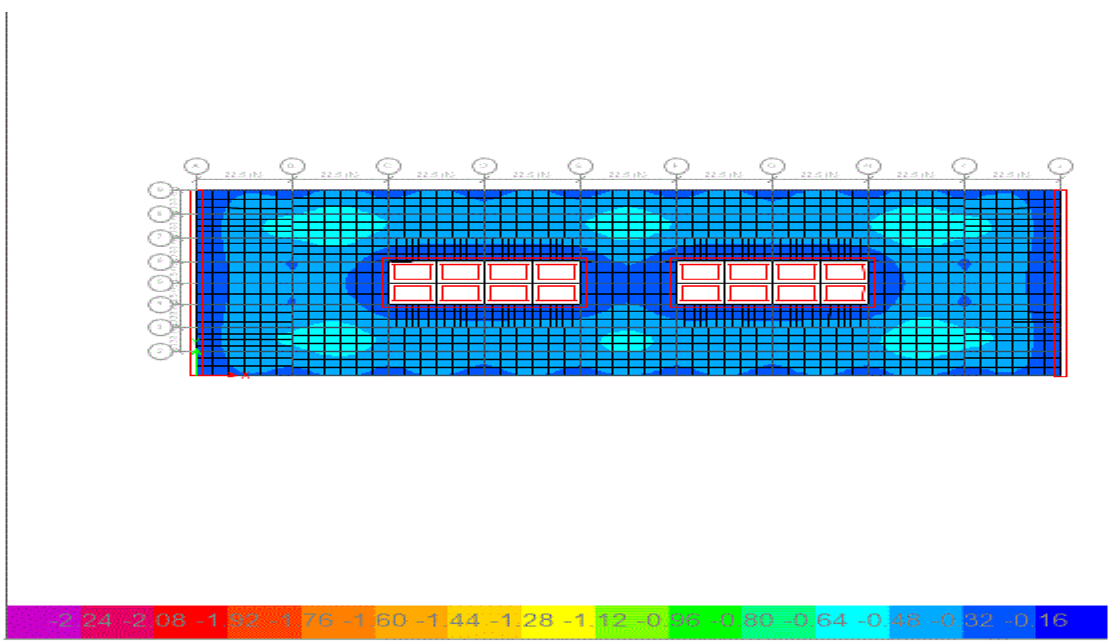


Figure 40 RC slab deflection

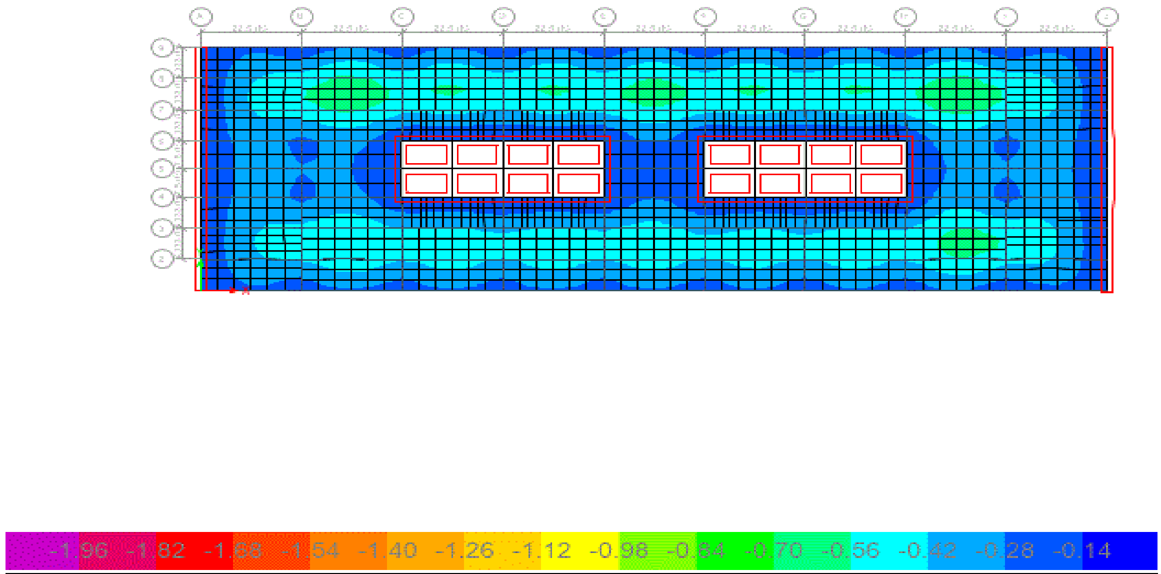


Figure 41 CLT slab deflection

Third criteria is the total base reaction. As mentioned before checking the total base reaction force is very important for the foundation design stage. In the table 23 and 24 is the total base reactions.

Table 23 RC frame, RC slab reaction forces

R.C						
load case	FX(kips)	FY(kips)	FZ(kips)	MX(kips.ft)	MY(kips.ft)	MZ(kips.ft)
DL+LL	0	0	475405.741	15300485	-48016848	1.07E-05
DL+EQx	-9139.351	0	297516.833	9544228	-33708921	292866.736
DL+EQy	0	-9139.351	297516.833	13227889	-30025260	-922146
DL+wind x	-11924.772	0	267765.15	8589805	-30540877	357884.929
DL+wind y	0	-23742.036	267765.15	16147617	-27022734	-2328984

Table 24 RC frame, CLT slab reaction forces

CLT						
load case	FX (kips)	FY(kips)	FZ(kips)	MX(kips.ft)	MY(kips.ft)	MZ(kips.ft)
DL+LL	0	0	395433.434	12701465	-39919652	-1.82E-05
DL+EQx	-6921.316	0	230873.244	7378378	-26027161	220584.0511
DL+EQy	0	-6921.316	230873.244	10127942	-23277596	-697416
DL+wind x	-11924.772	0	207785.92	6640540	-24467980	357884.9291
DL+wind y	0	-23742.036	207785.92	14198352	-20949837	-2328984

The last criteria is the foundation demand. Foundation as mentioned before is very important structural element, in the table 25 below is the foundation results

Table 25 Foundation Demand for RC building

Building type	RC building with RC slab	RC building with CLT slab
Raft foundation depth (m)	3	2.6
Raft foundation As (ft^2/ft)	0.13 for negative moment 0.027 for positive moment	0.11 for negative moment 0.018 for positive moment
Pile foundation settlement (mm)	0.6	0.5

Chapter 9: Conclusion

60 story building with four models each have different combination of hybrid structure have been analyzed by ETABS using load cases mentioned in chapter 5. In this chapter will be a summary of the results from all models. The project main objective is to compare all models with same specification but different floor system. Two models are concrete structure with concrete slab and CLT slab, other two are steel with concrete slab and CLT slab. The foundation is made from two parts the matt foundation and underneath it comes the piles to increase the fixture of the building. The pile is designed according to the highest load from the column

Comparing steel frames with CLT and Concrete slabs. The drift in steel frame with reinforced concrete slab was less the CLT slab, the steel stress and strain ratio was higher in the reinforced concrete slab structure than the CLT slab structure that indicates an opportunity to save more material if we designed the frame according to the CLT reaction forces , reaction forces for the CLT slab structure was less than the reinforced concrete slab structure by 20%, Mat foundation demand for CLT slab structure was less than the reinforced concrete slab structure by 20%. From 2m - 2.5m

Comparing concrete frames with CLT and Concrete slabs. The drift in concrete frame with reinforced concrete slab was less than the concrete frame with CLT by 18%. The difference between the concrete slab and CLT slab is that the CLT has 15% more deflection than concrete and the less 17% in total reaction force acting on column. Mat Foundation demand for CLT is from 2.6m - 3m.

