Sudan University of Science and Technology

College of Graduate Studies

Finite Element Study of the Use of Reinforced Concrete Grids in Large Spans Slabs

(Case Study: Eltadamon Tower)

دراسة العنصر المحدد لإستخدام شبكيات الخرسانة المسلحة للبلاطات طويلة الأبحر

(دراسة حالة: برج التضامن)

A thesis Submitted to Department of Construction Engineering College of Engineering in partial Fulfillment of the Requirements for the Degree of Master of Science in Construction Engineering.

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July 2018

DEDICATION

This research is dedicated firstly to my parents, my family members and my friends who have helped me without getting tired in accomplishing my tasks. It also goes to my entire civil engineering's colleagues.

ACKNOWLEDGEMENT

All praise to **Allah** subhanahu WA taala the Benevolent, most Gracious, and most Merciful.

Our most and sincere deepest appreciation to my parents, my brother and my sisters who stood with me through thick and thin, supported Mein any way possible and encouraged me continuously to achieve my goals.

My most heat felt thanks and appreciation to my supervisor **prof. Abdelrahman Elzubeir** who is one of the most empathic person I have ever met, who spent his time, energy and was with me from the beginning till the end, ever ready to help and show me the right way.

I sincerely thank **Eng. Mohamed Musa** for his hard working and patience with me until I achieved my goals, hope Allah help him.

I have to thank our Dean, lecturers who taught us everything that we need to know. May Allah reward them abundantly.

ABSTRACT

The research reviewed the structural systems used for buildings with long spans. The use of the grid slabs for long spans was studied using the finite element method. The primary objective was to carry out a parametric study of the effect of spacing and depth of ribs for grid slabs used in long spans. A three – storeys building was selected and analyzed under dead loads using Structural Analysis Program (ETABS). The grid slabs were used as a distribution of fixed width ribs with varying spacings and the depths which were varied until suitable depth and spacing was obtained based on the results of the vertical displacements. This was considered to be the optimum grid system. A six- storeys concrete building, of known results, was then analyzed and designed using the optimum grid system (ETABS). The dead and live loads and wind loads were applied to the building and the results were checked by comparing them with published results. The comparison showed close agreement between the results.

This confirmed the accuracy of the optimum grid system. The case study building was chosen as Altadamon tower (ALTBT). The steel truss system used in long spans was replaced by a concrete grid slabs system which was analyzed and designed using the optimum grid system (ETABS). The dead, live and wind loads were applied to the selected building (ALTBT). The design results were verified and checked according to BS 8110 requirements, thus confirming the correctness of the proposed grid system.

التجريد

استعرض هذا البحث الانظمة الانشائية المستخدمة للمباني ذات الأبحر الطويلة. اجريت دراسة لاستخدام البلاطات الشبكيه للأبحر الطويلة باستخدام طريقة العنصر المحدد. وقد كان الهدف الأساسي لدراسة جدوي تاثير التباعد وعمق الابيام العارضات المضلعة للبلاطات الشبكية التي تستخدم في الأبحر الطويلة. أختير مبني مكون من ثلاثة طوابق وتم تطبيق الاحمال الميته حيث حلل باستخدام برنامج التحليل الأنشائي(ETABS) واستخدمت البلاطات الشبكيه بعرض ثابت وتم توزيع العارضات المضلعة بأبعاد وأعماق مختلفة حيث تم تغيرها للحصول علي العمق والبعد المناسبين استنادا علي نتائج الازاحات الراسية وأعتبر أن هذا النظام الشبكي المثالي. أختير مبني خرساني، معلوم النتائج مكون من ستة طوابق وتم تحليله وتصميمه باستخدام النظام الشبكي المثالي (ETABS) وتم تطبيق الاحمال الميتة والحية واحمال الرياح علي المبني وتم التحقق من النتائج بمقارنتها مع النتائج المنشورة حيث أظهرت المقارنة تقارب كبير في النتائج وبالتالي أكدت دقة النموذج المثالي.

أختير مبني برج التضامن(ALTBT) لدراسة الحالة وتم استبدال نظام جمالون الفولاذ المستخدم بنظام البلاطات الشبكية حيث التحليل والتصميم باستخدام النظام الشبكي المثالي وبرنامج (ETABS) وطبقت الأحمال الميتة والحية وأحمال الرياح علي المبني المختار(ALTBT) وتم التحقق من نتائج التصميم والتحليل وفقا للمدونة البرطانية BS8110 مما يؤكد صحة نموذج النظام الشبكي المقترح.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction:

Grid systems consist of beams spaced at regular intervals in perpendicular directions, monolithic with slab. They are generally employed for structural reasons for large spans such as auditoriums, theatre halls and show rooms of shops where column free space is often the main requirement. The sizes of the beams running in perpendicular directions are generally kept the same. From study of literature, it can be understood that the economy of a grid slab is not only affected by the geometry, but also the design parameters.

The following are some of the parameters that affect the overall cost of grid floor:

1- Size of grid floor and spacing of ribs (in x and y directions)

2- Grade of concrete and grade of steel

3- Live load on the slab

4- Thickness of slab, width of rib and depth of rib

However, the structural design is controlled by thickness of slab, width of rib and depth of rib. Hence, the study of their effect on the cost of the grid floor is important. (Ponnada, M.R., 2014).

Approximate methods, such as equivalent static analysis, Rankine and Grashoff method and analysis by plate theory were previously used to analyse grid floor systems. (Halkude and Mahamuni, 2014).

Accurate matrix and numerical methods such as the stiffness method and the finite element method are frequently used nowadays. (Halkude and Mahamuni, 2014).

The finite element analysis can be extended to non linear analysis including static and dynamic nonlinear analysis (response spectrum method or time history method)

The analysis is usually carried out using package programs such as ETABS.

1.2 Research problem statement:

As stated above the structural design of grid systems is controlled by the thickness of slab, width of rib and depth of rib. Accurate analysis based on the finite element method is to be used to evaluate the effect of these on the cost of the grid. Package computer program systems such as ETABS are to be used to carry out a parametric study of the effect of factors which enables the evaluation of cost reduction and choice of the optimum combination of spacing and depth.

1.3 Research Objectives:

1- To present a review of the different types of grid system slabs that are used in large span buildings.

2- To study the use of numerical methods of analysis and design of grid slabs.

3- To carry out a parametric study of the effect of spacing and depth of ribs.

4- To obtain an optimum grid system based on a parametric study using ETABS for grid slabs.

5-To perform the analysis and design of Altadamon tower, as a case study, using the optimum grid system and ETABS.

6- To verify the accuracy, according to the British standards, of the analysis and design results obtained.

1.4 Methodology:

Firstly, a comprehensive literature review based on references and published papers were carried out. The review included ribbed and grid slabs.

Secondly, the necessary analysis and design data and parameters were obtained and the theoretical background and how to use ETABS in modeling grid systems was studied.

Thirdly, the parametric study was carried out based on selected grid systems applied on a three floors building and a six floors building under gravity and lateral loads.

Fourthly, the application of the optimum grid system obtained to analyze and design the case study building, and to check for wind load.

Finally, conclusions and recommendations were drawn and the research thesis was prepared.

1.5 Thesis of Outlines:

- Chapter one presents general introduction including the problem statement, objectives, methodology and out lines.
- Chapter two presents literature review including grid slabs and ribbed slabs, types of grid systems, how to use grid systems and a review of previous research work.
- Chapter three presents the necessary analysis and design data and parameters and explains how to use ETABS program in modeling grid systems.
- Chapter four presents the parametric study based on variable spacing and depth of ribs applied on a three floors building and six floors building under gravity and lateral loads.
- Chapter five presents Altadamon tower model and its analysis and design and check for wind load
- Chapter six presents conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction:

Ribbed slabs are made up of wide band beams running between columns with narrow ribs spanning the orthogonal direction normally the ribs and beams are the same depth. A thin topping slab completes the system. (https://aww.concrete centre.com> floors, December 2017)

A grid slab is a type of building material that has two-directional reinforcement one the outside of the material, giving it the shape of the pockets on a waffle as shown in Figure (2.1).(khorajiya et.al)

An assembly of intersecting beams placed at regular interval and interconnected to a slab of nominal thickness is known as grid floor or waffle floor. These slabs are used to cover a large column free area and therefore are good choice for public assembly halls. The structure is monolithic in nature and has more stiffness. It gives pleasing appearance and the maintenance cost of these floors is less. Construction of the grid slabs is cost prohibitive. By investigating various parameters, the cost effective solution can be found for the grid slabs, for which proper method of analysis need to be used. There are various approaches available for analyzing the grid slab system. (Bhatia and Golait, 2016), (Halkude and Mahamuni, 2014), (Halkude et. al., 2015).

Grid slabs are generally employed for structural reasons for large spans such as auditoriums, theatre halls and show rooms of shops where column free space is required and the ceiling is advantageously utilized for concealed architectural lighting. The sizes of the beams running in perpendicular directions are generally kept the same. From study of literature, it can be understood that the economy of a grid slab is not only affected by the geometry, but also the design parameters.

The following are some of parameters that affect the overall cost of grid floor: Size of grid floor and spacing of ribs (in x and y directions) ,Grade of concrete and grade of steel, Live load on the slab and thickness of slab, width of rib and depth of rib. However, the structural design is controlled by thickness of slab, width of rib and depth of rib. Hence the study of their effect on the cost of grid floor is important. (Santhosh et. al, 2016), (Halkudev et. al, 2015), (Halkude and Mahamuni, 2014),(Sathawane and Deotal).

2.2 Historical back ground:

2.2.1 Types of one way ribbed slab:

As stated by Alzanen, 2012 in his comparison between hollow block slabs and flat slabs in design and cost carried out by introducing voids to the soffit of a slab reduces dead weight and increases the efficiency of the concrete section. A slightly deeper section of **one way joists** is required but these stiffer floors facilitate longer spans and provision of holes.

Such floors are economic in the range 8 to 12m. The saving of materials tends to be offset by some complication in formwork. Polystyrene moulds has made the choice of trough profile infinite and largely superseded the use of standard T moulds. Ribs should be at least 125mm wide to suit reinforcement detailing. Figure (2.2) shows such one way joists (Alzanen, 2012).

One way joists with wide beams as with solid slab arrangements, has a relatively wide, shallow cross section which reduces the overall depth of floor while permitting longer spans. Used in car parks, offices, where spans in one direction are predominant and live loads are relatively light, slab spans up to 10m(centre line support to centreline 16m are economic). Figure (2.3) shows one way joists with wide beams. (Alzanen, 2012).

Troughed slabs are popular in spans up to 12m as they combine the

advantages of ribbed slabs with level soffits. Economic depths depend on the widths of beams used. The Figure (2.4) shows troughed slab. (Alzanen, 2012).

As stated by Alzanen, 2012 and (www.Scaff.com> decking> trough, 2017) advantages, disadvantages and features of one way ribbed slab are:

Advantages are: medium to long spans, Light weight, holes in topping easily accommodated and large holes can be accommodated.

Disadvantages are: higher from work costs than for other slab systems slower and slightly greater floor thickness.

Features are: one way spanning ribbed slabs can achieve longer spans than traditional flat slabs, reduces concrete volumes, potential for reduction in slab thickness and weight, good quality finish achievable for exposed soffits subject to specification, light weight and easy to fix and strike and detailed take off service available.

2.2.2 Types of grid slabs:

As present Khorujiya et.al **Diagrid grid slab** as shown in Figure (2.5), **orthogonal grid slab** as shown in Figure (2.6), and **three- way grids for triangular& hexagonal areas** as shown in Figure (2.7).

As presented by Rajkumar and Venkateswarlu, 2017 and Bhatia and Golait, 2016 the advantages, features, uses and benefits of grid slabs are:

Advantages of grid slab are: grids are very efficient in transferring concentrated loads and in having the entire structure participate in the load carrying action, reduce the depth to span ratio of rectangular grids and reduction in depth towers, structural and other cost by reducing the height of the building.

Features of grid slab are: They are used on flat sites, no beam excavation is required, no controlled or rolled fill is used, Courd board slab panel/void formers are used, Slab panels are on 1 meter grids (approximately), Trench mesh or individual bars can be used and there is minimal concrete volume.

Uses of grid slab are : grid slabs can be used as both ceiling and floor slab used in the areas where number of columns are provided i.e., it is basically used in the areas which has huge spans, used for specialized projects that involves clean rooms, spaces requiring seclusion from low frequency vibration or those needing low floor deflections, the concrete grid slab is often used for industrial and commercial buildings while wood and metal waffle slabs are used in many other construction sites, This form of construction is used in airports, parking, garages, commercial and industrial buildings, residences and other structures requiring extra stability and the main purpose of employing this technology is for its strong foundation characteristics of crack and sagging resistance. Grid slab also holds a greater amount of load compared with conventional concrete slabs.

Benefits of grid slab are: all elements of the space grid contribute to the load carrying capacity, loads are distributed more evenly to the supports, this can reduce the cost of the supporting structures especially when heavy moving loads may be applied to the space grid (e.g. overhead cranes),deflections are reduced compared to plane structures of equivalent span, depth and applied loading, assuming that the structural elements are of similar size and the open nature of the structure between the two plane grids allows easy installation of mechanical and electrical services and air-handling ducts within the structural depth.

Figure 2.1: Grid slab system (khorajiya et.al).

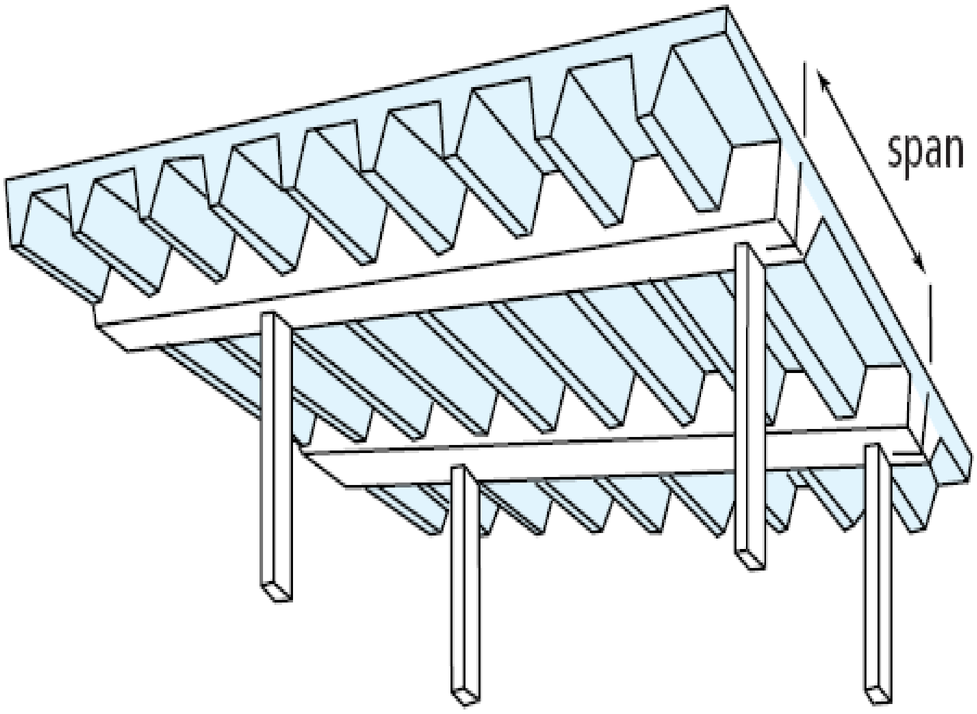


Figure 2.2: One way joists (Alzanen, 2012).

Figure 2.3: One way joists with wide beams (Alzanen, 2012).

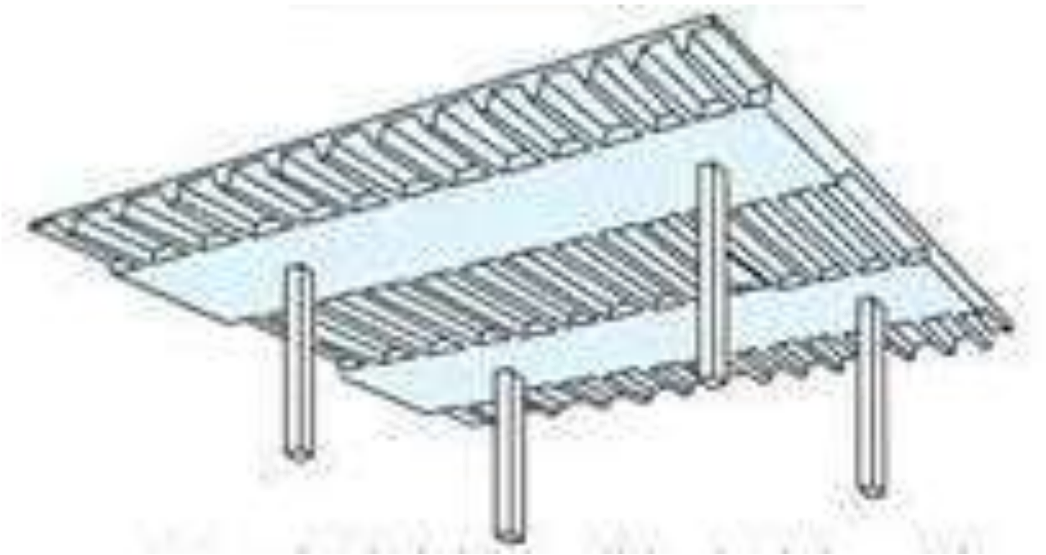


Figure 2.4: Troughed slab(Alzanen, 2012).

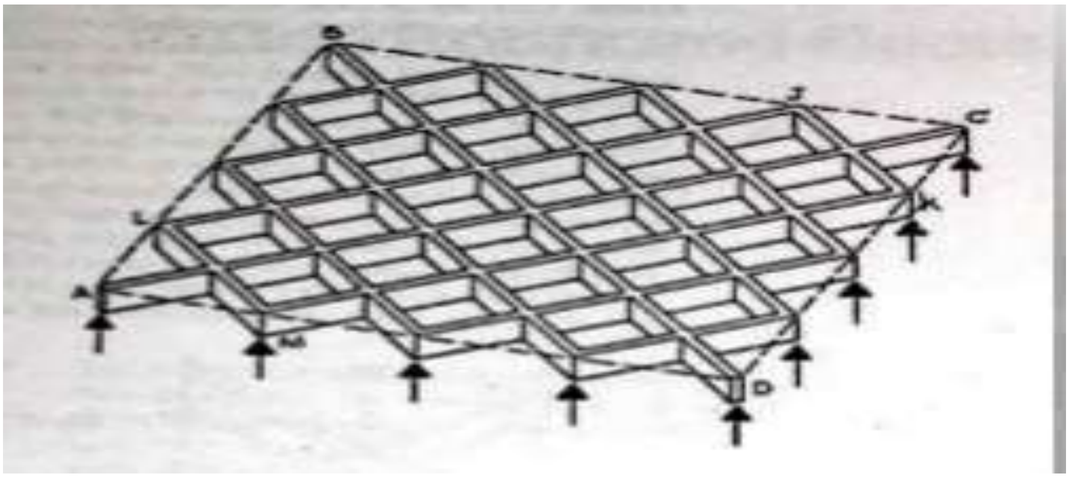


Figure 2.5: Diagrid grid slab (khorajiya et.al).