Comparing concrete and steel frames. Overall structure performance for the steel frame was better than the concrete. Either with reinforced concrete slab or CLT slab. As the drift for steel frame is very close than the concrete frame. The matt foundation for steel frame with CLT is 2m while the mat foundation for concrete frame with CLT slab is 2.6m.

For the four models the pile foundation will have the same diameter and the same length. To have fair comparison between the four models. The settlement will differ from the concrete frame with concrete slab from the concrete frame with CLT slab by 17%. And for the steel frame with concrete slab is more than steel frame with CLT slab by 21%. No matter what size the diameter and the length of the pile are chosen. If the diameter and length of the pile does not change in the four models the settlement will be the same.

Finally from a structural performance perspective the steel with CLT slab was the lightest and have more potential to save materials from the other models. However it had higher drift. To obtain better result design the steel frame with CLT slab according to the weight and reaction of CLT slab. This will result in smaller section of sub beam therefore less weight on the girder and on the columns resulting in reduction of the reaction on the foundation. By that it will save more material.

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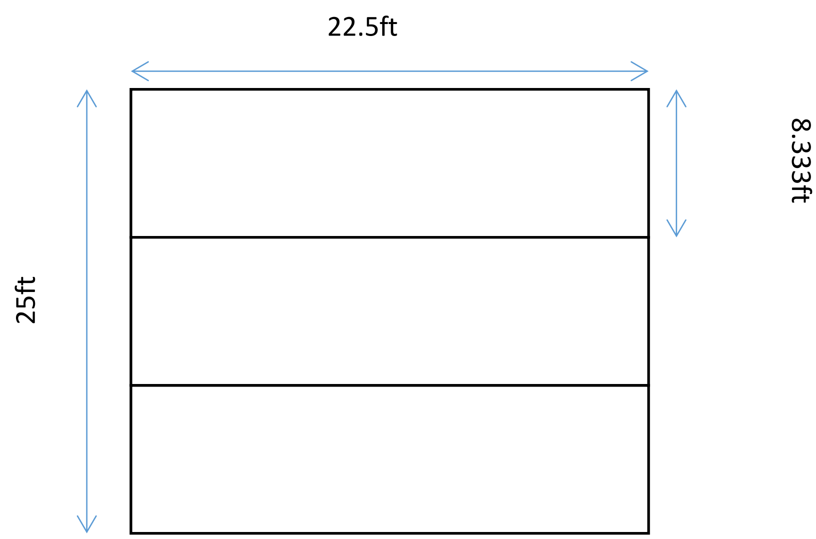
Appendix A (Planar design)

Design of slabs



One way slab check

$\frac{l}{B} = \frac{8.333ft}{22.5ft} = 0.37$ (from ACI code)

Slab thickness check

$\frac{l}{28} = \frac{22.5 \times 12}{28} = 9.64in$ Reduce to 9.5in

Concrete slab

Loads subjected on slab

Density of concrete: 2500kg/m³

Total weight of slab

WDslab= $\frac{9.5in}{12ft} \times \frac{0.150kips}{ft} = \frac{0.11875kips}{ft^2}$

WL=$\frac{5KN}{m^2} = \frac{0.1044kips}{ft^2}$ $from\ SBC$

Density of glass = $\frac{25KN}{m^3}$

Glass interior = 10mm from pillcington.com

Wglass interior =$\frac{25KN}{m^3} \times 10mm \times \frac{1m}{1000mm} = \frac{0.25KN}{m^2} = \frac{0.005221kips}{ft^2}$

Glass exterior = 28mm from CNUK.CO.UK

Wglass exterior =$\frac{25KN}{m^3} \times 28mm \times \frac{1m}{1000mm} = \frac{0.7KN}{m^2} = \frac{0.0146kips}{ft^2}$

Density of ceramic = $\frac{23.5KN}{m^3}$ $from\ SBC$

Thickness of ceramic tile = 4mm From Market

WDceramic = $\frac{23.5KN}{m^3} \times 4mm \times \frac{1m}{1000mm} = \frac{0.094KN}{m^2} = \frac{0.00196kips}{ft^2}$

Density of Mortar =$\frac{20.5KN}{m^3}$ $from\ SBC$

Thickness of Mortar = $\frac{1}{16}in = 1.6mm\ from\ archtoolbox.com$

WDmortar = $\frac{20.5KN}{m^3} \times 1.6mm \times \frac{1m}{1000mm} = \frac{0.0328KN}{m^2} = \frac{0.000685kips}{ft^2}$

Total Dead load = $\frac{(0.11875+0.005221+0.0146+0.00196+0.000685)\ kips}{ft^2} = \frac{0.147216kips}{ft^2}$

Live load = $\frac{0.1044kips}{ft^2}$

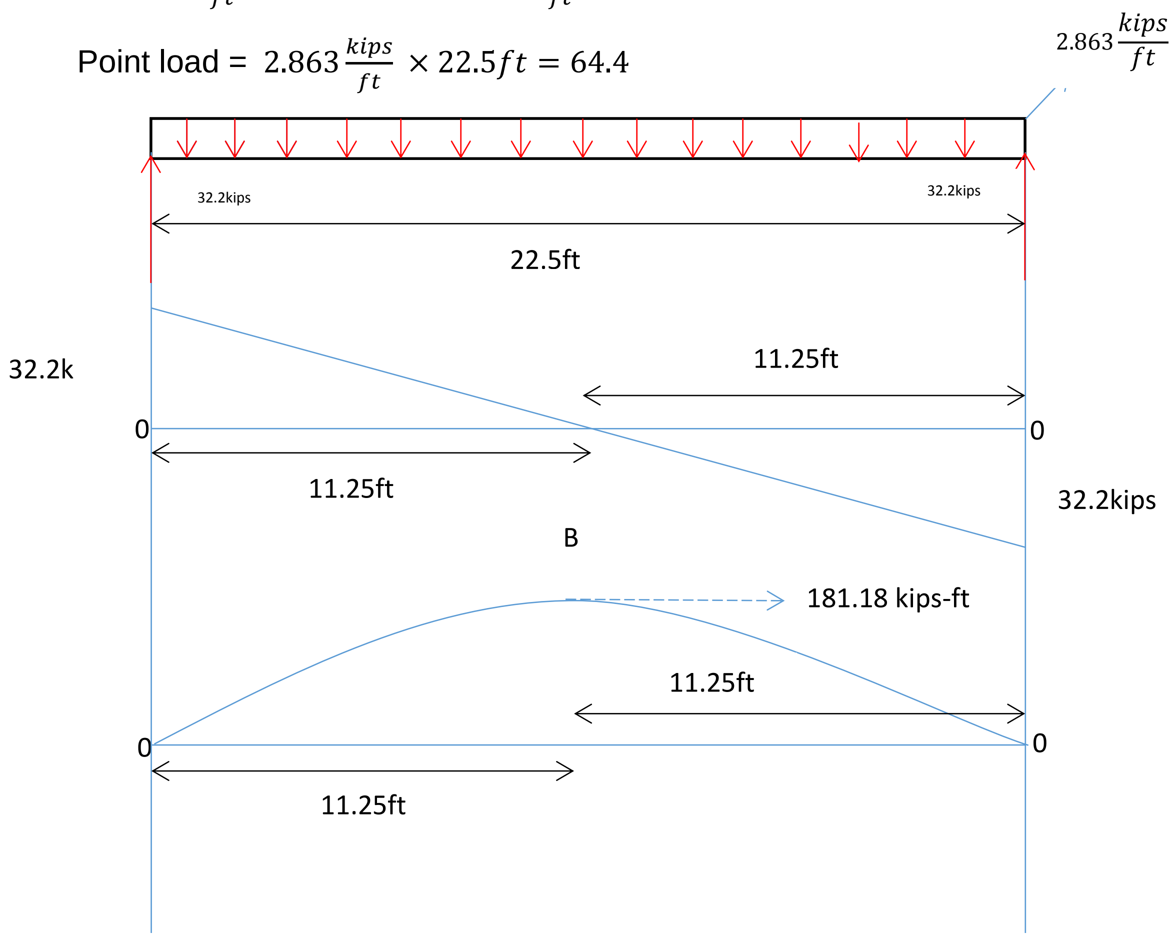
Ultimate load Wu = 1.2D + 1.6L = $0.147216(1.2) + 0.1044(1.6) = 0.3437\frac{kips}{ft^2}$

Sub beam design

Load subjected on the beam = Wu × Width

$= 0.3437 \frac{kips}{ft^2} \times 8.333ft = 2.863 \frac{kips}{ft}$

Point load = $2.863 \frac{kips}{ft} \times 22.5ft = 64.4$



Max MB = $\left(32.21\text{kips} \times \frac{22.5}{2} ft\right) - \left(2.863 kips \times \frac{22.5}{2} ft \times \frac{22.5}{4} ft\right) = 181.18\ kips.ft$

ρ = $\frac{0.85fc\prime}{fy} \times \beta(\frac{\varepsilon c}{\varepsilon t + \varepsilon c})$

ρb = $\frac{0.85 \times 4}{60} \times 0.85 \left(\frac{0.003}{0.00207 + 0.003}\right) = 0.0285$

Beam dimensions design

$\frac{\text{Mu}}{bd^2}$ ≤ (Φ × ρm × fy (1- $\frac{fy}{1.7(fc')}$ ×ρm))

$\frac{\text{181.18kips.ft}}{bd^2}$ ≤ (0.9 × 0.021375 × 60(1- $\frac{60}{1.7(4)}$ ×0.021375))

bd^2=2322.82in^3

d = 2b

b=8.5in, d=17in, h=20in

Area of steel in beam

AS,req = ρ × b × d

ρ = $\frac{0.85\times4000}{60000}\times 1-\sqrt{\left(1-\frac{2\times983.4}{0.85(4000)}\right)}=0.01988$

ρmin=0.0033 , ρmax=0.0214

AS,req = 0.01988 × 8.5 × 17 = 2.87 in^2 Roundup to 2.9in^2

From the area of steel tables and number of bars 5#7 has area of 3.0in^2 which is larger than the steel minimum needed.

Checking the compatibility of steel area with available width

b min = 2(1.5)+2(0.375)+ 3(0.875)=6.375

Spacing between bars = 8.5in - 6.375in = 2.125in

2.125/2=1.0625in

2 layer in the bottom, reinforcing steel of #7 which of those 3 in lower layer and 2 in upper layer.

Total concrete weight of sub beam = $150\frac{lb}{ft^3}\left(\frac{8.5\times20-5\times0.6}{144}\right)=\ 173.96\frac{lb}{ft}$

Total steel weight of sub beam = $2.044\times5=10.22\frac{lb}{ft}$

Total weight of sub beam = $173.96\frac{lb}{ft}+10.22\frac{lb}{ft}=184.18\frac{lb}{ft}$

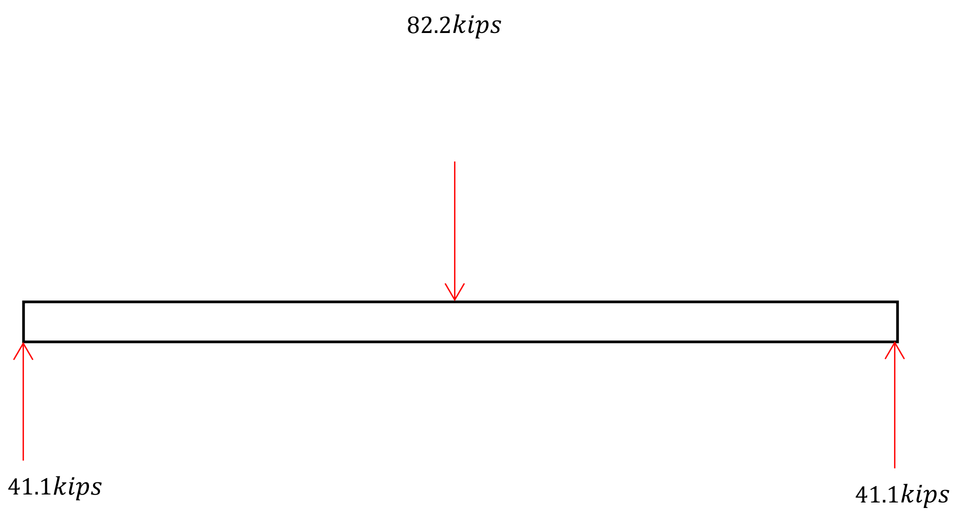
Main beam (Girder)