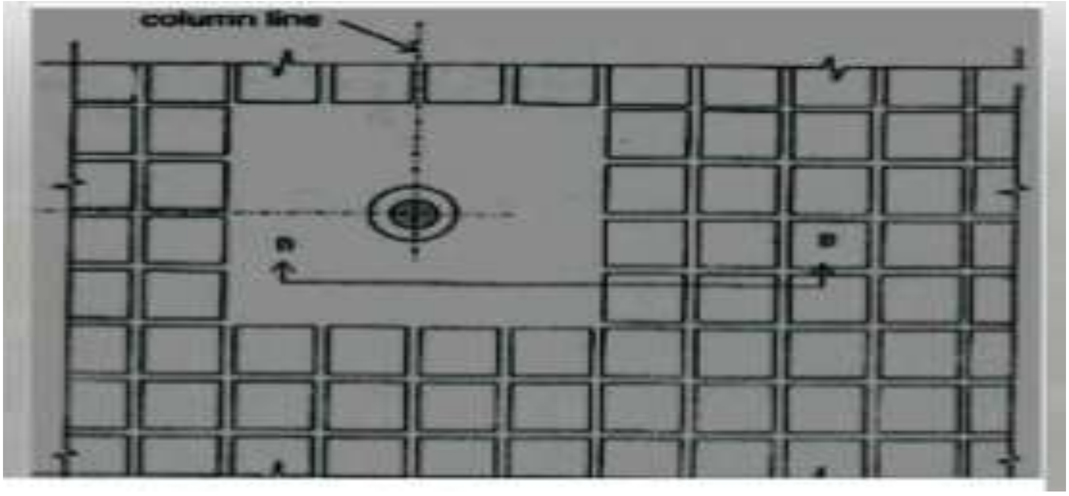


Figure 2.6: Orthogonal grid slab (khorajiya et.al).

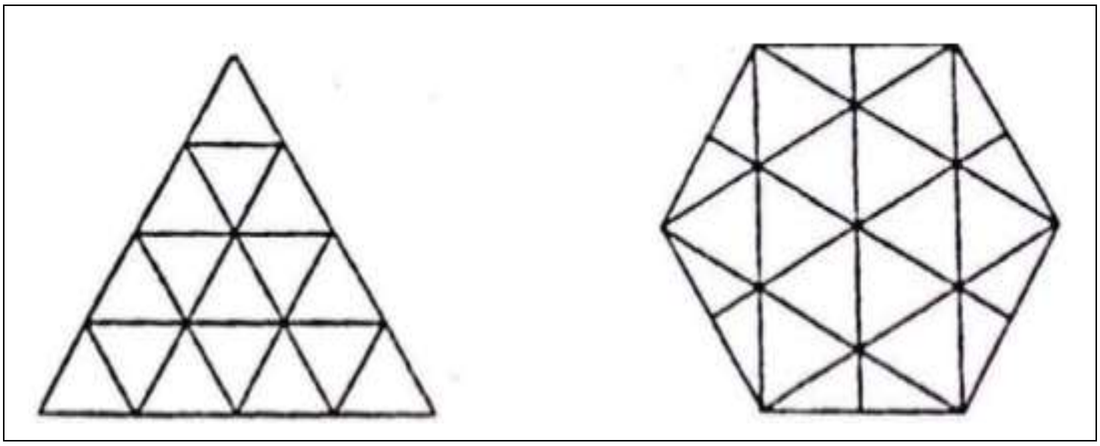


Figure 2.7: Three way grids for triangular& hexagonal areas (khorajiya et.al).

2.3 Previous studies:

Bhatia and Golait, 2016 Studied the response of flat slabs grid slabs systems in conventional RC Buildings: They stated that: the analysis can be performed on the basis of external action, the behavior of structure or structural materialsand the type of structural model selected. Based on the type of external action and behavior of structure, they further classified the analysis follows: equivalent static analysis, nonlinear static analysis, response spectrum method and time history method.

,Halkude and Mahamuni, 2014, stated that grid system is highly redundant structural system and therefore statically indeterminate. Various approaches available for the analysis of grid floor frame were listed as follows: Analysis of grid by **Rankine-Grashoff method** which is an approximate method. It is based on equating deflections in either direction at the junctions of ribs. This method is suitable for small span grids with the spacing of ribs not exceeding 1.50 m. In this method the slab is considered as simply supported on edges as shown in Figure (2.8). Bending, torsion moments and shears are obtained per unit width of slab strip**. Plate Analogy method** which is rigorous method of analysis. This is based on Timoshenkos analysis of orthotropic plate theory considering plane stress analysis. As in Rankine-Grashoff method, in this method also the analysis is done by considering the grid simply supported on edges as shown in Figure (2.8). Bending, torsion moments and shears are obtained per unit width of slab strip**. Stiffness method** which method is based on matrix formulation of the stiffness of the structure and gives closed form solution. By using this method the analysis can be done by considering rigid supports as well. Various application softwares are available to carry out analysis by this method. Halkude and Mahamuni,2014, their work while analyzing grid floor frame by stiffness method, the simple supports were considered at closer distance so as to simulate the support conditions similar to Rankine-Grashoff method and plate theory- as shown in Figure (2.9).

Santhosh et al, 2016 stated that ETABS was used to analysis the R.C moment resisting frame structure of ground+ five storeys(G+5) considering the gravity and lateral loads. The following conclusion was drawn from theis work:

i. Maximum time period is 3.53901sec for model 1 in the structure
ii. For maximum time period the natural frequency is 0.28256 cycles/sec
iii. Maximum axial forces in the structure is 23031.36 kN
iv. Maximum diaphragm drift is 0.0077
v. Design of R.C.C column size 230*450 mm (reinforcement 8no,s @12dia) 0.874% reinforcement
vi. Designs of R.C.C slab 200mm thickness 8 mm dia 230mm spacing.

Chowdhury and Singh, 2010, stated that: some designers apply **Rankine Grashoff theory** for design of waffle slab. In this method, waffle slab is assumed to be simply supported on all four edges. Figure (2.10) shows plan of grid floor and displacements at the centre of the slab in x and y directions are assumed to be compatible".They, also stated that **Finite Element Analysis (FEM)** is used for many real life waffle structures, having complicated boundary conditions. To arrive at the correct solution. However, accuracy of the solution is restricted by availability of the right kind of plate element in the finite element library and degree of mesh refinement. It has been often found that despite the best meshing; the results obtained have either an upper or lower bound solution compared to exact analysis. "Additionally, intense labour involvement in development of the mathematical model, preparation of input data and extraction of design parameters for final design often makes the analysis expensive and time consuming. Clearly, these factors do not make FEM an automatic choice".

Mallick and Bhushan(1983) had furnished solutions to the problem of analysis by considering the waffle slab as grillage beam, providing an approximate solution to the system, wherein they had clearly stated that their approach may only be used for preliminary design and that it must be substantiated by a detailed computer analysis.

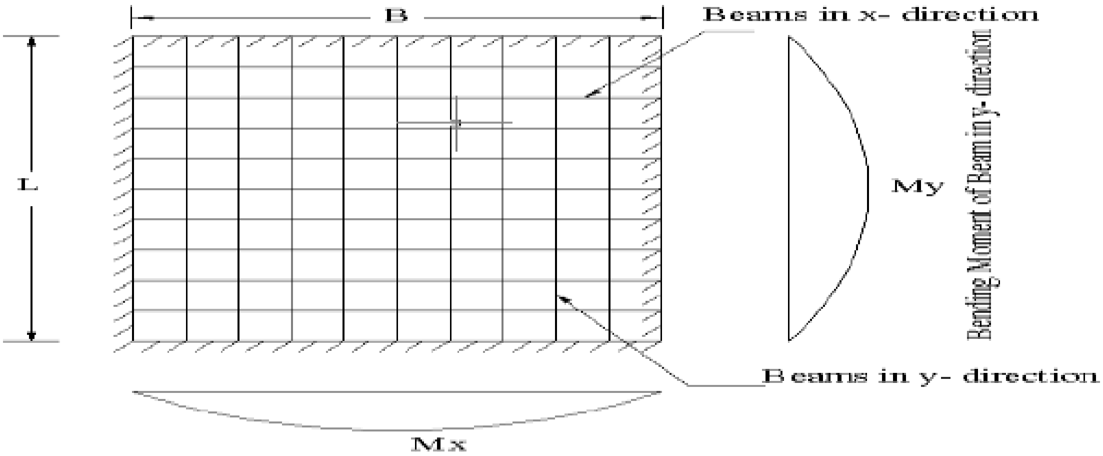


Figure2.8: Typical grid considered in Rankine-Grashoff and plate theory (Below grid).

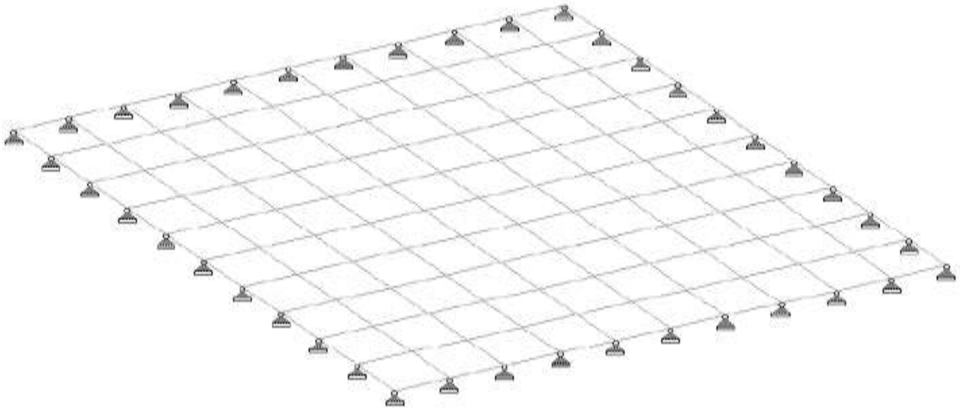


Figure 2.9: Typical grid floor considered in stiffness method.

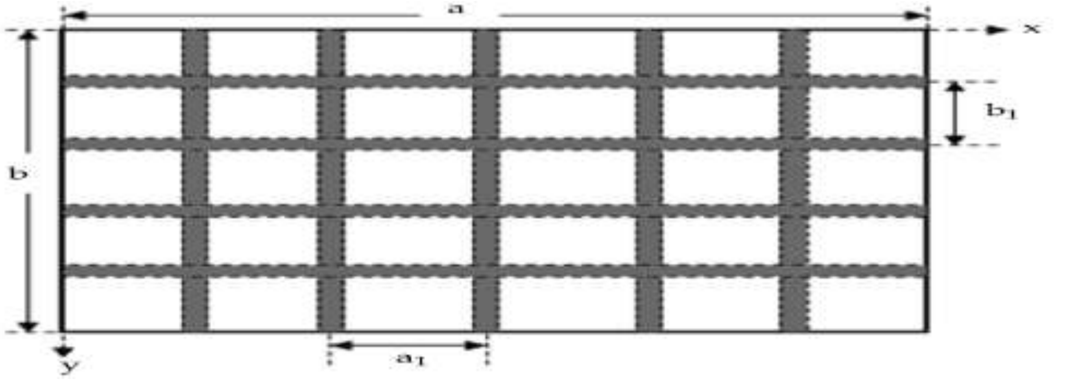


Figure 2.10: Plan of grid floor.

CHAPTER THREE

LOADS ON GRID SYSTEMS AND METHOD OF ANALYSIS AND DESIGN

3.1 Introduction:

Loads in buildings are higher than those in ordinary buildings, in order to increase the value of loads and the high impact of lateral loads.Therefore, the types of materials used. Review of the loads that are exposed to high buildings and loads in terms of type and value in addition to explaining how calculation of wind loads on high buildings, it willalso explain how to use the ETABS program.

3.2 Loading: (Smith and Coull, 1991)

Loading on tall buildings differs from loading on low- rise buildings in its accumulation into much larger structural forces, in the increased ignificance of wind loading, and in the greater importance of dynamic effects.The collection of gravity loading over a large number of stories in a tall building can produce column loads of an order higher than those in low- rise buildings. Wind loading on tall building acts not only over avery large building surface, but also with greater intensity at the greater heights and with a larger moment arm about the base than on a low- rise building. Although wind loading on a low- rise building usually has an insingnificant influence on the design of the structure, wind on a high- rise building can have adominant influence on its structural arrangement and design. In an extreme case of a very slender or flexible structure, the motion of the building in the wind may have to be considered in assessing the loading applied by the wind.

In earthquake regions, any inertial loads from the shaking of the ground may well exceed the loading due to wind and, therefore. Be dominant in influencing the buildings structural from, design, and cost. As an intertial problem, the buildings dynamic response plays a large part in influencing and in estimating the loading on the structure.

3.2.1 Gravity loading: (Smith and Coull,1991)

Although the tributary areas and therefore the gravity loading. Supported by the beams and slabs in a tall building do not differ from those in a low- rise building. The accumulation in the former of many stories of loading by the columns and walls can be very much greater. As in a low- rise building.:

- Dead loading is calculated from the designed member sizes and estimated material densities. This is prone to minor inaccuracies such as differences between the real and the designed sizes, and between the actual and the assumed densities.
- Live loading is specified as the internsity of a uniformly distributed floor load according to the occupancy or use of the space. In certain situations such as in parking areas, offices and rooms, it should be considered for the alternative worst possibility of specified concentrated loads.The magnitudes of live loading specified in the codes are estimates based on a combination of experience and the results of typical field surveys. There are differences between the live load magnitudes in the codes of different countries.

3.2.2 Wind load: (Smithand and Coull,1991)

The lateral loading due to wind or earthquake is the major factor that causes the design of high- rise buildings to differ from those of low-to medium rise buildings. For buildings of up to about 10 stories and of typical proportions, the design is rarely affected by wind loads. Above this height, however, the increase in size of the structural members, and the possible rearrangement of the structure to account for wind loading, incurs a cost premium that increases progressively with height.

With innovations in architectural treatment, increases in the strengths of materials and advances in methods of analysis, tall building structures have become more efficient and lighter and, consequently, more prone to deflect and even to sway under wind loading. This served as a spur to research. This has produced significant advances in understanding the nature of wind loading and in developing methods for its estimation. These developments have been mainly in experimental and theoretical techniques for determining the increase in wind loading due to gusting and the dynamic interaction of structures with gust forces.

The foreword of BS 6399-2 makes it clear that, like CP3-V-2, BS6399-2 is intended for use only for sites in the UK.Nevertheless, many countries accept designs assessed to the current UK standard, so the relevant procedure is given. This is explained in more detial below. Only the basic wind speed and climate factors are unique to the UK, so there is need to obtain the relevant site wind speed, Vs, for the overseas site. This is the hourly- mean wind speed at 10m above open level ground appropriate to the geographical location of the site. This is a standard meteorological parameter, so should be available from the local meteorological authority.

If given a gust wind speed compatible with CP3-V-2, it should be treated as follows:

- Take the gust speed to be the effective wind speed,Ve, for H= 20m in country terrain, in the standard method.
- Determine Vs by dividing the gust speed by the terrain- and- building factor for the reference terrain in appendix A (Table A5)
- Determine the appropriate value of Sb for the relevant effective height and site location, from Table 4 and multiply by Vs to obtain Ve.
- Basic wind speed Vb= 44.704 m/s
- Site in town Hr= 20m
- Building type factor Kp=1 (see appendix A Table A3)
- The dynamic augmentation factor Cr=0.064 (see appendix A Figure A1)
- Direction factor Sd= 0.85 (see appendix A Table A4)
- The terrain and building factor obtained= Sb (see appendix A Table A5)
- Internal pressure coefficient Cpi = -0.3 (see appendix A Table A6)

3.3 Numerical methods of analysis: (Lui,Y., 1998)

The main numerical methods of structural analysis are:

- Force or flexibility method
- Displacement or stiffness method
- Finite element method

The method, mostly used and adopted here is the finite element method. The basic concepts finite element method are as follows:

The finite element method (FEM), is based on the idea of building a complicated objet with simple blocks, or, dividing a omplicated object into small and manageable pieces. Application of this simple ideal can be found every where in every day life as well as in engineering.

FEM in structural analysis procedures is as follows:

- Divide structure into pieces(element with nodes).
- Describe the behavior of the physical quantities on each element.
- Connect (assemble) the elements at the nodes to form an approximate system of equations for the whole structure.
- Solve the system of equations involving unknown quantities at the nodes (e.g., displacements).
- Calculate desired quantities (e.g., strains and stresses) at selected elements

Invention of programs that work on the analysis and design of high buildings contributed to save time and effort and high a ccuracy in the results. These programs work on the system of finite elements, where the origin is divided into small elements in the form of a network and examples of these programs are (SAP, ETABS, STAAD prog) .It is worth mentioning that the elements for columns, beams and ties are know in these programs as frame elements, and those for slabs, shear walls and ramps as shell elements.In this research analysis and design has been carried out using ETABS.

3.4 ETABS computer program:

3.4.1 General (Ali, 2016)

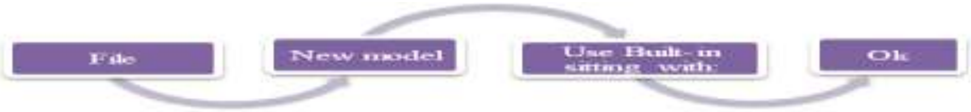
The special features of the ETABS program greatly reduce the amount of input required. This includes the definition of beams and columns as a simple grid system rather than a complex materix of nodes and elements. The in herent assumption of rigid floor system in ETABS makes it idea for defining floor systems in high rise buildings.

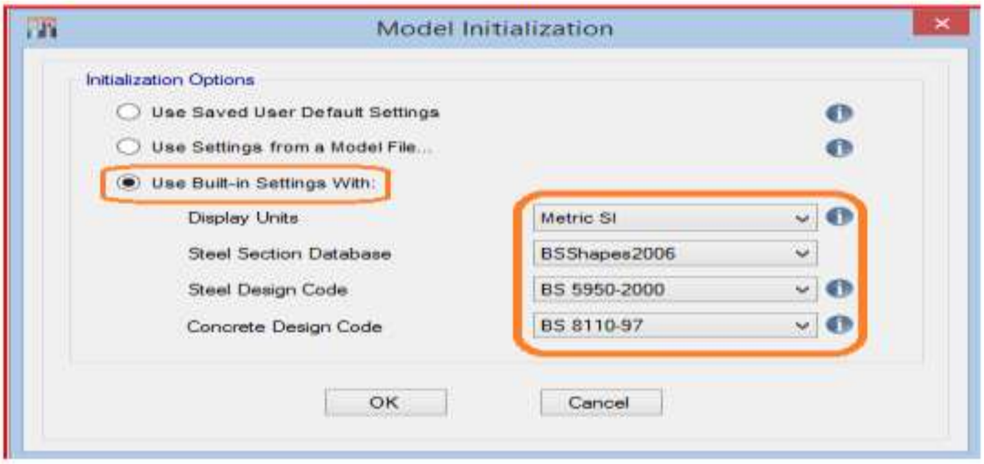
3.4.2 ETABS features: (Ali, 2016)

ETABS is special purpose computer program for the linear and non- linear static and dynamic analysis of buildings. ETABS offers a comprehensive 3-D analysis and design for multi storey building structures. A complete suite of windows graphical tools and utilities are included with the base package, a modeler and a post. Processor for viewing all results, including mode shapes, forces diagram and deflected shapes. The ETABS buildings may be un-symmetrical and non-rectangular in plan. The program considers a building system as an assemblage of vertical frames interconnected at eash storey level by horizontal floor diaphragms. The vertical frames are idealized as an assemblage of column, beam, brace and wall elements inter connected by horizontal floor diaphragm slabs which may be rigid or flexible in their own plane.