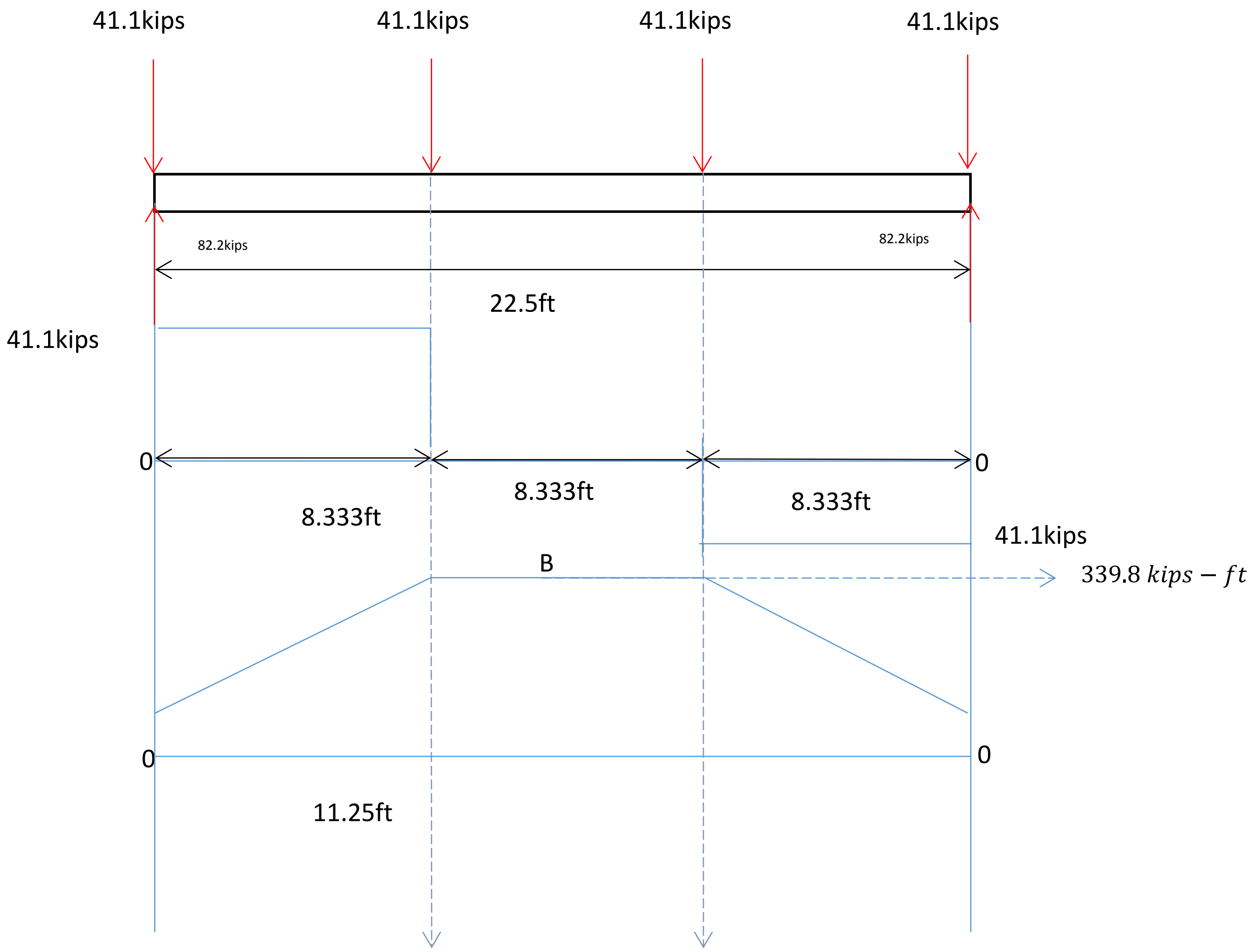
Slab weight = $(1.2)2.863\frac{kips}{ft} = 3.436\frac{kips}{ft}$

Sub beam = $(1.2)0.184\frac{kips}{ft} = 0.221\frac{kips}{ft}$

Total weight = $3.436\frac{kips}{ft} + 0.221\frac{kips}{ft} = 3.657\frac{kips}{ft}$

$3.657\frac{kips}{ft} \times 11.25\text{ft} = 41.1\text{kips}$





Max MB = $(41.1\text{kips} \times 16.6ft) - (82.2kips \times 16.6ft) + (41.1kips \ \times 8.333ft) =$ $339.8\ kips - ft$

$\frac{\text{Mu}}{bd^2}$ ≤ (Φ × ρm × fy (1- $\frac{fy}{1.7(fc')}$ ×ρm))

$\frac{339.8\text{kips.ft}}{bd^2}$ ≤ (0.9 × 0.021375 × 60(1- $\frac{60}{1.7(4)}$ ×0.021375))

bd^2=4356.4in^3

d = 2b

b=10.3in

Reduce to 9.5

b=9.5in, d=19in, h=22i

Area of steel in sub beam

AS,req = ρ × b × d

K‾=$\frac{Mu}{\phi bd^2} = \frac{339.8\frac{kips}{ft}}{0.9\times9.5\times19^2}\times\frac{12in}{1ft}\times\frac{1000}{1kips} = 1321.1$

ρ = $\frac{0.85\times4000}{60000}\times 1-\sqrt{\left(1-\frac{2\times1321.1}{0.85(4000)}\right)} = 0.03$

Increase b=10.5in d=21in h=24in

New K‾=$\frac{Mu}{\phi bd^2} = \frac{339.8\frac{kips}{ft}}{0.9\times10.5\times21^2}\times\frac{12in}{1ft}\times\frac{1000}{1kips} = 978.4$

ρ = $\frac{0.85\times4000}{60000}\times 1-\sqrt{\left(1-\frac{2\times978.4}{0.85(4000)}\right)} = 0.0197$

ρmin=0.0033 , ρmax=0.0214

Area of steel in girder

AS,req = ρ × b × d

AS,req = 0.0197 × 10.5 × 21 = 4.35 in^2 Roundup to 4.5in^2

From the area of steel tables and number of bars 3#11 has area of 4.68in^2 which is larger than the steel minimum needed.

Checking the compatibility of steel area with available width

b min = 2(1.5)+2(0.375)+ 3(1.41)=7.98in

Spacing between bars = 10.5in - 7.98in = 2.52in 2.52/2=1.26in

Total concrete weight of sub beam = $150\frac{lb}{ft^3}\left(\frac{10.5\times24-5\times1.56}{144}\right) = 257.6\frac{lb}{ft}$ Total steel weight of sub beam = $5.313\times5 = 26.565\frac{lb}{ft}$

Total weight of sub beam = $257.6\frac{lb}{ft} + 26.565\frac{lb}{ft} = 284.2\frac{lb}{ft}$

Appendix B (Steel column calculations)

column 1 Load (critical)	Length (ft)	Length (ft)	Area (ft2)	Thick-ness(ft)	Volume (ft3)	Pressure force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)=Area*Pressure force or Area*thickness*density
Live	22.5	20	450	0	0	0.1044	0	1.6	75.168
Dead	22.5	20	450	0	0	0.028467	0	1.2	15.37218
Slab	22.5	20	450	0.79167	356.2515	0	0.15	1.2	64.12527
Sub-beam	0	22.5	0.0778	0	1.7505	0	0.49	1.2	1.029294
Girder	0	20	0.133	0	2.66	0	0.49	1.2	1.56408
Total									157.25882

column 2 Load	Length (ft)	Length (ft)	Area (ft2)	Thick-ness (ft)	Volume (ft3)	Pressure force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)= Area*Pressure force or Area*thickness*density
Live	11.25	12.5	140.625	0	0	0.1044	0	1.6	23.49
Dead	11.25	12.5	140.625	0	0	0.028467	0	1.2	4.80380625
Slab	11.25	12.5	140.625	0.79167	111.32859	0	0.15	1.2	20.03914688
Sub-beam	0	0	0	0	0	0	0.49	1.2	0
Girder	0	23.75	0.133	0	3.15875	0	0.49	1.2	1.857345
Total									50.190298

column 3 Load	Length (ft)	Length (ft)	Area (ft2)	Thick-ness (ft)	Volume (ft3)	Pressure force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)=Area*Pressure force or Area*thickness*density
Live	22.5	12.5	281.25	0	0	0.1044	0	1.6	46.98
Dead	22.5	12.5	281.25	0	0	0.028467	0	1.2	9.6076125
Slab	22.5	12.5	281.25	0.7916	222.657	0	0.15	1.2	40.07829375
Sub-beam	0	0	0	0	0	0	0.49	1.2	0
Girder	0	22.5	0.133	0	2.9925	0	0.49	1.2	1.75959
Total									98.425496

column 4 Load	Length (ft)	Length (ft)	Area (ft2)	Thick-ness (ft)	Volume (ft3)	Pressure Force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)=Area*Pressure force or Area*thickness*density
Live	11.25	7.5	84.375	0	0	0.1044	0	1.6	14.094
Dead	11.25	7.5	84.375	0	0	0.028467	0	1.2	2.88228375
Slab	11.25	7.5	84.375	0.79167	66.797156	0	0.15	1.2	12.02348813
Sub-beam	0	11.25	0.0778	0	0.87525	0	0.49	1.2	0.514647
Girder	0	7.5	0.133	0	0.9975	0	0.49	1.2	0.58653
Total									30.100949

Appendix C (Reinforce concrete column calculation)

column 1 Load (critical)	Length (ft)	Length (ft)	Area (ft2)	Thick-ness(ft)	Volume (ft3)	Pressure force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)=Area*Pressure force or Area*thickness*density
Live	22.5	20	450	0	0	0.1044	0	1.6	75.168
Dead	22.5	20	450	0	0	0.028467	0	1.2	15.37218
Slab	22.5	20	450	0.79167	356.2515	0	0.15	1.2	64.12527
Sub-beam	0	22.5	1.18	0	26.55	0	0.15	1.2	4.779
Girder	0	20	1.451	0	29.02	0	0.15	1.2	5.2236
Total									164.66805

column 2 Load	Length (ft)	Length (ft)	Area (ft2)	Thick-ness(ft)	Volume (ft3)	Pressure force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)=Area*Pressure force or Area*thickness*density
Live	11.25	12.5	140.625	0	0	0.1044	0	1.6	23.49
Dead	11.25	12.5	140.625	0	0	0.028467	0	1.2	4.803
Slab	11.25	12.5	140.625	0.79167	111.328	0	0.15	1.2	20.039
Sub-beam	0	0	0	0	0	0	0.15	1.2	0
Girder	0	23.75	1.451	0	34.461	0	0.15	1.2	6.203
Total									54.5359

column 3 Load	Length (ft)	Length (ft)	Area (ft2)	Thick-ness (ft)	Volume (ft3)	Pressure force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)=Area*Pressure force or Area*thickness*density
Live	22.5	12.5	281.25	0	0	0.1044	0	1.6	46.98
Dead	22.5	12.5	281.25	0	0	0.028467	0	1.2	9.6076125
Slab	22.5	12.5	281.25	0.7916	222.657	0	0.15	1.2	40.07829375
Sub-beam	0	0	0	0	0	0	0.15	1.2	0
Girder	0	22.5	1.451	0	32.647	0	0.15	1.2	5.8765
Total									102.542

column 4 Load	Length (ft)	Length (ft)	Area (ft2)	Thick-ness (ft)	Volume (ft3)	Pressure Force (kip/ft2)	Density (kip/ft3)	Factor	Pu(kip)=Area*Pressure force or Area*thickness*density
Live	11.25	7.5	84.375	0	0	0.1044	0	1.6	14.094
Dead	11.25	7.5	84.375	0	0	0.028467	0	1.2	2.88228375
Slab	11.25	7.5	84.375	0.79167	66.797156	0	0.15	1.2	12.02348813
Sub-beam	0	11.25	1.18	0	13.275	0	0.15	1.2	2.3895
Girder	0	7.5	1.451	0	10.882	0	0.15	1.2	1.9588
Total									30.100949

Appendix D (Foundation calculation)

Steel frame RC slab:

label	x	Y	Q Total	My	Mx	Ix	Iy	A	q
			kips	kip.ft	kip.ft	ft^4	ft^4	ft2	kips/ft^2
1	-101.25	32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.14566
23	101.25	32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	29.99404
11	-101.25	-32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.67752
20	101.25	-32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.5259
29	-33.75	32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.09512
26	33.75	32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.04458
14	-33.75	-32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.62698
17	33.75	-32.5	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.57644
75	101.25	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.25997
7	-101.25	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.41159
325	-36	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.36273
337	36	0	399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.30883
			399294.7	-33677.2	-37863.3	4627431	44978730	13162.5	30.33578

q avg	b1	L	soil reac-tion	total column load	Avg load	modified avg	F	distributed	u	u	fc'	d
kips/ ft^2	ft	Ft	kips	kips	kips	kips/ft 2		kips/f t	kips	MN	MN /m2	m
30.06985	6.25	202.5	38057.16	37771.31	37914.23	29.95692	1.003784	187.2308	4184.91	18.615	27.5	2.5