3.4.3 Basic process:

The following provides abroad over view of the basic modeling, analysis, and design processes: Figure 3.1 shows the model unitization, Figure 3.2 shows grid options in new model quick templates, Figure 3.3 shows the define storey levels, Figure 3.4 shows the dfine material property, Figure 3.5.a and 3.5.b shows the define section properties& detail reber, Figure 3.6 shows the define slab, Figure 3.7 shows the define shear wall, Figure 3.8 shows assign restraints, Figure 3.9 shows the auto edge constrains, Figure 3.10 shows the assign diaphragms, Figure 3.11 shows the define load patterm& wind data, Figure 3.12 shows the define load combnation, Figure 3.13 shows the enter load values, Figure 3.14 shows automatic rectangular mesh setting for floor& wall, Figure 3.15 shows check model, Figure 3.16 shows macth analysis and design, Figure 3.17 shows success sections in the design test, Figure 3.18 shows the slab for export from ETABS to SAFE, Figure 3.19 shows import slab from program ETABS to SAFE, Figure 3.20 shows the design preferences code, Figure 3.21 shows the main cover slabs, Figure 3.22 shows determination of concrete cover for beams and the results are obtained in similar Figures as shown in chapter five and Figure 3.22 shows run and display show slab design.





Initialization Options

○ Use Saved User Default Settings

○ Use Settings from a Model File...

● Use Built-in Settings With:

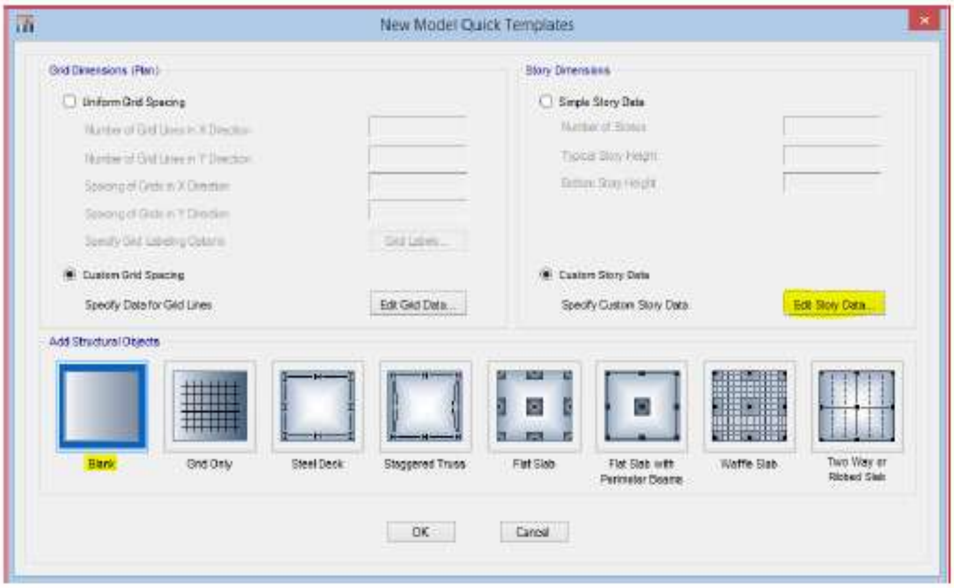
Display Units: Metric SI

Steel Section Database: BSShapes2006

Steel Design Code: BS 5950-2000

Concrete Design Code: BS 8110-97

Figure 3.1: Model unitization



Grid Dimensions (Plan)

☐ Uniform Grid Spacing

Number of Grid Lines in X Direction

Number of Grid Lines in Y Direction

Spacing of Grids in X Direction

Spacing of Grids in Y Direction

Specify Grid Labeling Options

● Custom Grid Spacing

Specify Data for Grid Lines

Story Dimensions

○ Simple Story Data

Number of Stories

Typical Story Height

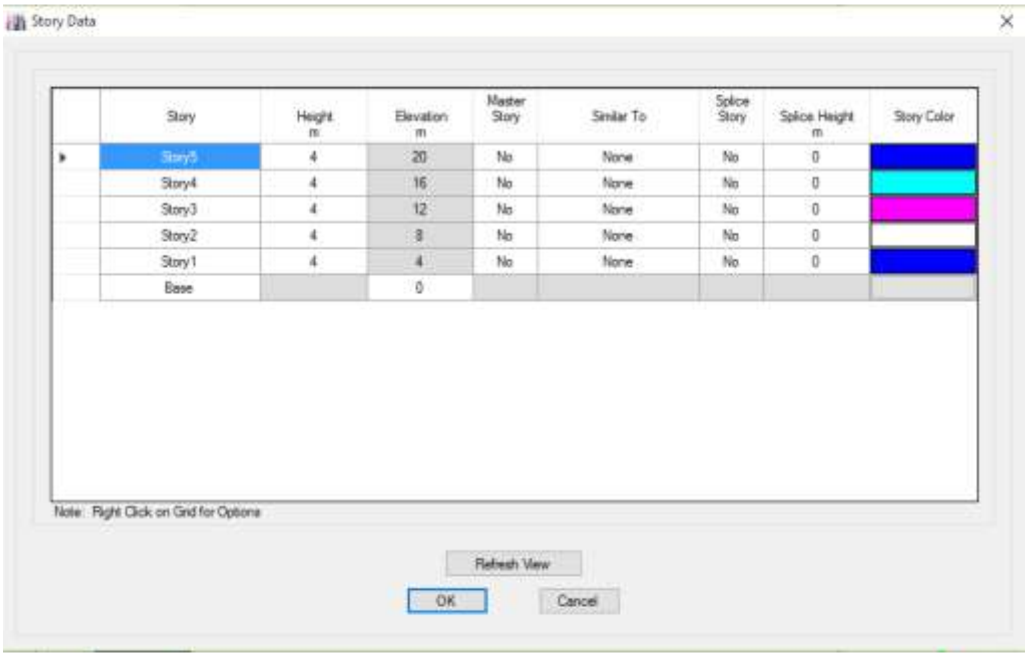
Bottom Story Height

● Custom Story Data

Specify Custom Story Data

Add Structural Objects

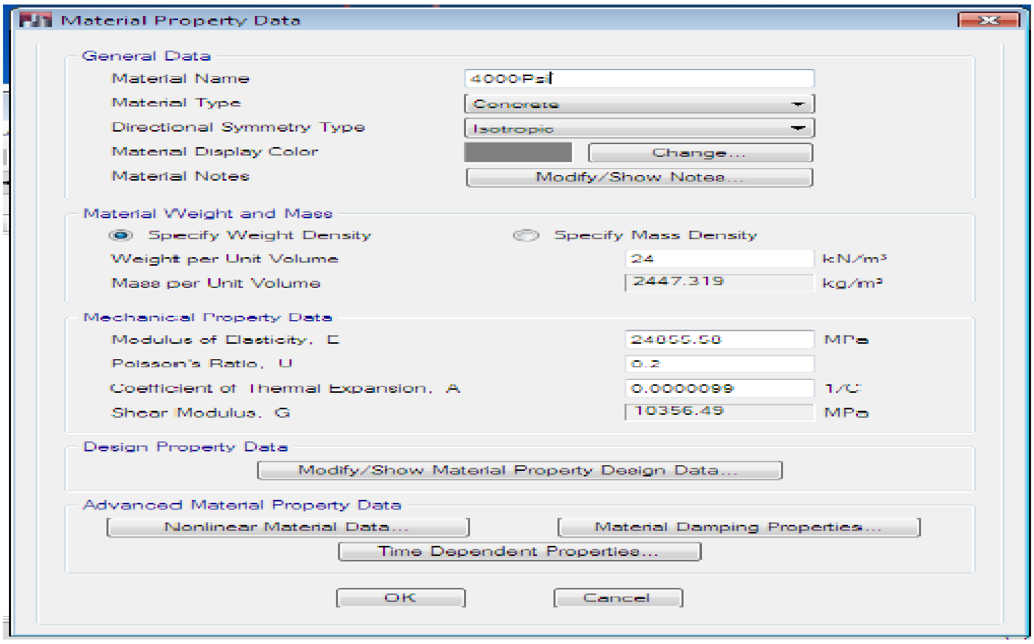
Figuer 3.2: Grid options in new model quick templates


Story Data

	Story	Height m	Elevation m	Master Story	Similar To	Splice Story	Splice Height m	Story Color
▸	Story5	4	20	No	None	No	0	🟦
	Story4	4	16	No	None	No	0	🟦
	Story3	4	12	No	None	No	0	🟪
	Story2	4	8	No	None	No	0	⬜
	Story1	4	4	No	None	No	0	🟦
	Base		0					

Note: Right Click on Grid for Options

Figure 3.3: Define storey levels


Material Property Data

General Data
Material Name: 4000Psi
Material Type: Concrete
Directional Symmetry Type: Isotropic
Material Display Color
Material Notes

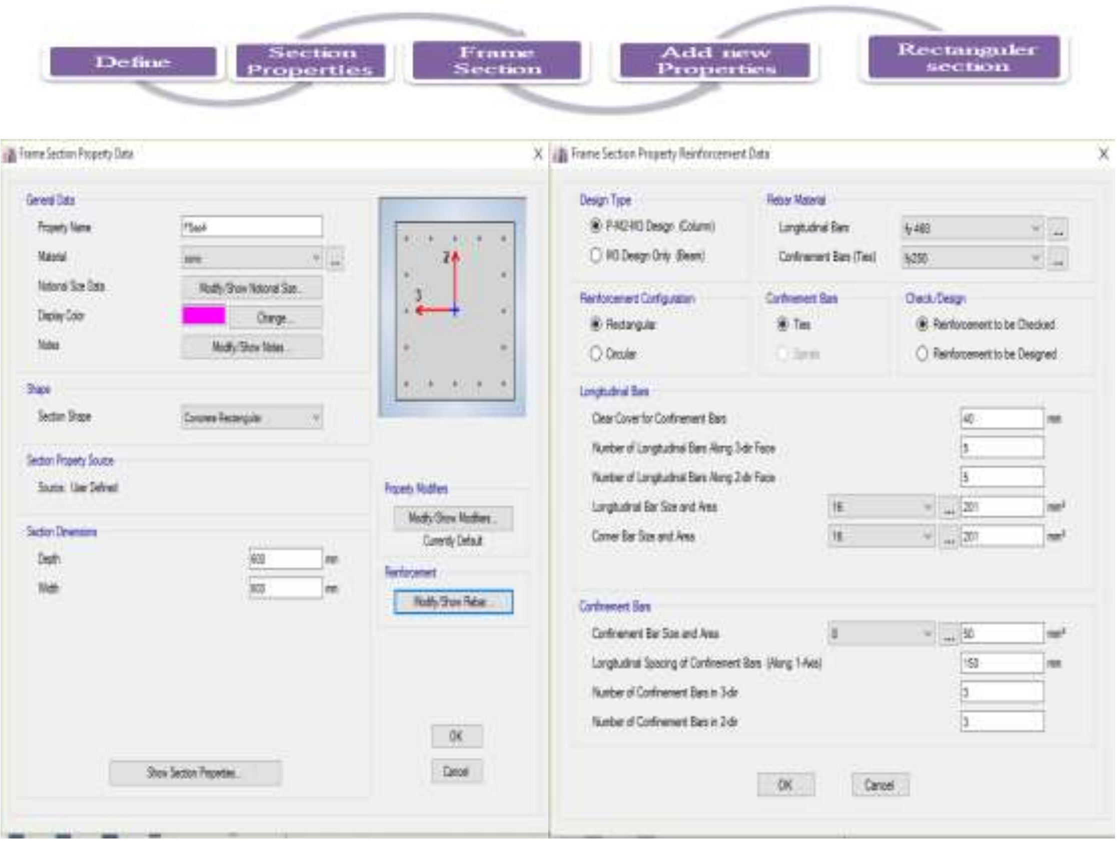
Material Weight and Mass
● Specify Weight Density ○ Specify Mass Density
Weight per Unit Volume: 24 kN/m³
Mass per Unit Volume: 2447.319 kg/m³

Mechanical Property Data
Modulus of Elasticity, E: 24855.58 MPa
Poisson's Ratio, U: 0.2
Coefficient of Thermal Expansion, A: 0.0000099 1/C
Shear Modulus, G: 10356.49 MPa

Design Property Data

Advanced Material Property Data

Figure 3.4: Define material property



Frame Section Property Data

General Data

Property Name: [illegible]

Material: [illegible]

Shape

Section Shape: Concrete Rectangular

Section Property Source

Source: User Defined

Section Dimensions

Depth: 600 mm

Width: [illegible] mm

Frame Section Property Reinforcement Data

Design Type: ● P-M2-M3 Design (Column) ○ M3 Design Only (Beam)

Rebar Material: Longitudinal Bars: fy 460; Confinement Bars (Ties): fy250

Reinforcement Configuration: ● Rectangular ○ Circular

Confinement Bars: ● Ties ○ Spirals

Check/Design: ● Reinforcement to be Checked ○ Reinforcement to be Designed

Longitudinal Bars

Clear Cover for Confinement Bars: 40 mm

Number of Longitudinal Bars Along 3-dir Face: 5

Number of Longitudinal Bars Along 2-dir Face: 5

Longitudinal Bar Size and Area: 16, 201 mm²

Corner Bar Size and Area: 16, 201 mm²

Confinement Bars

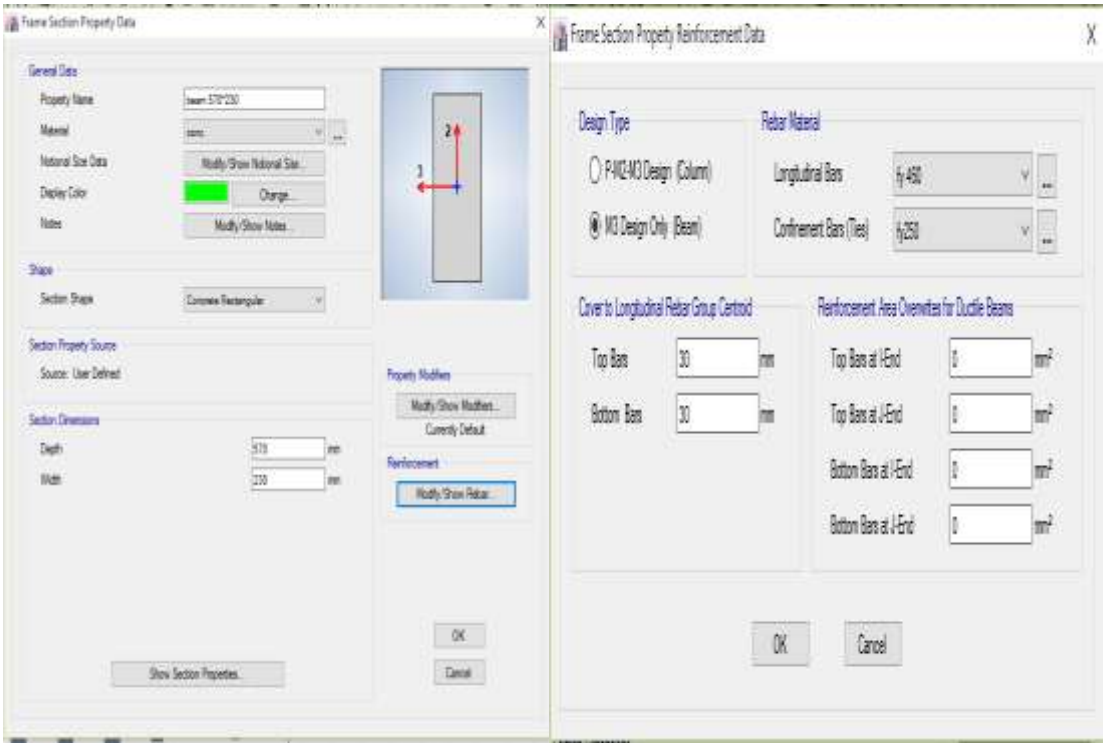
Confinement Bar Size and Area: 8, 50 mm²

Longitudinal Spacing of Confinement Bars (Along 1-Axis): 150 mm

Number of Confinement Bars in 3-dir: 3

Number of Confinement Bars in 2-dir: 3

Figure 3.5.a: Define section properties &detail rebar



Frame Section Property Data

General Data

Property Name: beam 570*230

Shape

Section Shape: Concrete Rectangular

Section Property Source

Source: User Defined

Section Dimensions

Depth: 570 mm

Width: 230 mm

Frame Section Property Reinforcement Data

Design Type: ○ P-M2-M3 Design (Column) ● M3 Design Only (Beam)

Rebar Material: Longitudinal Bars: fy 460; Confinement Bars (Ties): fy250

Cover to Longitudinal Rebar Group Centroid

Top Bars: 30 mm

Bottom Bars: 30 mm

Reinforcement Area Overwrites for Ductile Beams

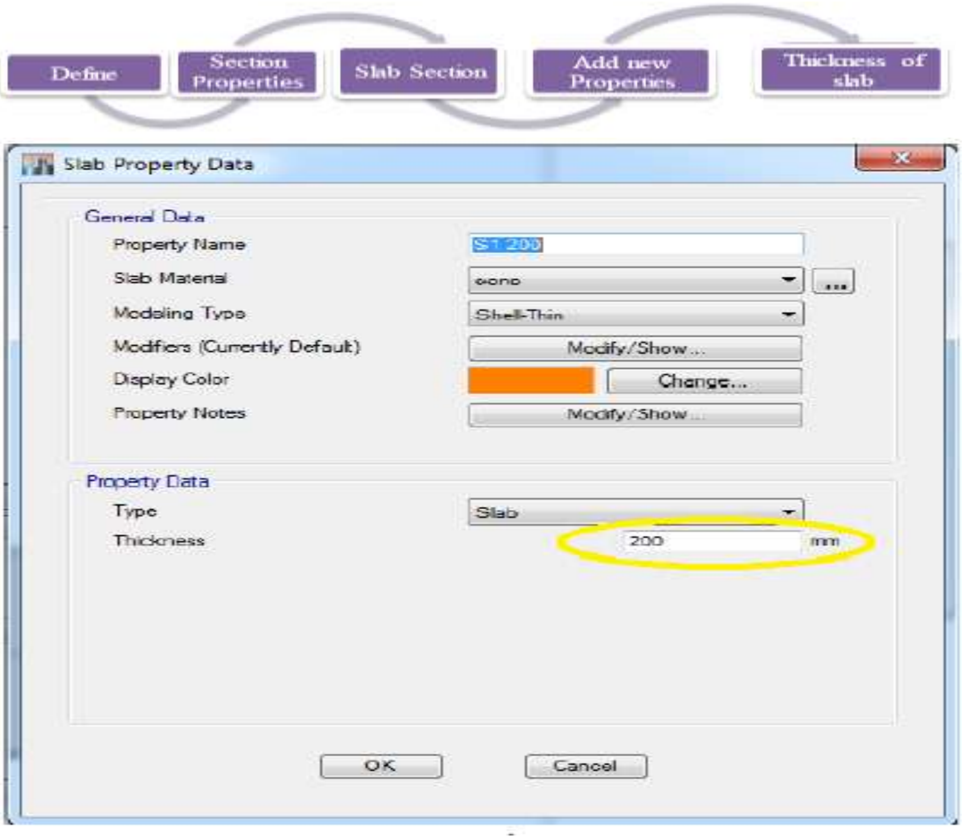
Top Bars at I-End: 0 mm²

Top Bars at J-End: 0 mm²

Bottom Bars at I-End: 0 mm²

Bottom Bars at J-End: 0 mm²

Figure 3.5.b: Define section properties &detail rebar



Slab Property Data

General Data

Property Name: S1 200

Slab Material: conc

Modeling Type: Shell-Thin

Modifiers (Currently Default): Modify/Show...