Pile foundation	Raft depth (m)	L(m)	diameter pile(m)	area of pile (m2)	Q(kn)	elastic (Gpa)	Elastic settlement
1	2.5	7.5	0.03	0.0007065	24349.56	2E+11	0.00129243
2	2.5	7.5	0.04	0.001256	24349.56	2E+11	0.00072699
3	2.5	7.5	0.05	0.0019625	24349.56	2E+11	0.00046527
4	2.5	7.5	0.06	0.002826	24349.56	2E+11	0.00032311

Steel frame CLT slab:

label	x	Y	Q Total	My	Mx	Ix	Iy	A	q
			kips	kip.ft	kip.ft	in^4	in^4	ft2	kips/ft^2
1	-101.25	32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.24725
23	101.25	32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.09569
11	-101.25	-32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.41294
20	101.25	-32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.26138
29	-33.75	32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.19673
26	33.75	32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.14621
14	-33.75	-32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.36242
17	33.75	-32.5	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.3119
75	101.25	0	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.17854
7	-101.25	0	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.3301
325	-36	0	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.28126
337	36	0	319247.4	-33664.1	-11795.3	4627431	44978730	13162.5	24.22737

q avg	b1	L	Soil- reaction	total column load	Avg- load	modified avg
kips/ft^2	Ft	ft	kips	kips	kips	kips/ft2
24.17147	6.25	202.5	30592.02	30665.17	30628.6	24.20037

F	distrbuted	u	u	fc'	d
	kips/ft	kips	MN	MN/m2	m
0.998807	151.2523	3451.76	15.354	27.5	2

CLT pile foundation	Raft depth (m)	L(m)	diameter pile(m)	area of pile (m2)	Q(kn)	elastic (Gpa)	Elastic settlment
1	2	8	0.03	0.0007065	19300.83	2E+11	0.001092758
2	2	8	0.04	0.001256	19300.83	2E+11	0.000614676
3	2	8	0.05	0.0019625	19300.83	2E+11	0.000393393
4	2	8	0.06	0.002826	19300.83	2E+11	0.000273189

RC frame RC slab:

Label	x	y	Q Total
			kips
1	-101.25	32.5	475405.741
23	101.25	32.5	475406.741
11	-101.25	-32.5	475407.741
469	101.25	-32.5	475408.741
29	-33.75	32.5	475409.741
26	33.75	32.5	475410.741
14	-33.75	-32.5	475411.741
17	33.75	-32.5	475412.741
75	101.25	0	475413.741
7	-101.25	0	475414.741
325	-36	0	475415.741
337	36	0	475416.741

My	Mx	Ix	Iy	A	q
kip.ft	kip.ft	in^4	in^4	ft2	kips/ft^2
-117789.2974	-150063.9955	4627431.25	44978730.47	13162.5	35.32939648
-117788.2974	-150062.9955	4627431.25	44978730.47	13162.5	34.79917923
-117787.2974	-150061.9955	4627431.25	44978730.47	13162.5	37.43742931
-117786.2974	-150060.9955	4627431.25	44978730.47	13162.5	36.90720702
-117785.2974	-150059.9955	4627431.25	44978730.47	13162.5	35.15295797
-117784.2974	-150058.9955	4627431.25	44978730.47	13162.5	34.97628022
-117783.2974	-150057.9955	4627431.25	44978730.47	13162.5	37.26093761
-117782.2974	-150056.9955	4627431.25	44978730.47	13162.5	37.08424882
-117781.2974	-150055.9955	4627431.25	44978730.47	13162.5	35.8536695
-117780.2974	-150054.9955	4627431.25	44978730.47	13162.5	36.38400969
-117779.2974	-150053.9955	4627431.25	44978730.47	13162.5	36.21322268
-117778.2974	-150052.9955	4627431.25	44978730.47	13162.5	36.02476346

q avg	b1	L	Soil- reaction	total column load	Avg load
kips/ft^2	ft	ft	kips	kips	kips
35.06428786	6.25	202.5	44378.23932	75797.205	60087.72216

modified avg	F	distrbuted	u	u	fc'	d
kips/ft2		kips/ft	kips	MN	MN/m2	m
47.47671874	0.792743244	296.7294921	7191.0195	31.987	27.5	3

pile foundation	raft depth	L	Q	diameter	area of pile	E	elastic settlement
1	3	7	49751.321	0.03	0.0007065	2E+11	0.00246468
2	3	7	49752.321	0.04	0.001256	2E+11	0.00138641
3	3	7	49753.321	0.05	0.0019625	2E+11	0.00088732
4	3	7	49754.321	0.06	0.002826	2E+11	0.000616207

RC frame CLT slab:

label	x	y	Q Total	My	Mx	Ix	Iy	A	q
			kips	kip.ft	kip.ft	in^4	in^4	ft2	kips/ft^2
1	-101.25	32.5	395433.434	-117789.47	-149941.167	4627431.25	44978730.47	13162.5	29.25449072
23	101.25	32.5	395434.434	-117788.47	-149940.167	4627431.25	44978730.47	13162.5	28.7242727
11	-101.25	-32.5	395435.434	-117787.47	-149939.167	4627431.25	44978730.47	13162.5	31.36079822
469	101.25	-32.5	395436.434	-117786.47	-149938.167	4627431.25	44978730.47	13162.5	30.83057516
29	-33.75	32.5	395437.434	-117785.47	-149937.167	4627431.25	44978730.47	13162.5	29.07805195
26	33.75	32.5	395438.434	-117784.47	-149936.167	4627431.25	44978730.47	13162.5	28.90137394
14	-33.75	-32.5	395439.434	-117783.47	-149935.167	4627431.25	44978730.47	13162.5	31.18430626
17	33.75	-32.5	395440.434	-117782.47	-149934.167	4627431.25	44978730.47	13162.5	31.00761721
75	101.25	0	395441.434	-117781.47	-149933.167	4627431.25	44978730.47	13162.5	29.7779003
7	-101.25	0	395442.434	-117780.47	-149932.167	4627431.25	44978730.47	13162.5	30.30824127
325	-36	0	395443.434	-117779.47	-149931.167	4627431.25	44978730.47	13162.5	30.137454
337	36	0	395444.434	-117778.47	-149930.167	4627431.25	44978730.47	13162.5	29.94899451

q avg	b1	L	soil reaction	total column load	Avg load
kips/ft^2	Ft	ft	kips	kips	kips
28.98938171	6.25	202.5	36689.68622	62922.181	49805.93361

modified avg	F	distrbuted	u	u	fc'	d
kips/ft2		kips/ft	kips	MN	MN/m2	m
39.35283643	0.791548113	245.9552277	5935.4583	26.402	27.5	2.6

pile foundation	raft depth	L	Q	diameter	area of pile	E	elastic settlement
1	2.6	7.4	41134.129	0.03	0.0007065	2E+11	0.002154229
2	2.6	7.4	41134.129	0.04	0.001256	2E+11	0.001211754
3	2.6	7.4	41134.129	0.05	0.0019625	2E+11	0.000775522
4	2.6	7.4	41134.129	0.06	0.002826	2E+11	0.000538557

Appendix E

Steel frame RC slab:

Story	Elevation	X-Dir	Y-Dir	Inter-story drift
	Ft	in	in	in
Story60	597.6	0.482792	52.349636	1.090378
Story59	587.8	0.470112	51.259258	1.09058
Story58	578	0.462567	50.168678	1.090942
Story57	568.2	0.456611	49.077736	1.091444
Story56	558.4	0.44956	47.986292	1.092044
Story55	548.6	0.441924	46.894248	1.092693
Story54	538.8	0.433989	45.801555	1.093345
Story53	529	0.425765	44.70821	1.093881
Story52	519.2	0.417116	43.614329	1.094435
Story51	509.4	0.408292	42.519894	1.094868
Story50	499.6	0.399316	41.425026	1.095146
Story49	489.8	0.390137	40.32988	1.095223
Story48	480	0.380799	39.234657	1.095058
Story47	470.2	0.371333	38.139599	1.094607
Story46	460.4	0.361767	37.044992	1.093832
Story45	450.6	0.352115	35.95116	1.09269
Story44	440.8	0.342472	34.85847	1.091155
Story43	431	0.332822	33.767315	1.08909
Story42	421.2	0.323118	32.678225	1.086667
Story41	411.4	0.313426	31.591558	1.083727
Story40	401.6	0.303761	30.507831	1.080247
Story39	391.8	0.294061	29.427584	1.076188
Story38	382	0.284344	28.351396	1.07151
Story37	372.2	0.274617	27.279886	1.066178
Story36	362.4	0.264887	26.213708	1.060152
Story35	352.6	0.255157	25.153556	1.053396

Story34	342.8	0.245462	24.10016	1.04588
Story33	333	0.235787	23.05428	1.037509
Story32	323.2	0.226178	22.016771	1.02836
Story31	313.4	0.216594	20.988411	1.018327
Story30	303.6	0.207076	19.970084	1.007379
Story29	293.8	0.197605	18.962705	0.99548
Story28	284	0.188199	17.967225	0.982589
Story27	274.2	0.178872	16.984636	0.968669
Story26	264.4	0.169636	16.015967	0.953678
Story25	254.6	0.160688	15.062289	0.937579
Story24	244.8	0.151598	14.12471	0.920348
Story23	235	0.143688	13.204362	0.901836
Story22	225.2	0.134417	12.302526	0.882216
Story21	215.4	0.126285	11.42031	0.861303
Story20	205.6	0.118026	10.559007	0.839078
Story19	195.8	0.109902	9.719929	0.81549
Story18	186	0.101903	8.904439	0.790496
Story17	176.2	0.094021	8.113943	0.764041
Story16	166.4	0.086251	7.349902	0.73608
Story15	156.6	0.078583	6.613822	0.706561
Story14	146.8	0.071007	5.907261	0.675433
Story13	137	0.063512	5.231828	0.642645
Story12	127.2	0.056091	4.589183	0.608146
Story11	117.4	0.048742	3.981037	0.571888
Story10	107.6	0.041593	3.409149	0.533818
Story9	97.8	0.036735	2.875331	0.493892
Story8	88	0.031804	2.381439	0.452065
Story7	78.2	0.027191	1.929374	0.408294
Story6	68.4	0.0252	1.52108	0.362544
Story5	58.6	0.023796	1.158536	0.314768

Steel frame CLT slab:

Story	Elevation	X-Dir	Y-Dir	Inter-story drift
	Ft	in	in	in
Story60	597.6	0.551139	56.956087	1.197542
Story59	587.8	0.518124	55.758545	1.159912
Story58	578	0.507028	54.598633	1.175309
Story57	568.2	0.500972	53.423324	1.179014
Story56	558.4	0.494672	52.24431	1.181429
Story55	548.6	0.487455	51.062881	1.187545
Story54	538.8	0.479591	49.875336	1.199136
Story53	529	0.475569	48.6762	1.161068
Story52	519.2	0.462674	47.515132	1.163607
Story51	509.4	0.454283	46.351525	1.165923
Story50	499.6	0.445691	45.185602	1.168047
Story49	489.8	0.436916	44.017555	1.169881
Story48	480	0.427892	42.847674	1.171367
Story47	470.2	0.418623	41.676307	1.172449
Story46	460.4	0.409134	40.503858	1.173081
Story45	450.6	0.39949	39.330777	1.173182
Story44	440.8	0.389158	38.157595	1.17287
Story43	431	0.383324	36.984725	1.17146
Story42	421.2	0.369349	35.813265	1.170048
Story41	411.4	0.36	34.643217	1.167924
Story40	401.6	0.350197	33.475293	1.165191
Story39	391.8	0.340236	32.310102	1.161787
Story38	382	0.330144	31.148315	1.157673
Story37	372.2	0.31994	29.990642	1.152814
Story36	362.4	0.309647	28.837828	1.14718
Story35	352.6	0.299268	27.690648	1.140726
Story34	342.8	0.288637	26.549922	1.133489

Story33	333	0.279832	25.416433	1.125165
Story32	323.2	0.267843	24.291268	1.116201
Story31	313.4	0.25767	23.175067	1.106269
Story30	303.6	0.24737	22.068798	1.095399
Story29	293.8	0.237025	20.973399	1.083544
Story28	284	0.226656	19.889855	1.070667
Story27	274.2	0.216271	18.819188	1.056729
Story26	264.4	0.20587	17.762459	1.041691
Story25	254.6	0.195421	16.720768	1.025501
Story24	244.8	0.184747	15.695267	1.008203
Story23	235	0.176608	14.687064	0.989374
Story22	225.2	0.164316	13.69769	0.969646
Story21	215.4	0.154389	12.728044	0.948527
Story20	205.6	0.144514	11.779517	0.926035
Story19	195.8	0.134646	10.853482	0.902094
Story18	186	0.124837	9.951388	0.876626
Story17	176.2	0.11512	9.074762	0.849548
Story16	166.4	0.105525	8.225214	0.820546
Story15	156.6	0.096079	7.404668	0.789186
Story14	146.8	0.086806	6.615482	0.756365
Story13	137	0.07773	5.859117	0.721735
Story12	127.2	0.068879	5.137382	0.684946
Story11	117.4	0.060277	4.452436	0.646105
Story10	107.6	0.051939	3.806331	0.604874
Story9	97.8	0.043863	3.201457	0.561238
Story8	88	0.036607	2.640219	0.514997
Story7	78.2	0.036095	2.125222	0.456256
Story6	68.4	0.035197	1.668966	0.414414
Story5	58.6	0.033841	1.254552	0.371226