Display Color: Change...

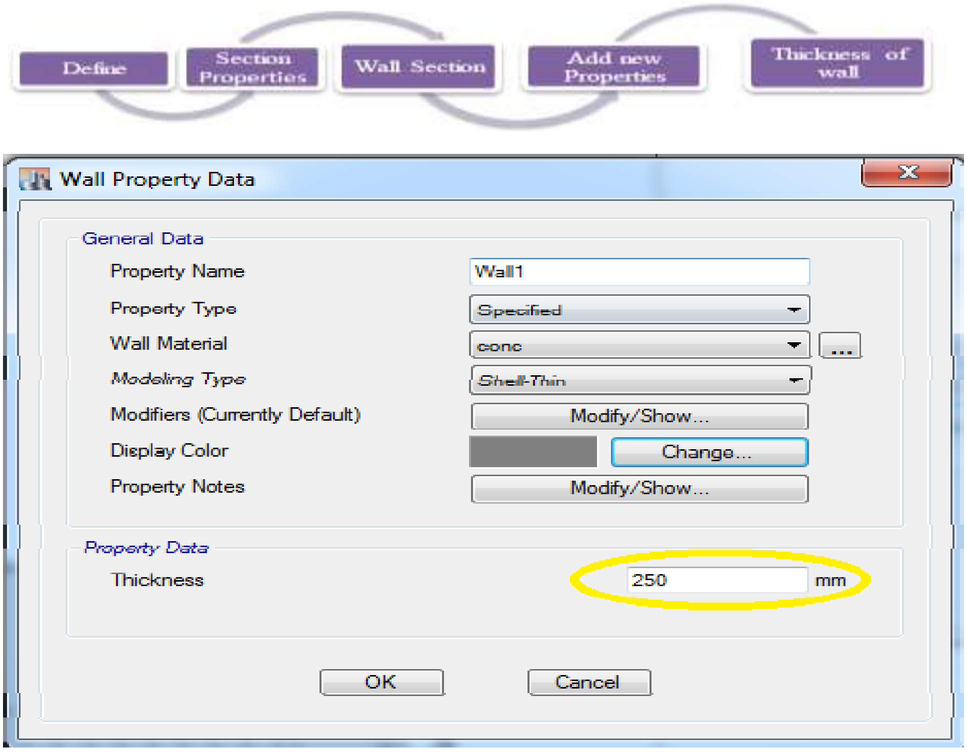
Property Notes: Modify/Show...

Property Data

Type: Slab

Thickness: 200 mm

Figure 3.6: Define slab



Wall Property Data

General Data

Property Name: Wall1

Property Type: Specified

Wall Material: conc

Modeling Type: Shell-Thin

Modifiers (Currently Default): Modify/Show...

Display Color: Change...

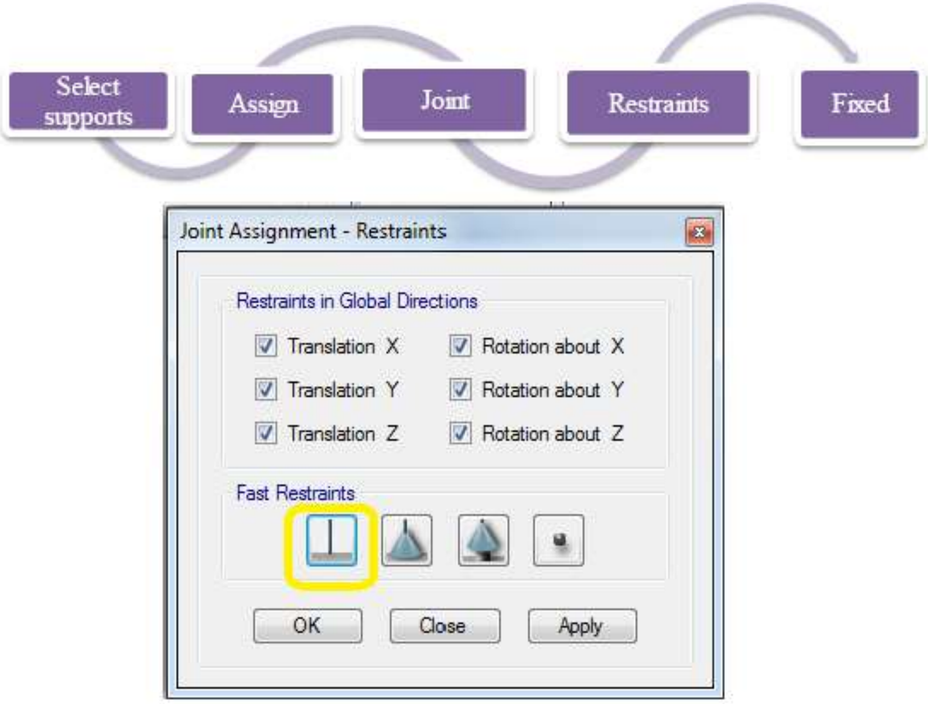
Property Notes: Modify/Show...

Property Data

Thickness: 250 mm

Figure 3.7: Define shear wall

- **Draw structures (column, Beams, shear wall, slab)**



Joint Assignment - Restraints

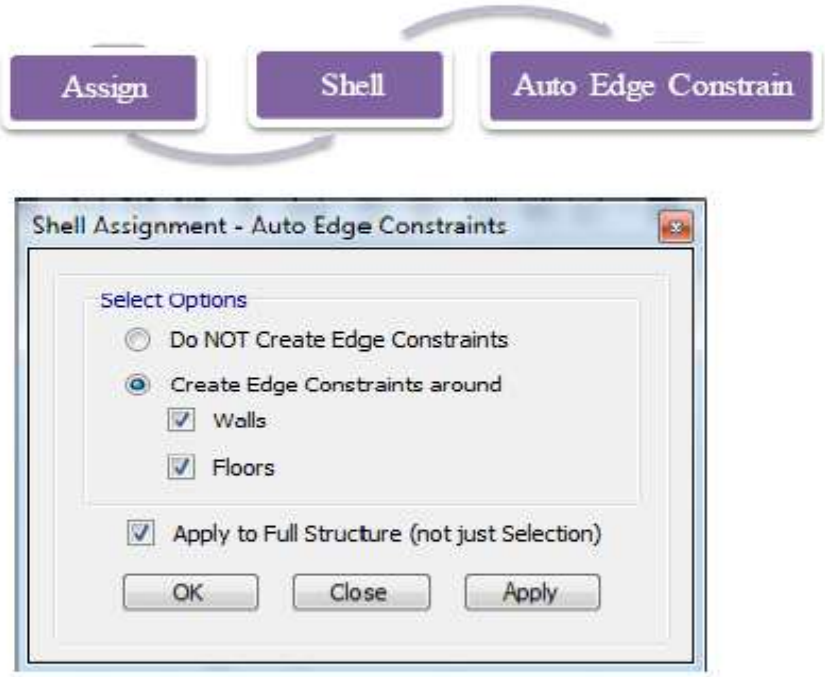
Restraints in Global Directions

☑ Translation X ☑ Rotation about X

☑ Translation Y ☑ Rotation about Y

☑ Translation Z ☑ Rotation about Z

Figure 3.8: Assign restraints



Shell Assignment - Auto Edge Constraints

Select Options

○ Do NOT Create Edge Constraints

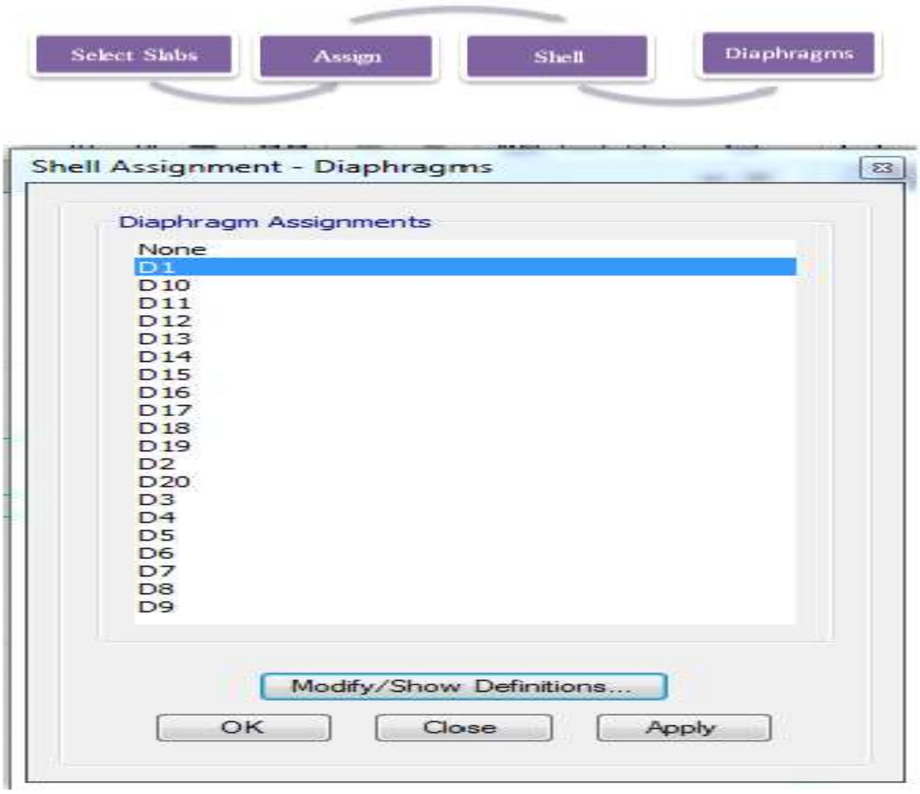
● Create Edge Constraints around

☑ Walls

☑ Floors

☑ Apply to Full Structure (not just Selection)

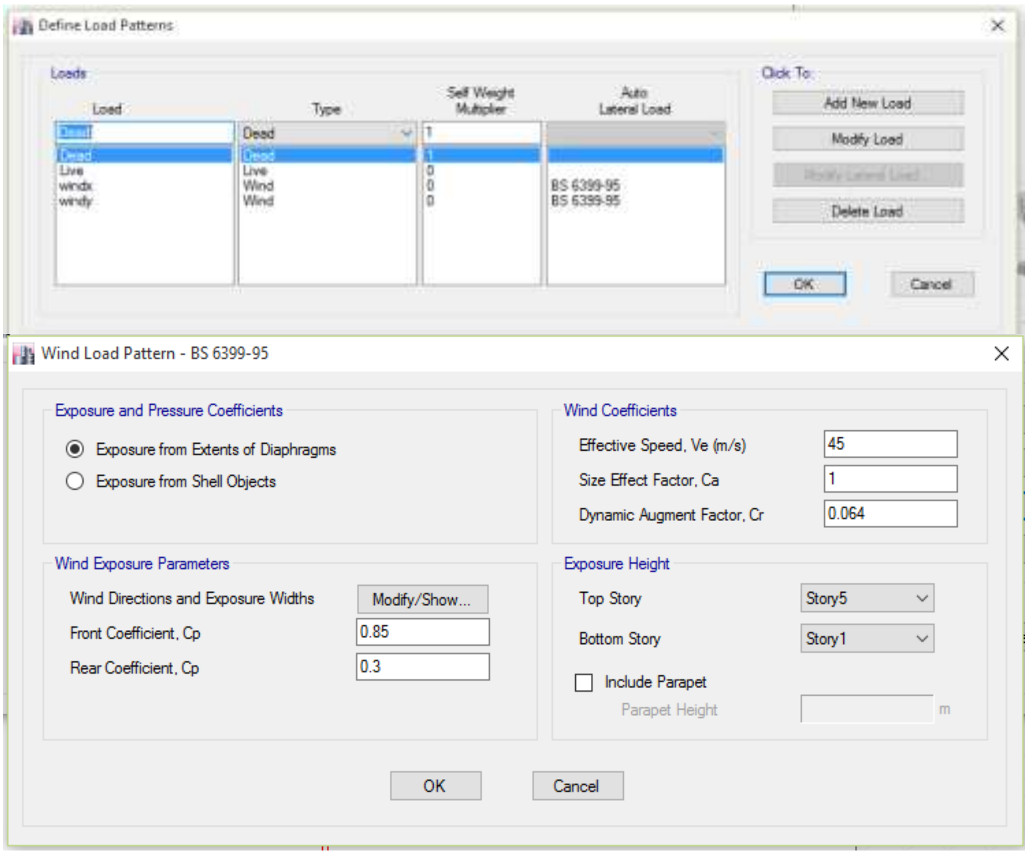
Figure 3.9: Auto edge constrain



Diaphragm Assignments

None
D1
D10
D11
D12
D13
D14
D15
D16
D17
D18
D19
D2
D20
D3
D4
D5
D6
D7
D8
D9

Figure 3.10: Assign diaphragms



Load	Type	Self Weight Multiplier	Auto Lateral Load
Dead	Dead	1	
Dead	Dead	1	
Live	Live	0	
windx	Wind	0	BS 6399-95
windy	Wind	0	BS 6399-95

Exposure and Pressure Coefficients

● Exposure from Extents of Diaphragms
○ Exposure from Shell Objects

Wind Coefficients

Effective Speed, Ve (m/s): 45
Size Effect Factor, Ca: 1
Dynamic Augment Factor, Cr: 0.064

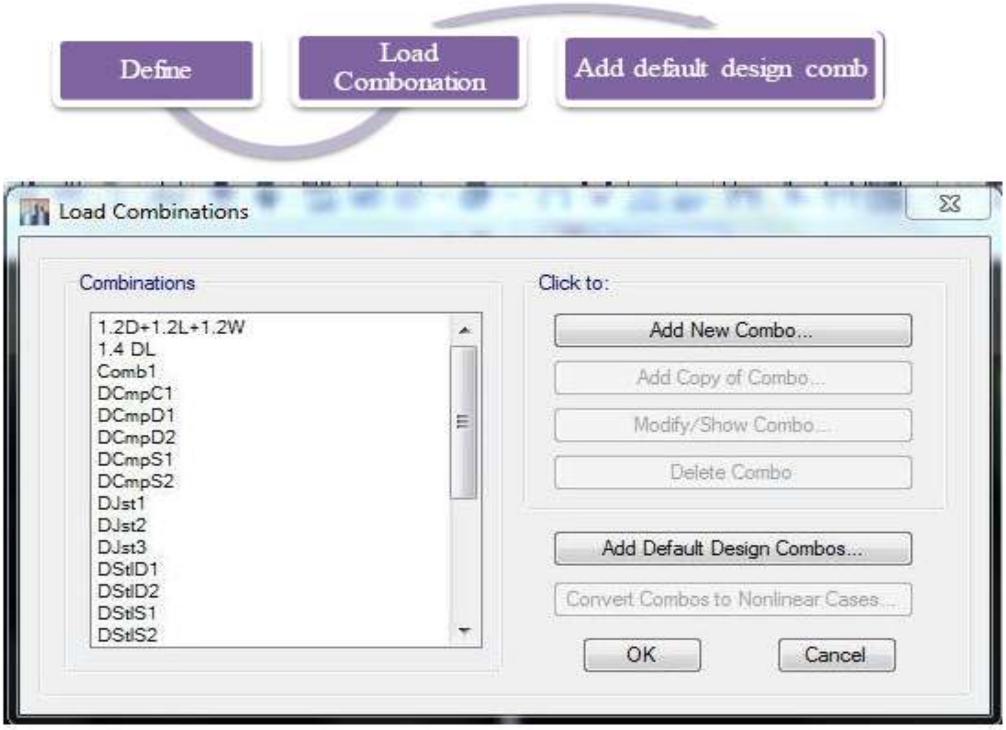
Wind Exposure Parameters

Wind Directions and Exposure Widths
Front Coefficient, Cp: 0.85
Rear Coefficient, Cp: 0.3

Exposure Height

Top Story: Story5
Bottom Story: Story1
☐ Include Parapet
Parapet Height m

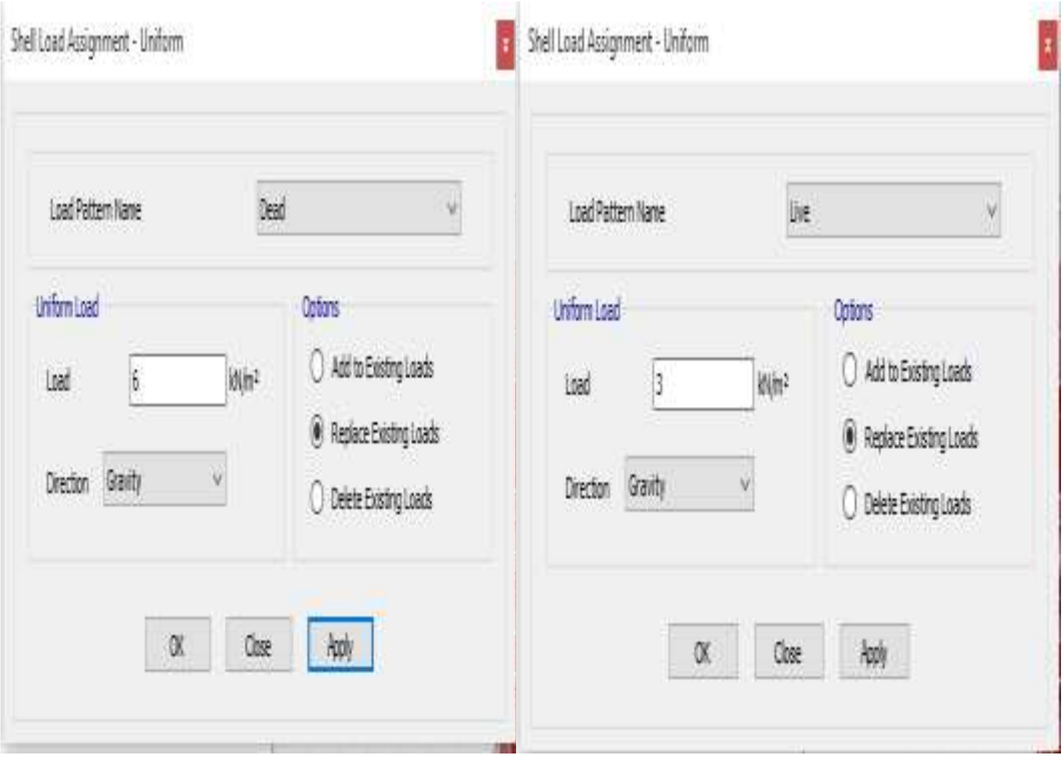
Figure 3.11: Define load patterm& wind data



Combinations

1.2D+1.2L+1.2W
1.4 DL
Comb1
DCmpC1
DCmpD1
DCmpD2
DCmpS1
DCmpS2
DJst1
DJst2
DJst3
DStlD1
DStlD2
DStlS1
DStlS2

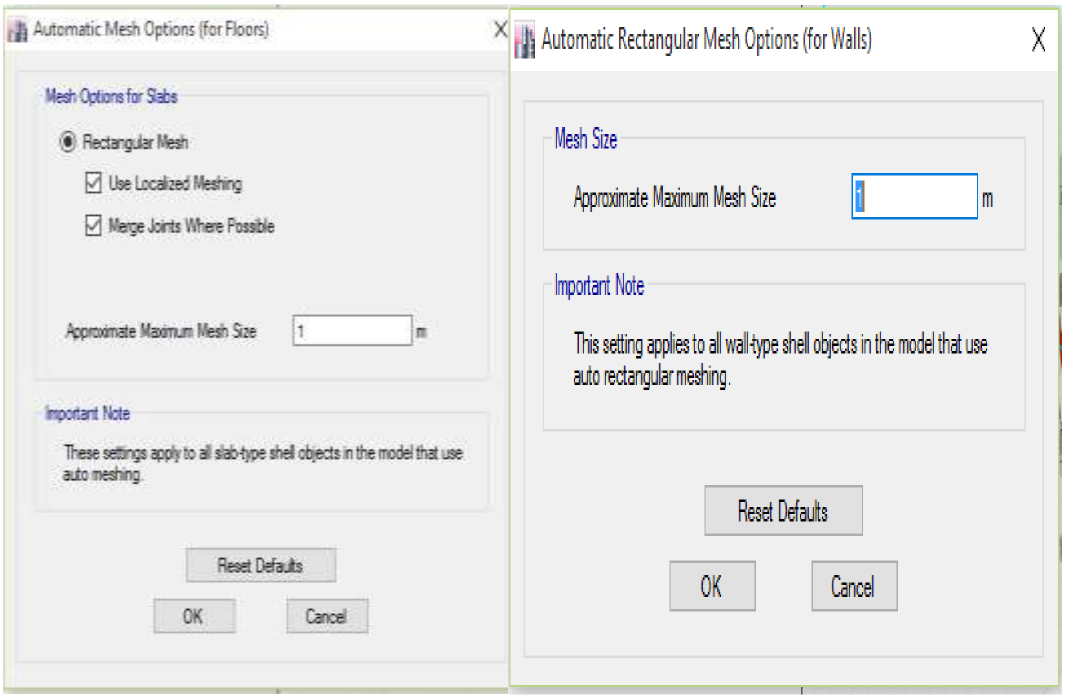
Figure 3.12: Define load combination



Load Pattern Name: Dead
Load: 6 kN/m²
Direction: Gravity
● Replace Existing Loads

Load Pattern Name: Live
Load: 3 kN/m²
Direction: Gravity
● Replace Existing Loads

Figure 3.13: Enter load values



● Rectangular Mesh

☑ Use Localized Meshing

☑ Merge Joints Where Possible

Approximate Maximum Mesh Size 1 m

Important Note

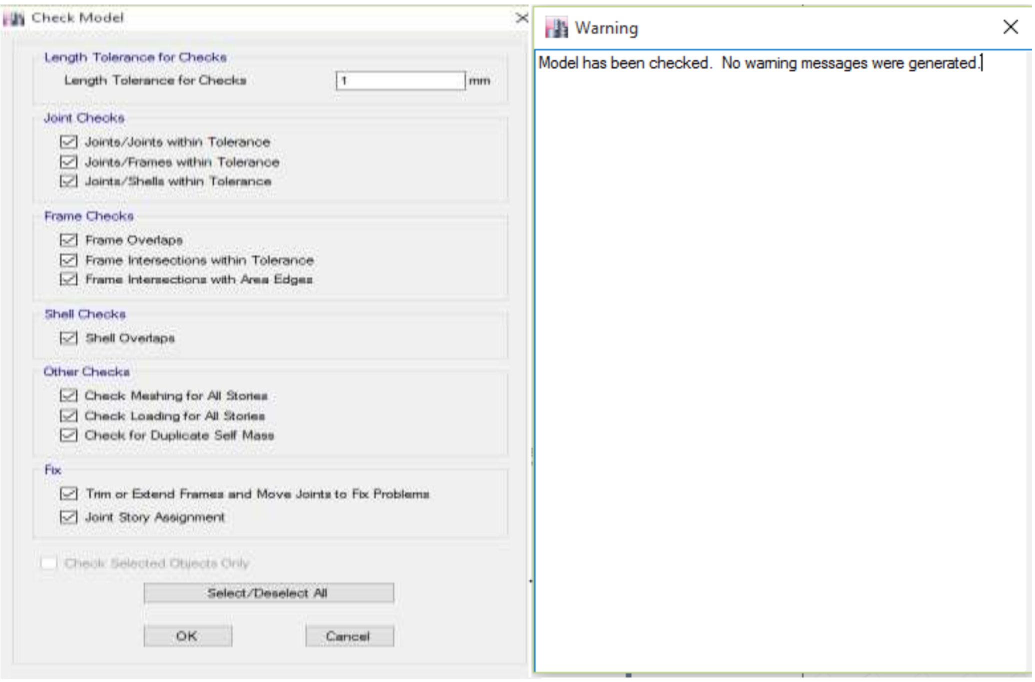
These settings apply to all slab-type shell objects in the model that use auto meshing.

Approximate Maximum Mesh Size 1 m

Important Note

This setting applies to all wall-type shell objects in the model that use auto rectangular meshing.

Figure 3.14: Automatic rectangular mesh setting for floor& wall



Length Tolerance for Checks 1 mm

☑ Joints/Joints within Tolerance

☑ Joints/Frames within Tolerance

☑ Joints/Shells within Tolerance

☑ Frame Overlaps

☑ Frame Intersections within Tolerance

☑ Frame Intersections with Area Edges

☑ Shell Overlaps

☑ Check Meshing for All Stories

☑ Check Loading for All Stories

☑ Check for Duplicate Self Mass

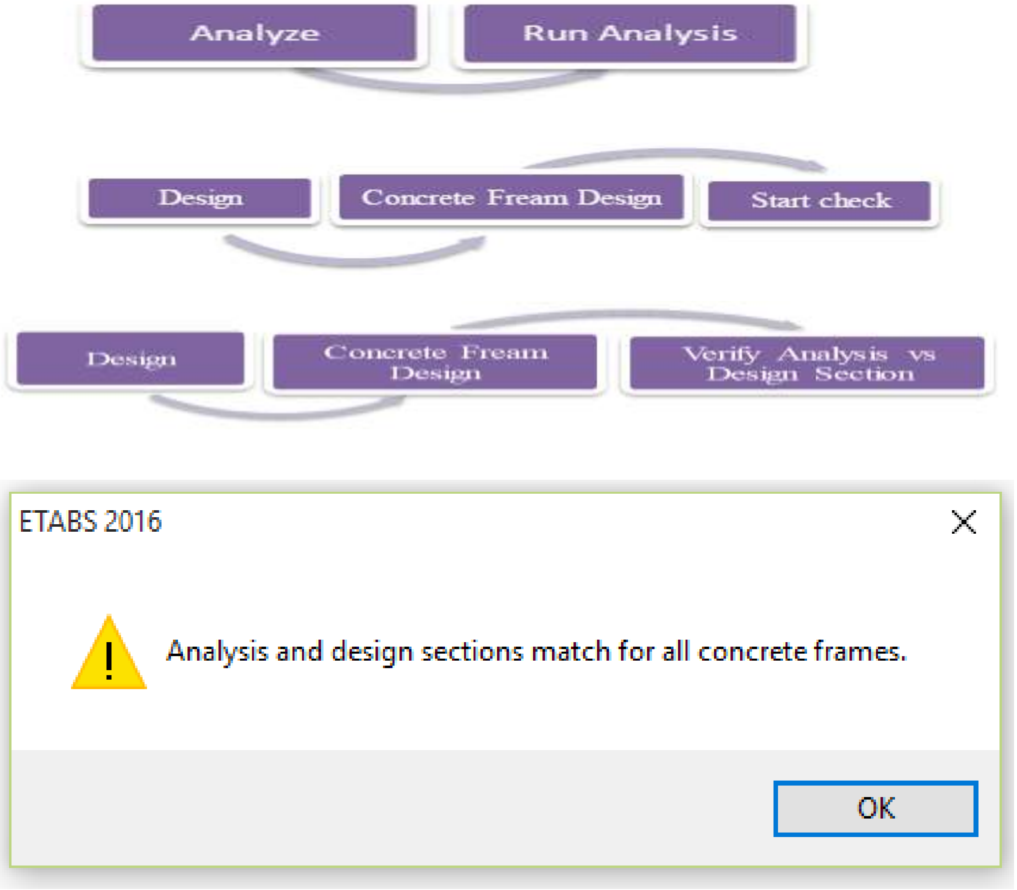
☑ Trim or Extend Frames and Move Joints to Fix Problems

☑ Joint Story Assignment

☐ Check Selected Objects Only

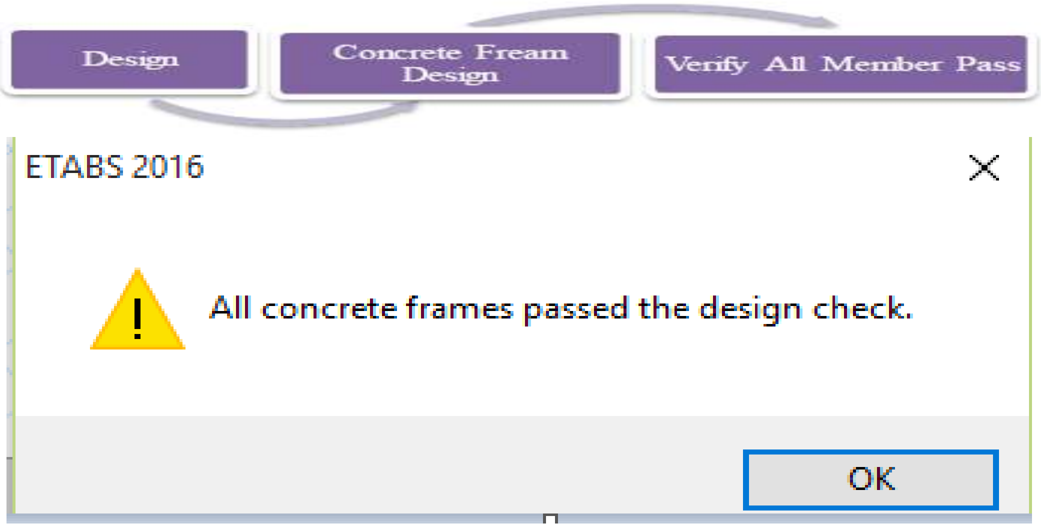
Model has been checked. No warning messages were generated.

Figure 3.15: Check model



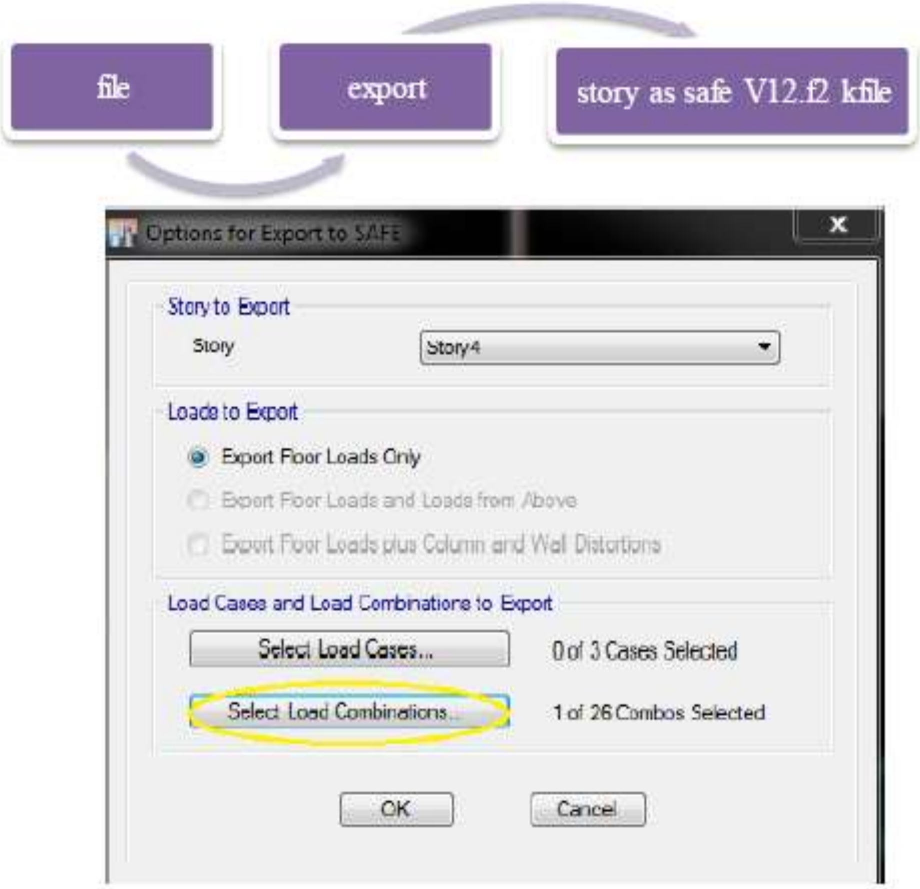
Analysis and design sections match for all concrete frames.

Figure 3.16: Match analysis and design



All concrete frames passed the design check.

Figure 3.17: Success sections in the design test



Options for Export to SAFE

Story to Export

Story: Story4

Loads to Export

● Export Floor Loads Only

○ Export Floor Loads and Loads from Above

○ Export Floor Loads plus Column and Wall Distortions

Load Cases and Load Combinations to Export

0 of 3 Cases Selected

1 of 26 Combos Selected

Figure 3.18: Slab for export from ETABS to SAFE

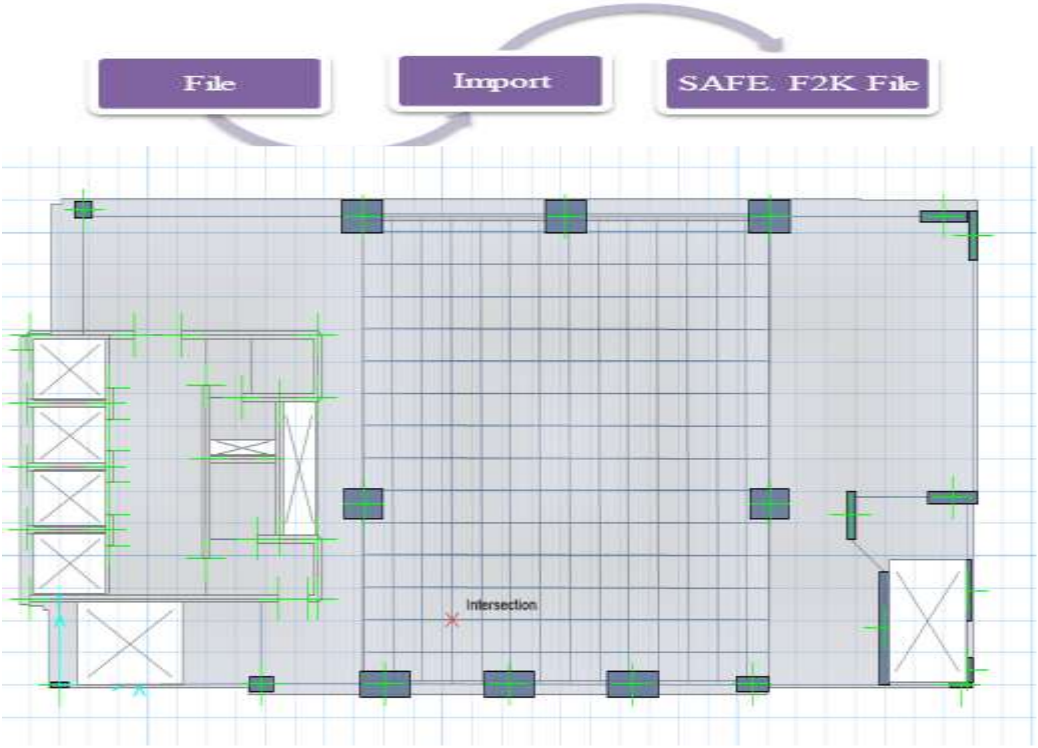
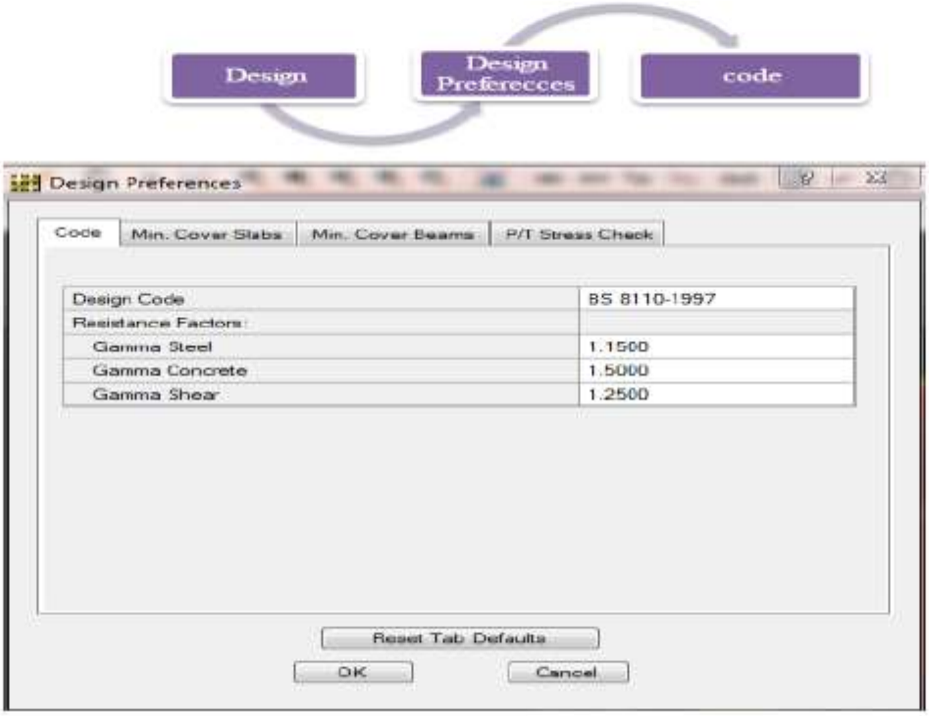
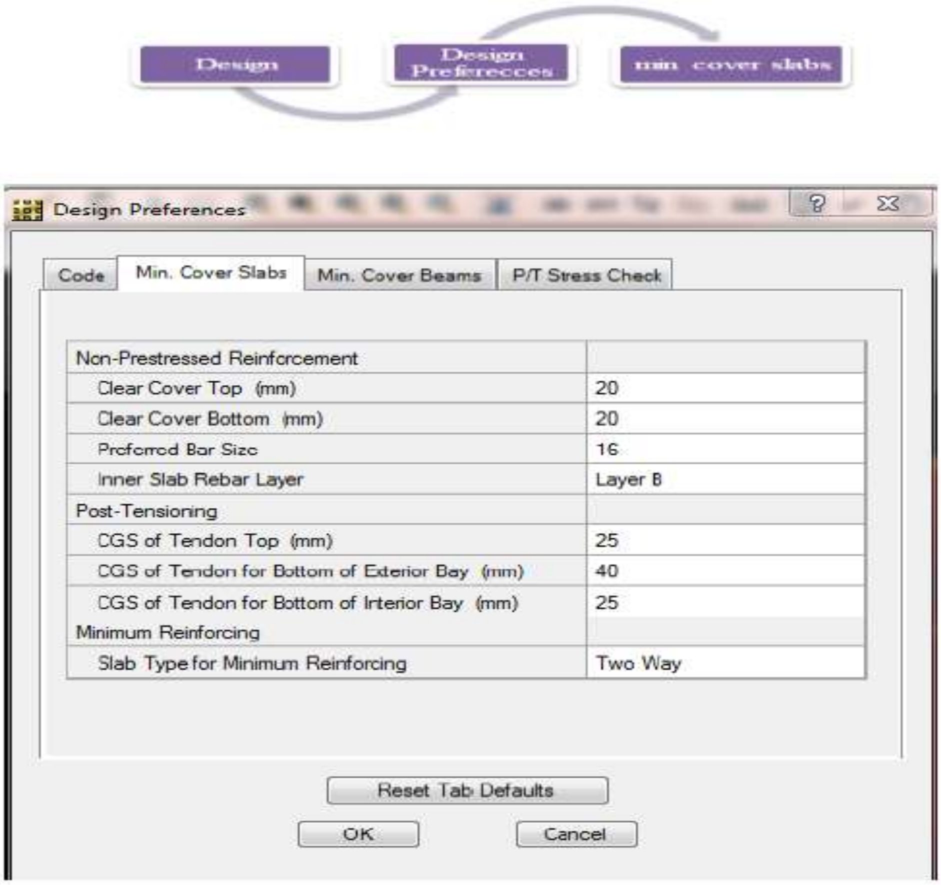