RC frame RC slab:

Story	Elevation	X-Dir	Y-Dir	Inter-story drift
	Ft	in	in	in
Story60	597.6	0.543306	51.804988	0.995342
Story59	587.8	0.532178	50.809646	0.995207
Story58	578	0.514212	49.814439	0.995919
Story57	568.2	0.499065	48.81852	0.997065
Story56	558.4	0.494962	47.821455	0.998683
Story55	548.6	0.489785	46.822772	1.000674
Story54	538.8	0.483684	45.822098	1.00316
Story53	529	0.476424	44.818938	1.00545
Story52	519.2	0.468868	43.813488	1.008419
Story51	509.4	0.460582	42.805069	1.011452
Story50	499.6	0.451723	41.793617	1.014564
Story49	489.8	0.442447	40.779053	1.017726
Story48	480	0.432851	39.761327	1.020843
Story47	470.2	0.423005	38.740484	1.023825
Story46	460.4	0.412973	37.716659	1.026673
Story45	450.6	0.402812	36.689986	1.029292
Story44	440.8	0.392545	35.660694	1.031763
Story43	431	0.382102	34.628931	1.033789
Story42	421.2	0.371799	33.595142	1.035595
Story41	411.4	0.36142	32.559547	1.036999
Story40	401.6	0.350952	31.522548	1.037938
Story39	391.8	0.340433	30.48461	1.038371
Story38	382	0.329889	29.446239	1.038251
Story37	372.2	0.319325	28.407988	1.037525
Story36	362.4	0.308745	27.370463	1.036147
Story35	352.6	0.298145	26.334316	1.034071
Story34	342.8	0.287525	25.300245	1.031244

Story33	333	0.276954	24.269001	1.027545
Story32	323.2	0.266552	23.241456	1.023086
Story31	313.4	0.256077	22.21837	1.017725
Story30	303.6	0.24559	21.200645	1.011401
Story29	293.8	0.235156	20.189244	1.004067
Story28	284	0.224803	19.185177	0.995673
Story27	274.2	0.214539	18.189504	0.986167
Story26	264.4	0.204337	17.203337	0.97549
Story25	254.6	0.194135	16.227847	0.963578
Story24	244.8	0.184132	15.264269	0.950343
Story23	235	0.174982	14.313926	0.935761
Story22	225.2	0.166231	13.378165	0.920067
Story21	215.4	0.156564	12.458098	0.90284
Story20	205.6	0.14677	11.555258	0.884013
Story19	195.8	0.137111	10.671245	0.863536
Story18	186	0.12755	9.807709	0.841342
Story17	176.2	0.118042	8.966367	0.817353
Story16	166.4	0.108567	8.149014	0.791486
Story15	156.6	0.099602	7.357528	0.763656
Story14	146.8	0.090728	6.593872	0.733778
Story13	137	0.08189	5.860094	0.701767
Story12	127.2	0.07308	5.158327	0.667538
Story11	117.4	0.064293	4.490789	0.631007
Story10	107.6	0.055962	3.859782	0.59209
Story9	97.8	0.049358	3.267692	0.550708
Story8	88	0.04264	2.716984	0.506782
Story7	78.2	0.035895	2.210202	0.46024
Story6	68.4	0.029388	1.749962	0.411017
Story5	58.6	0.024779	1.338945	0.359046

RC frame CLT slab:

Story	Elevation	X-Dir	Y-Dir	Inter-story drift
	Ft	in	in	in
Story60	597.6	0.648891	62.942813	1.277178
Story59	587.8	0.603103	61.665635	1.276911
Story58	578	0.592601	60.388724	1.277515
Story57	568.2	0.589717	59.111209	1.278247
Story56	558.4	0.58516	57.832962	1.27606
Story55	548.6	0.578173	56.556902	1.237977
Story54	538.8	0.570312	55.318925	1.259864
Story53	529	0.563955	54.059061	1.220121
Story52	519.2	0.553475	52.83894	1.231761
Story51	509.4	0.543899	51.607179	1.241681
Story50	499.6	0.534968	50.365498	1.231748
Story49	489.8	0.525732	49.13375	1.221697
Story48	480	0.515988	47.912053	1.227487
Story47	470.2	0.5058	46.684566	1.232854
Story46	460.4	0.495234	45.451712	1.237748
Story45	450.6	0.484386	44.213964	1.242126
Story44	440.8	0.473608	42.971838	1.245971
Story43	431	0.463132	41.725867	1.24885
Story42	421.2	0.451337	40.477017	1.25131
Story41	411.4	0.439645	39.225707	1.253083
Story40	401.6	0.428144	37.972624	1.254085
Story39	391.8	0.416558	36.718539	1.254272
Story38	382	0.404783	35.464267	1.253612
Story37	372.2	0.392819	34.210655	1.252068
Story36	362.4	0.3807	32.958587	1.249608
Story35	352.6	0.368507	31.708979	1.246196
Story34	342.8	0.356406	30.462783	1.241785

Story33	333	0.344403	29.220998	1.236292
Story32	323.2	0.33184	27.984706	1.229965
Story31	313.4	0.319317	26.754741	1.222593
Story30	303.6	0.306907	25.532148	1.214107
Story29	293.8	0.294494	24.318041	1.204473
Story28	284	0.282031	23.113568	1.193657
Story27	274.2	0.269531	21.919911	1.181619
Story26	264.4	0.257052	20.738292	1.168295
Story25	254.6	0.24472	19.569997	1.153601
Story24	244.8	0.23271	18.416396	1.137514
Story23	235	0.220901	17.278882	1.11965
Story22	225.2	0.208449	16.159232	1.103138
Story21	215.4	0.196207	15.056094	1.083535
Story20	205.6	0.184174	13.972559	1.062178
Story19	195.8	0.172201	12.910381	1.039244
Story18	186	0.160245	11.871137	1.014375
Story17	176.2	0.148323	10.856762	0.987457
Story16	166.4	0.136462	9.869305	0.958354
Story15	156.6	0.124687	8.910951	0.926566
Story14	146.8	0.113012	7.984385	0.892488
Story13	137	0.101448	7.091897	0.854751
Story12	127.2	0.090008	6.237146	0.814976
Story11	117.4	0.078728	5.42217	0.772152
Story10	107.6	0.067704	4.650018	0.725758
Story9	97.8	0.057134	3.92426	0.676545
Story8	88	0.047364	3.247715	0.62428
Story7	78.2	0.041642	2.623435	0.568454
Story6	68.4	0.040807	2.054981	0.508109
Story5	58.6	0.039106	1.546872	0.442951