Figure 3.19: Import slab from program ETABS to SAFE



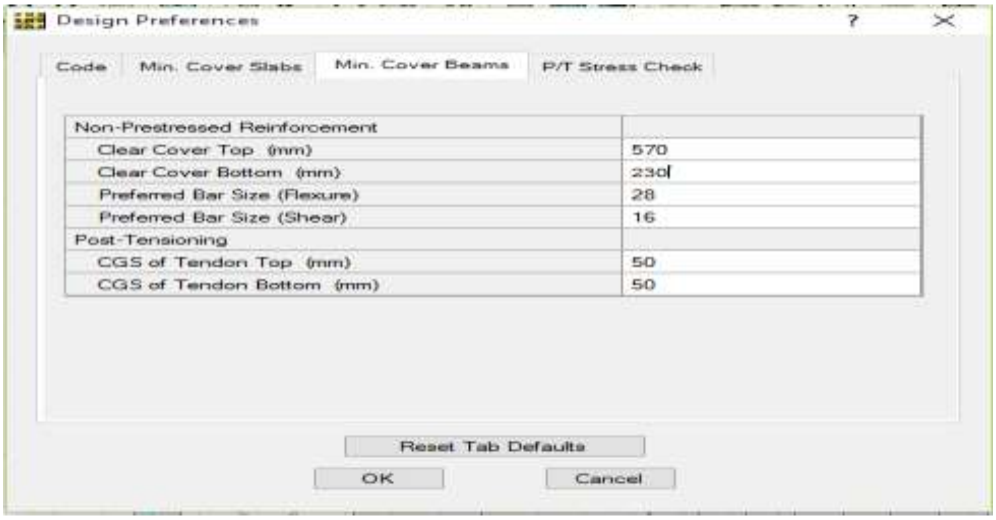
Design Code	BS 8110-1997
Resistance Factors:	
Gamma Steel	1.1500
Gamma Concrete	1.5000
Gamma Shear	1.2500

Figure 3.20: Design preferences code



Non-Prestressed Reinforcement	
Clear Cover Top (mm)	20
Clear Cover Bottom (mm)	20
Preferred Bar Size	16
Inner Slab Rebar Layer	Layer B
Post-Tensioning	
CGS of Tendon Top (mm)	25
CGS of Tendon for Bottom of Exterior Bay (mm)	40
CGS of Tendon for Bottom of Interior Bay (mm)	25
Minimum Reinforcing	
Slab Type for Minimum Reinforcing	Two Way

Figure 3.21: Min cover slabs



Non-Prestressed Reinforcement	
Clear Cover Top (mm)	570
Clear Cover Bottom (mm)	230
Preferred Bar Size (Flexure)	28
Preferred Bar Size (Shear)	16
Post-Tensioning	
CGS of Tendon Top (mm)	50
CGS of Tendon Bottom (mm)	50

Figure 3.22: Determination of concrete cover for beams

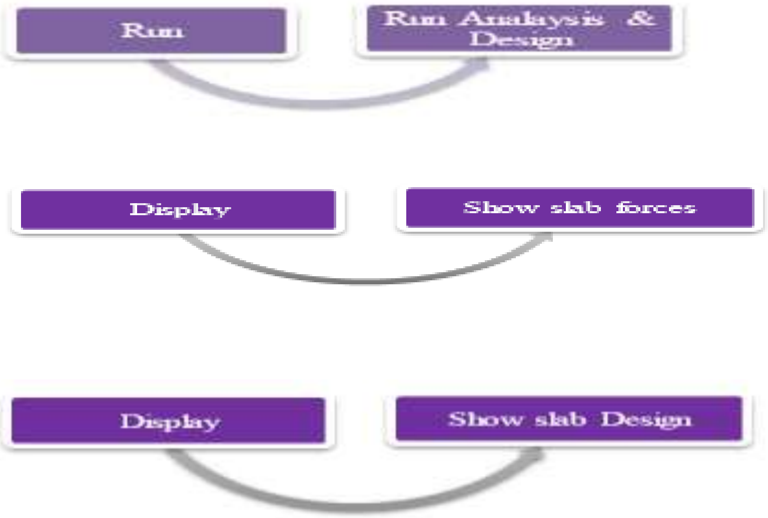


Figure 3.23: Run and display show slab design

CHAPTER FOUR

PARAMETRIC STUDY

4.1 Introduction:

The parametric study was based on analysing a three storey building using six storey combinations of different depth, width and spacing of ribs. The analysis was carried out using ETABS. Frame elements were used for columns and beams and shell elements were used for slabs. The optimum model obtained from the study was used to analyse and design a six storey building. The lateral stability under wind load was checked.

4.2 The Three Storey Building (TSB) Data:

The material and geometric properties of the 3- story building are presented in Table (4.1).

Table 4.1: Material and geometric properties of 3- storey.

Material name	concrete
Type of material	Isotropic
Mass per unit volume	2.4 kN/m^3
Modulus of elasticity	32 kN/mm^2
Poisson ratio	0.2
Grade of concrete	20 N/mm^2
Grade of steel	415 N/mm^2
Thickness of slab	200 mm

The loading on the building, dead load only, was as follows:

- Own weight from slab is calculated, based the variable dimsions, taking the unit weight of concrete as 24 kN/m^3

- Finishes +partitions loads= 4 kN/m^2

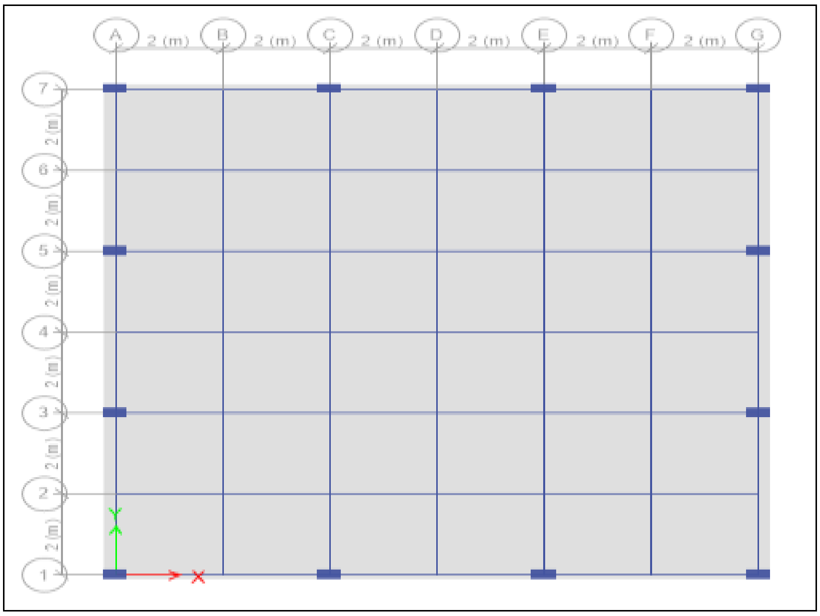
4.3TSB Grid System (1) Building (GS1):

4.3.1 GS1 Model:

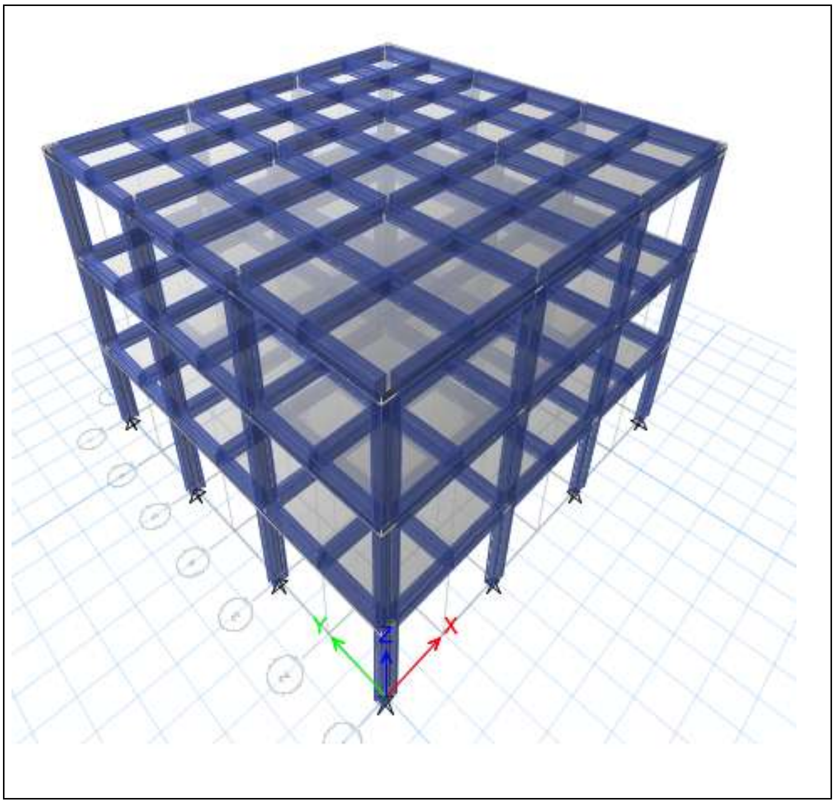
GS1 model was composed of a grid with 0.38 m depth, 0.23 m width and 2m* 2m spacing. The information shown in the Table (4.2) was used in the analysis by the ETABS program. Figure (4.1) illustrates the plan and final model of the GS1.

. **Table 4.2: GS1 model properties**

No	Item	Dimension
1	Plane dimensions	12*12 m
2	Length in x- direction	12 m
3	Length in y- direction	12 m
4	Floor to floor height	3.0 m
5	Number of stories height	G+ 2
6	Total height of the building	9 m
7	Size of column	230*450 mm
8	Panel dimension	4m*4m



(a) Plan



(b) Final model

Figure 4.1: Plan and final model of GS1.

4.3.2 GS1 Analysis Results and Discussion:

The dead load was applied to CB1 and the displacements were found as shown in Table (4.3). The maximum displacement was found to be equal to 4976.13 mm (4976.13mm > L/250=48mm) which is not acceptable. Therefore, the spacing was changed from 2 meters to 1 meter and the depth reduced resulting in Grid system (2) building (GS2).

Table 4.3: Maximum displacements for GS1.

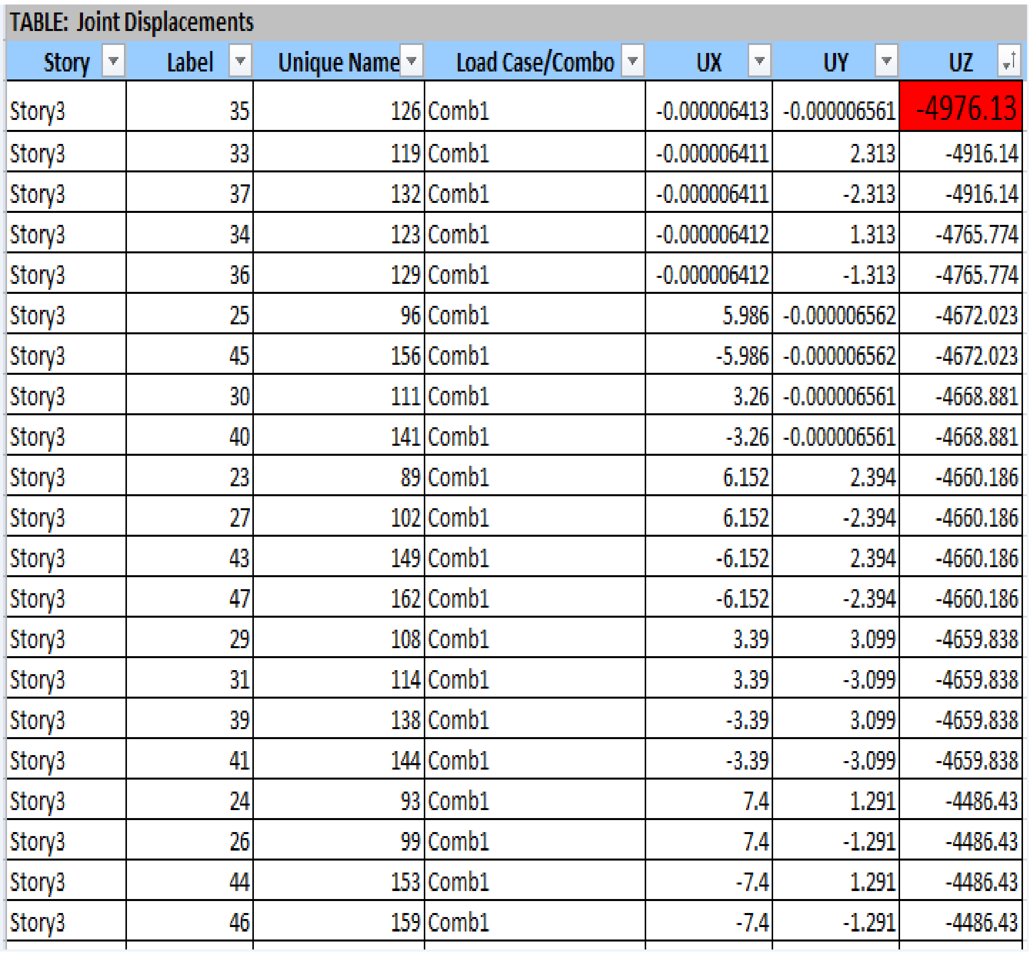


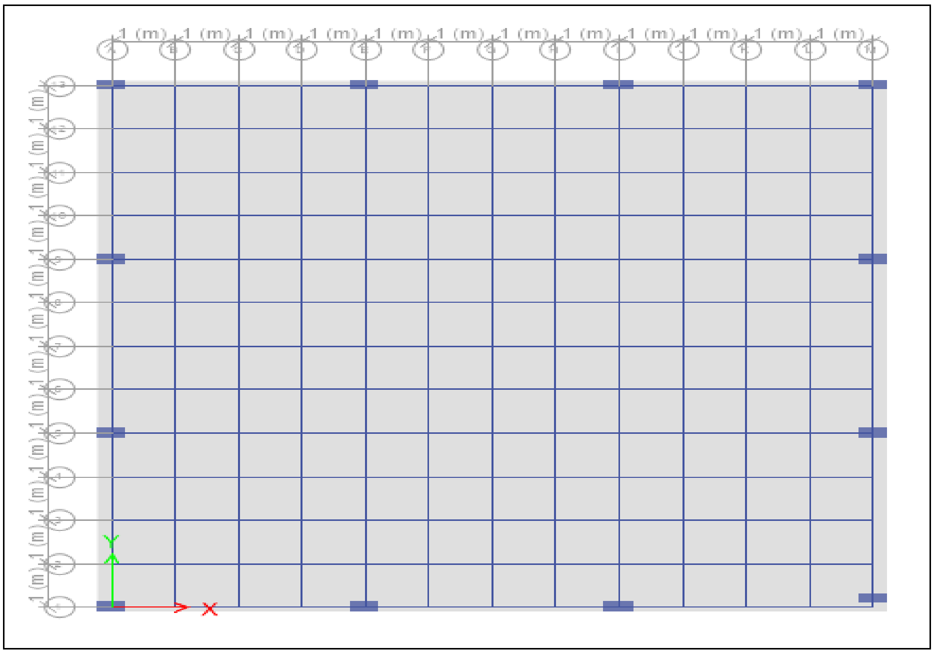
TABLE: Joint Displacements

Story	Label	Unique Name	Load Case/Combo	UX	UY	UZ
Story3	35	126	Comb1	-0.000006413	-0.000006561	-4976.13
Story3	33	119	Comb1	-0.000006411	2.313	-4916.14
Story3	37	132	Comb1	-0.000006411	-2.313	-4916.14
Story3	34	123	Comb1	-0.000006412	1.313	-4765.774
Story3	36	129	Comb1	-0.000006412	-1.313	-4765.774
Story3	25	96	Comb1	5.986	-0.000006562	-4672.023
Story3	45	156	Comb1	-5.986	-0.000006562	-4672.023
Story3	30	111	Comb1	3.26	-0.000006561	-4668.881
Story3	40	141	Comb1	-3.26	-0.000006561	-4668.881
Story3	23	89	Comb1	6.152	2.394	-4660.186
Story3	27	102	Comb1	6.152	-2.394	-4660.186
Story3	43	149	Comb1	-6.152	2.394	-4660.186
Story3	47	162	Comb1	-6.152	-2.394	-4660.186
Story3	29	108	Comb1	3.39	3.099	-4659.838
Story3	31	114	Comb1	3.39	-3.099	-4659.838
Story3	39	138	Comb1	-3.39	3.099	-4659.838
Story3	41	144	Comb1	-3.39	-3.099	-4659.838
Story3	24	93	Comb1	7.4	1.291	-4486.43
Story3	26	99	Comb1	7.4	-1.291	-4486.43
Story3	44	153	Comb1	-7.4	1.291	-4486.43
Story3	46	159	Comb1	-7.4	-1.291	-4486.43

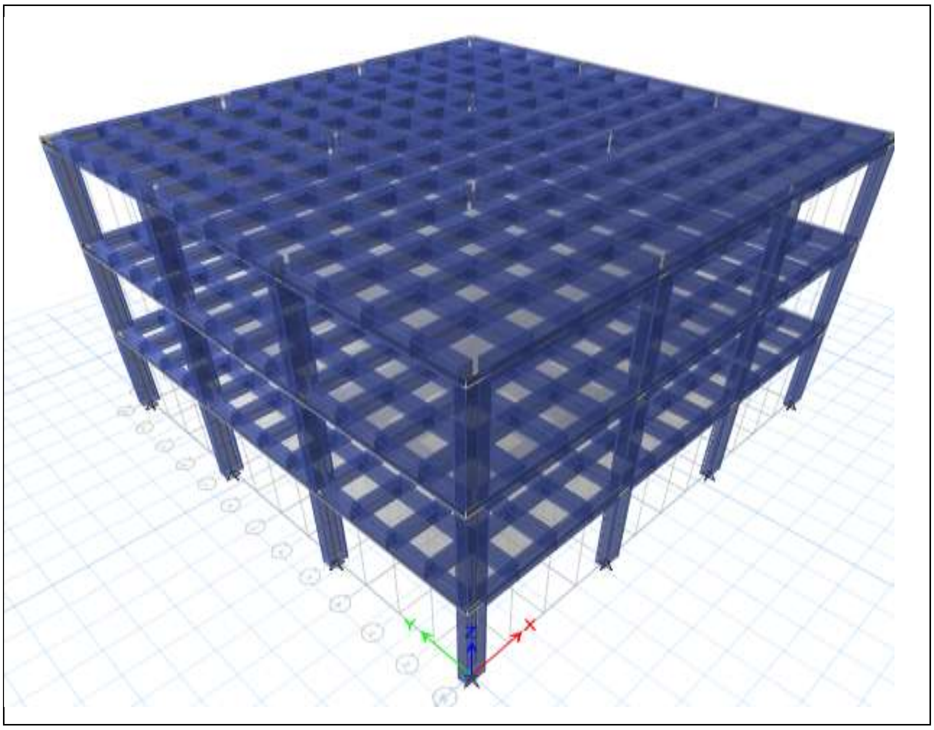
4.4 TSB Grid system (2) Building (GS2):

4.4.1 GS2 Model:

GS2 model was composed of grid with 0.38m depth, 0.23m width and 1m*1m spacing. Figure 4.2 illustrates the plan and final model of GS2.



(a) Plan



(b) Final model

Figure 4.2: Plan and final model of GS2.

4.4.2 GS2 Analysis Results and Discussion:

The dead load was applied to GS2 was found to be equal to 4063 mm (4063mm > L/250= 48mm) which is not acceptable. Therefore, the spacing was changed from 1 meter to 0.5 m with the original depth of GS1. This resulted in Grid system (3) building (GS3).

Table 4.4: The maximum displacements for GS2.

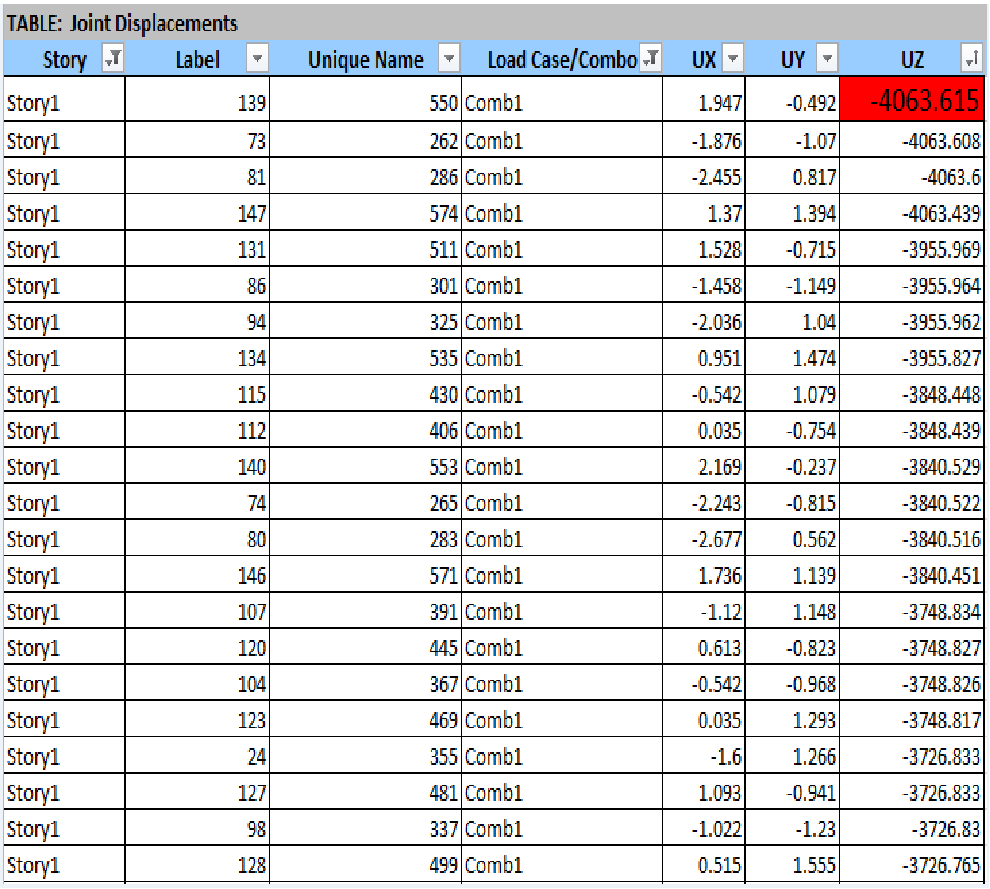


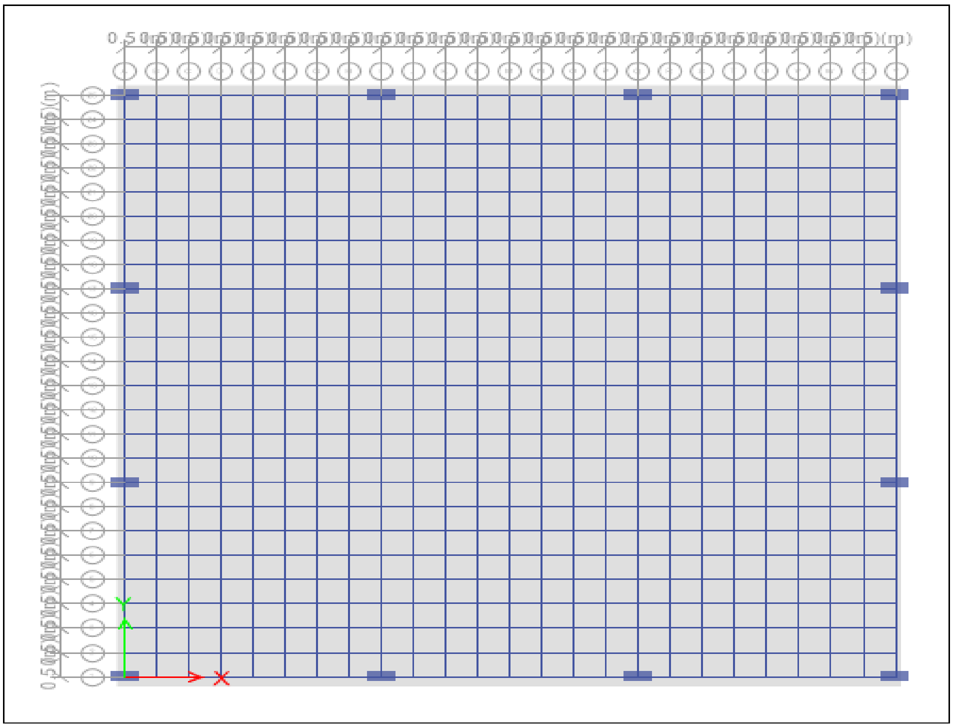
TABLE: Joint Displacements

Story	Label	Unique Name	Load Case/Combo	UX	UY	UZ
Story1	139	550	Comb1	1.947	-0.492	-4063.615
Story1	73	262	Comb1	-1.876	-1.07	-4063.608
Story1	81	286	Comb1	-2.455	0.817	-4063.6
Story1	147	574	Comb1	1.37	1.394	-4063.439
Story1	131	511	Comb1	1.528	-0.715	-3955.969
Story1	86	301	Comb1	-1.458	-1.149	-3955.964
Story1	94	325	Comb1	-2.036	1.04	-3955.962
Story1	134	535	Comb1	0.951	1.474	-3955.827
Story1	115	430	Comb1	-0.542	1.079	-3848.448
Story1	112	406	Comb1	0.035	-0.754	-3848.439
Story1	140	553	Comb1	2.169	-0.237	-3840.529
Story1	74	265	Comb1	-2.243	-0.815	-3840.522
Story1	80	283	Comb1	-2.677	0.562	-3840.516
Story1	146	571	Comb1	1.736	1.139	-3840.451
Story1	107	391	Comb1	-1.12	1.148	-3748.834
Story1	120	445	Comb1	0.613	-0.823	-3748.827
Story1	104	367	Comb1	-0.542	-0.968	-3748.826
Story1	123	469	Comb1	0.035	1.293	-3748.817
Story1	24	355	Comb1	-1.6	1.266	-3726.833
Story1	127	481	Comb1	1.093	-0.941	-3726.833
Story1	98	337	Comb1	-1.022	-1.23	-3726.83
Story1	128	499	Comb1	0.515	1.555	-3726.765

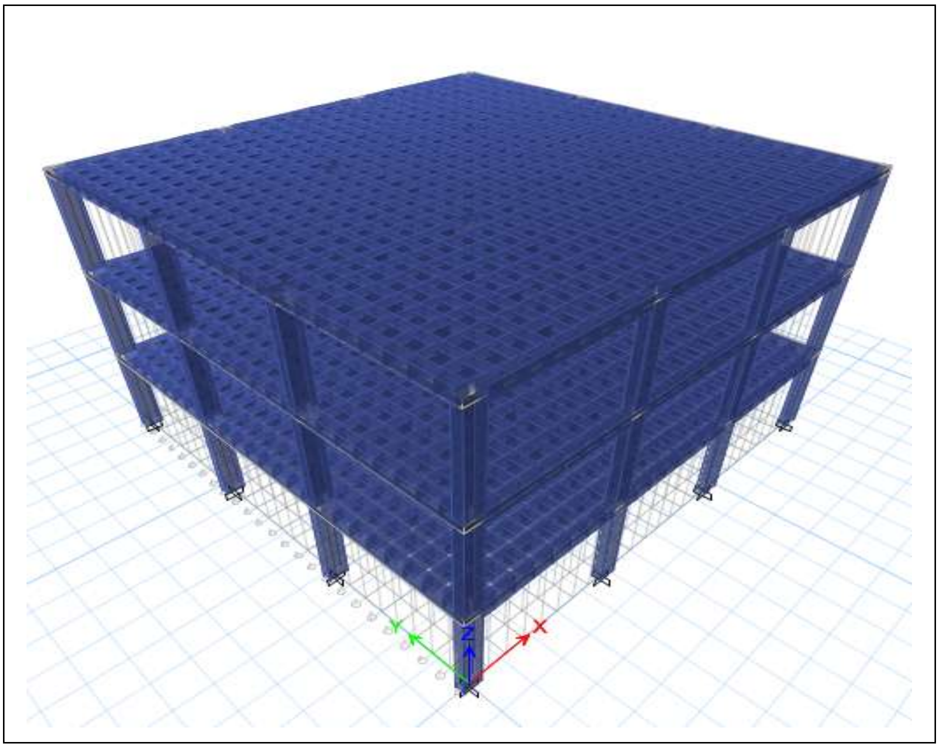
4.5 TSB Grid System (3) Building (GS3):

4.5.1 GS3 Model

GS3 model was composed of grid with 0.38m depth, 0.23 m width and 0.5*0.5 mm spacing. Figure (4.3) illustrates the plan and final model of GS3.



(a) Plan



(b) Final model

Figure 4.3: plan and final model of GS3.

4.5.2 GS3 Analysis reuslts and Discussion:

The dead load was applied to GS3 and the maximum displacements were found as shown in the Table (4.5). The maximum displacements was found to be equal to 5.553mm which is acceptable but may not be economical due to the additional quantiy of material required. This model is equivalent, in meterial quantity, to amodel with adepth of 1520 mm(4*380mm) for agrid of 2m*2m spacing.This was taken as Grid System(4) building (GS4).

Table 4.5: The maximum displacements for GS3.

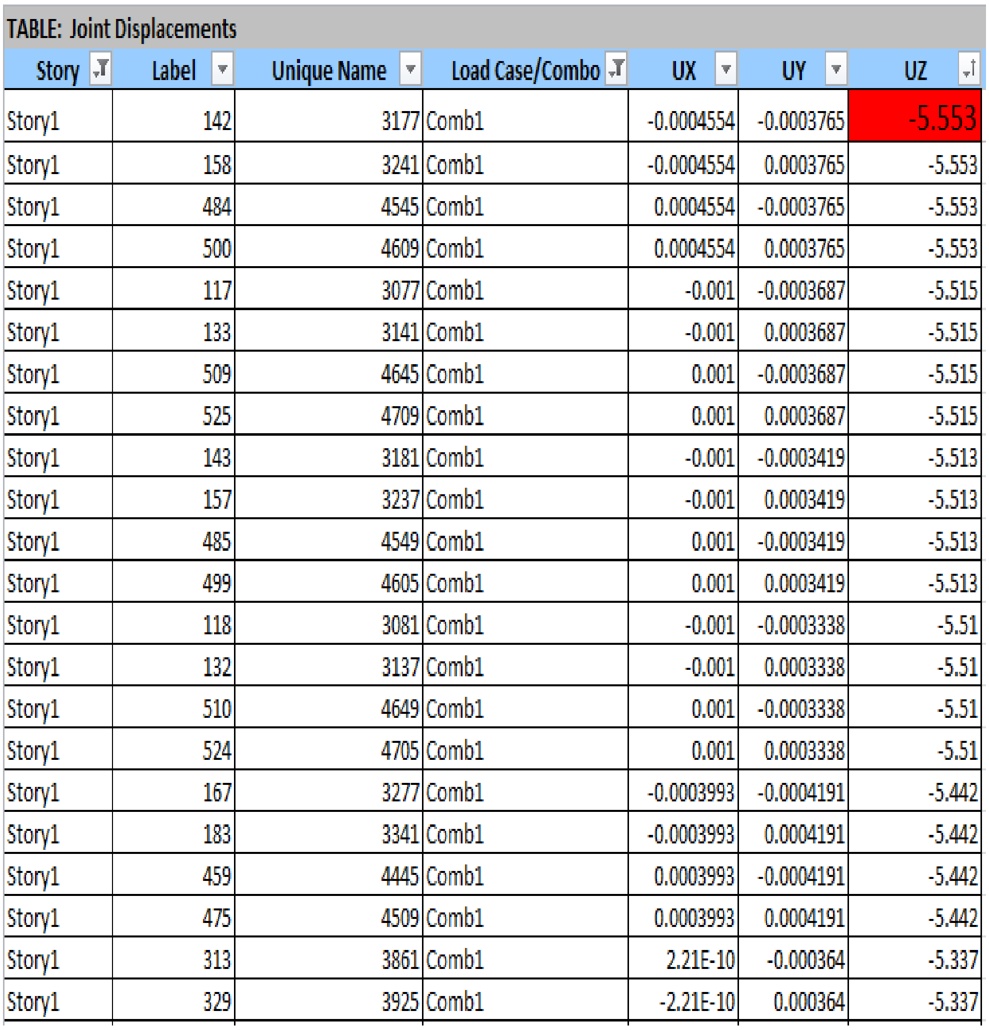


TABLE: Joint Displacements

Story	Label	Unique Name	Load Case/Combo	UX	UY	UZ
Story1	142	3177	Comb1	-0.0004554	-0.0003765	-5.553
Story1	158	3241	Comb1	-0.0004554	0.0003765	-5.553
Story1	484	4545	Comb1	0.0004554	-0.0003765	-5.553
Story1	500	4609	Comb1	0.0004554	0.0003765	-5.553
Story1	117	3077	Comb1	-0.001	-0.0003687	-5.515
Story1	133	3141	Comb1	-0.001	0.0003687	-5.515
Story1	509	4645	Comb1	0.001	-0.0003687	-5.515
Story1	525	4709	Comb1	0.001	0.0003687	-5.515
Story1	143	3181	Comb1	-0.001	-0.0003419	-5.513
Story1	157	3237	Comb1	-0.001	0.0003419	-5.513
Story1	485	4549	Comb1	0.001	-0.0003419	-5.513
Story1	499	4605	Comb1	0.001	0.0003419	-5.513
Story1	118	3081	Comb1	-0.001	-0.0003338	-5.51
Story1	132	3137	Comb1	-0.001	0.0003338	-5.51
Story1	510	4649	Comb1	0.001	-0.0003338	-5.51
Story1	524	4705	Comb1	0.001	0.0003338	-5.51
Story1	167	3277	Comb1	-0.0003993	-0.0004191	-5.442
Story1	183	3341	Comb1	-0.0003993	0.0004191	-5.442
Story1	459	4445	Comb1	0.0003993	-0.0004191	-5.442
Story1	475	4509	Comb1	0.0003993	0.0004191	-5.442
Story1	313	3861	Comb1	2.21E-10	-0.000364	-5.337
Story1	329	3925	Comb1	-2.21E-10	0.000364	-5.337

4.6 TSB Grid System (4) Building (GS4):

4.6.1 GS4 Model:

GS4 model was composed of grid with 1.52m depth, 0.23m width and 2m*2m spacing. Figure (4.4) illustrates the final model of GS4.

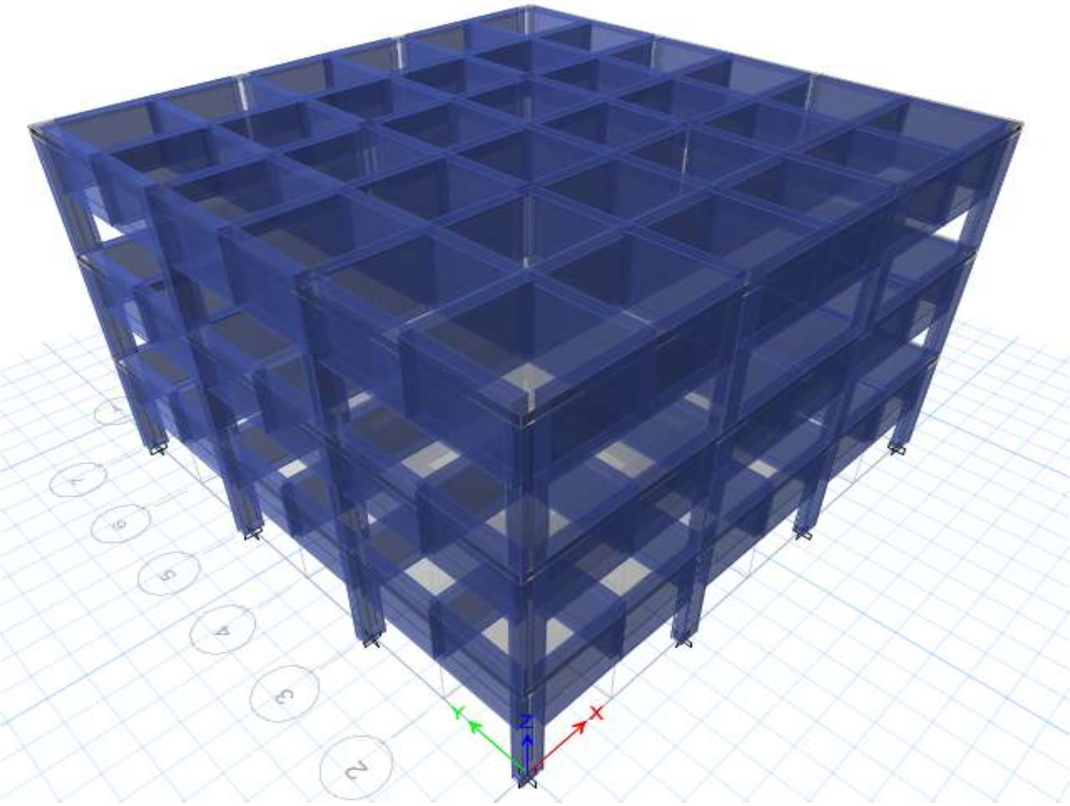


Figure 4.4: The final model for GS4.

4.6.2 GS4 Analysis Results and Discussion:

The dead load was applied to GS4 and the maximum displacements were found as shown in Table (4.6). The maximum displacement was found to be equal to 4.145 mm which is acceptable but the depth is large and will reduce the height of the floor so it impractical. Hence the equivalent model of 760 mm (2*380mm) depth with 1.0m*1.0m spacing was considered as Grid System (5) building (GS5).

Table 4.6: The maximum displacements for GS4.

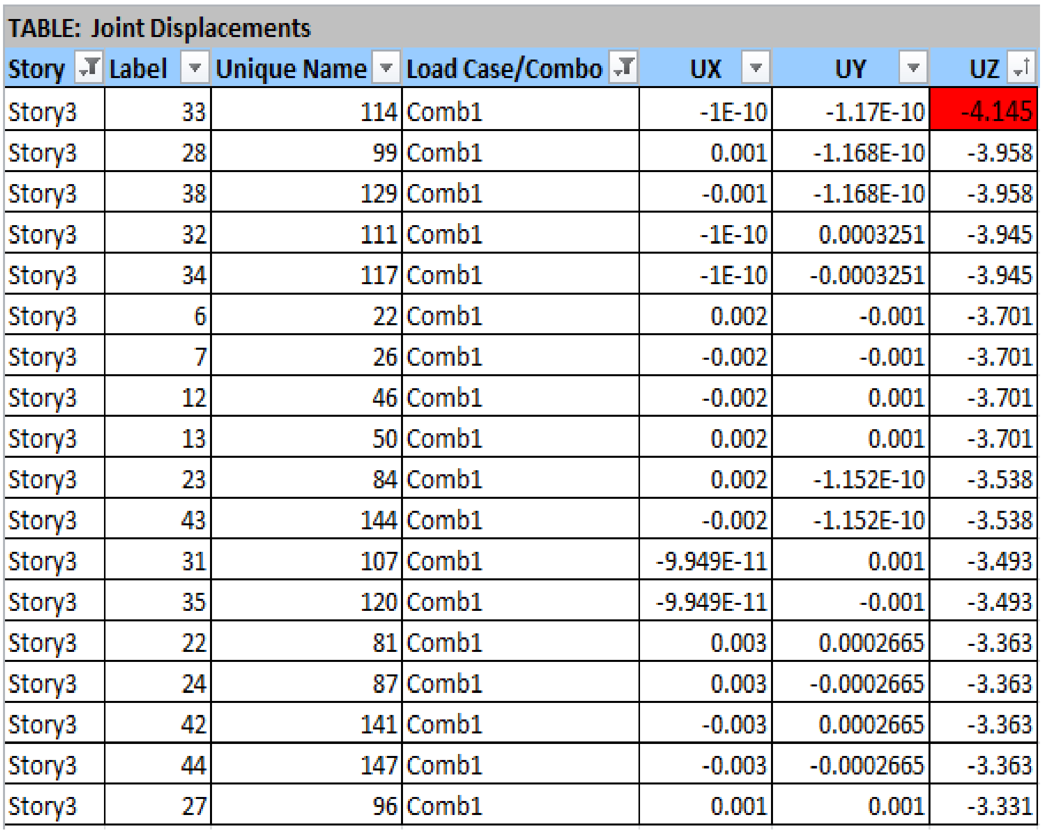


TABLE: Joint Displacements

Story	Label	Unique Name	Load Case/Combo	UX	UY	UZ
Story3	33	114	Comb1	-1E-10	-1.17E-10	-4.145
Story3	28	99	Comb1	0.001	-1.168E-10	-3.958
Story3	38	129	Comb1	-0.001	-1.168E-10	-3.958
Story3	32	111	Comb1	-1E-10	0.0003251	-3.945
Story3	34	117	Comb1	-1E-10	-0.0003251	-3.945
Story3	6	22	Comb1	0.002	-0.001	-3.701
Story3	7	26	Comb1	-0.002	-0.001	-3.701
Story3	12	46	Comb1	-0.002	0.001	-3.701
Story3	13	50	Comb1	0.002	0.001	-3.701
Story3	23	84	Comb1	0.002	-1.152E-10	-3.538
Story3	43	144	Comb1	-0.002	-1.152E-10	-3.538
Story3	31	107	Comb1	-9.949E-11	0.001	-3.493
Story3	35	120	Comb1	-9.949E-11	-0.001	-3.493
Story3	22	81	Comb1	0.003	0.0002665	-3.363
Story3	24	87	Comb1	0.003	-0.0002665	-3.363
Story3	42	141	Comb1	-0.003	0.0002665	-3.363
Story3	44	147	Comb1	-0.003	-0.0002665	-3.363
Story3	27	96	Comb1	0.001	0.001	-3.331

4.7 TSB Grid System (5) Building (GS5):

4.7.1 GS5 Model:

GS5 was composed of grid with 0.76 m depth, 0.23 m width and 1.0m*1.0 m spacing. Figure (4.5) illustrates the final model of GS5.

4.7.2 GS5 Analysis Results and Discussion:

The dead load was applied to GS5 and the maximum displacements were found as shown Table (4.7). The maximum displacement was found to be equal to 7.676 mm which is acceptable with a reduced depth but with the same material quaintly. Thus a further reduction in depth from 760mm to 570mm (1.5*380mm) was considered as Grid System (6) building (GS6).

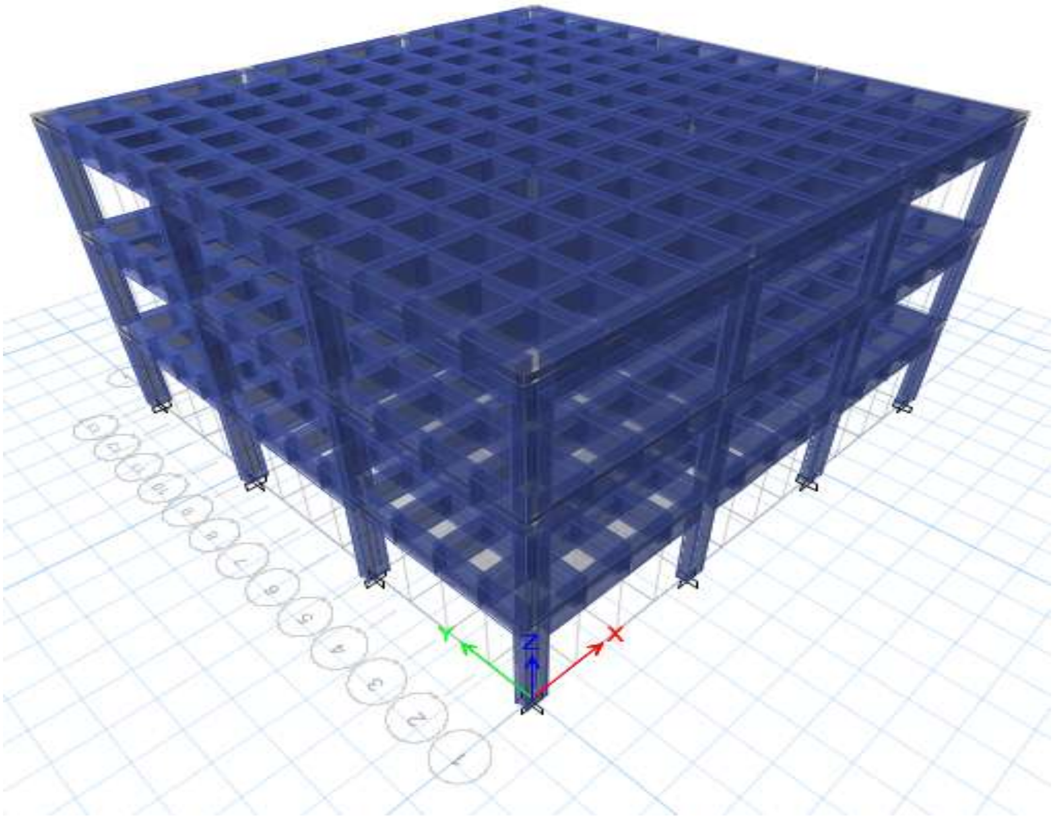


Figure 4.5: The final model of GS5

Table 4.7: The maximum displacements for GS5.

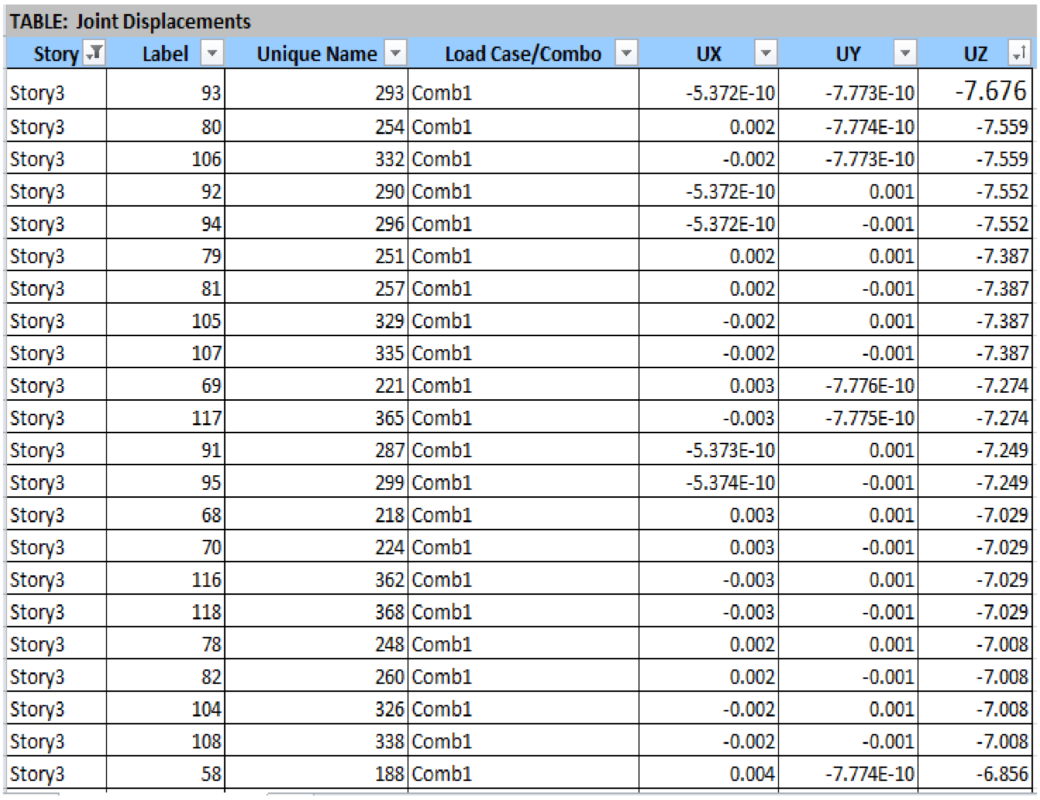


TABLE: Joint Displacements

Story	Label	Unique Name	Load Case/Combo	UX	UY	UZ
Story3	93	293	Comb1	-5.372E-10	-7.773E-10	-7.676
Story3	80	254	Comb1	0.002	-7.774E-10	-7.559
Story3	106	332	Comb1	-0.002	-7.773E-10	-7.559
Story3	92	290	Comb1	-5.372E-10	0.001	-7.552
Story3	94	296	Comb1	-5.372E-10	-0.001	-7.552
Story3	79	251	Comb1	0.002	0.001	-7.387
Story3	81	257	Comb1	0.002	-0.001	-7.387
Story3	105	329	Comb1	-0.002	0.001	-7.387
Story3	107	335	Comb1	-0.002	-0.001	-7.387
Story3	69	221	Comb1	0.003	-7.776E-10	-7.274
Story3	117	365	Comb1	-0.003	-7.775E-10	-7.274
Story3	91	287	Comb1	-5.373E-10	0.001	-7.249
Story3	95	299	Comb1	-5.374E-10	-0.001	-7.249
Story3	68	218	Comb1	0.003	0.001	-7.029
Story3	70	224	Comb1	0.003	-0.001	-7.029
Story3	116	362	Comb1	-0.003	0.001	-7.029
Story3	118	368	Comb1	-0.003	-0.001	-7.029
Story3	78	248	Comb1	0.002	0.001	-7.008
Story3	82	260	Comb1	0.002	-0.001	-7.008
Story3	104	326	Comb1	-0.002	0.001	-7.008
Story3	108	338	Comb1	-0.002	-0.001	-7.008
Story3	58	188	Comb1	0.004	-7.774E-10	-6.856

4.8 TSB Grid System (6) Building (GS6):

4.8.1GS6 Model:

GS6 model was composed of grid with 0.57 m depth, 0.23 m width and 1.0m*1.0m spacing. The figure (4.6) illustrates the final model of GS6.

4.8.2 GS6 Analysis Results and Discussion:

The dead load was applied to GS6 and the maximum displacements were found as shown in Table (4.8). The maximum displacement was found to be equal to 7.936mm which is acceptable with less material quantity.

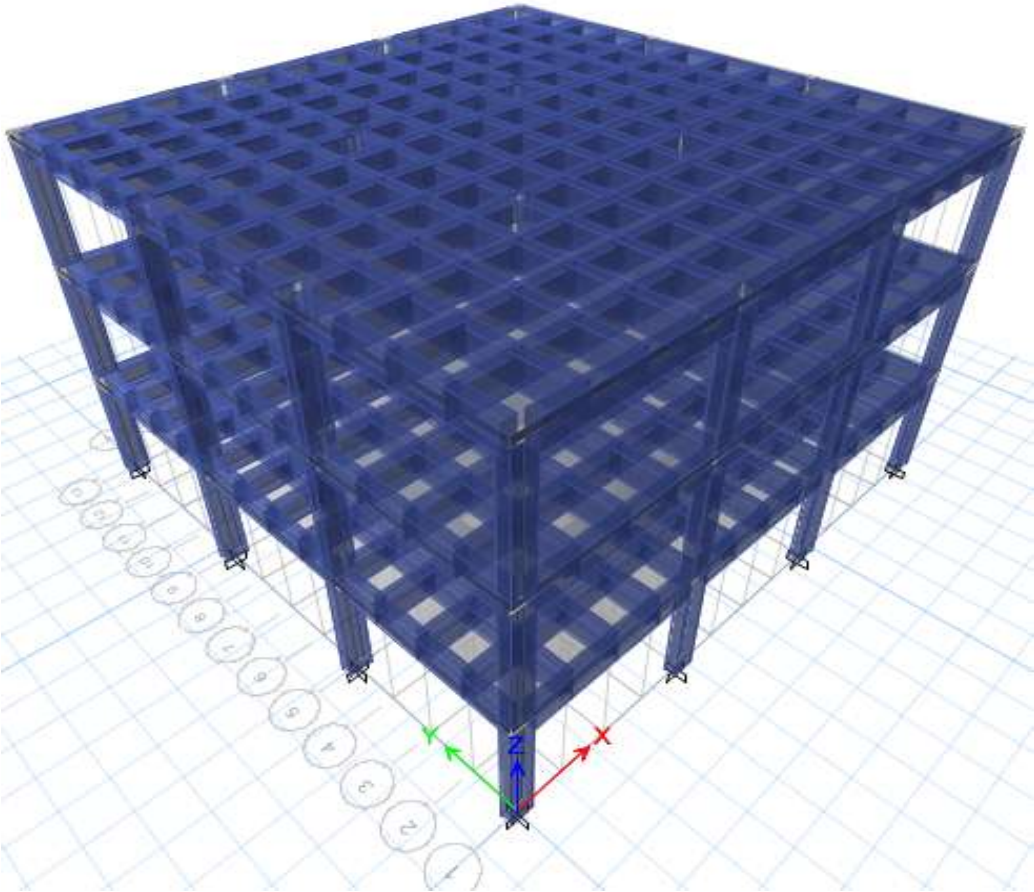


Figure 4.6: The final model of GS6.

Table 4.8: The maximum displacements for GS6.

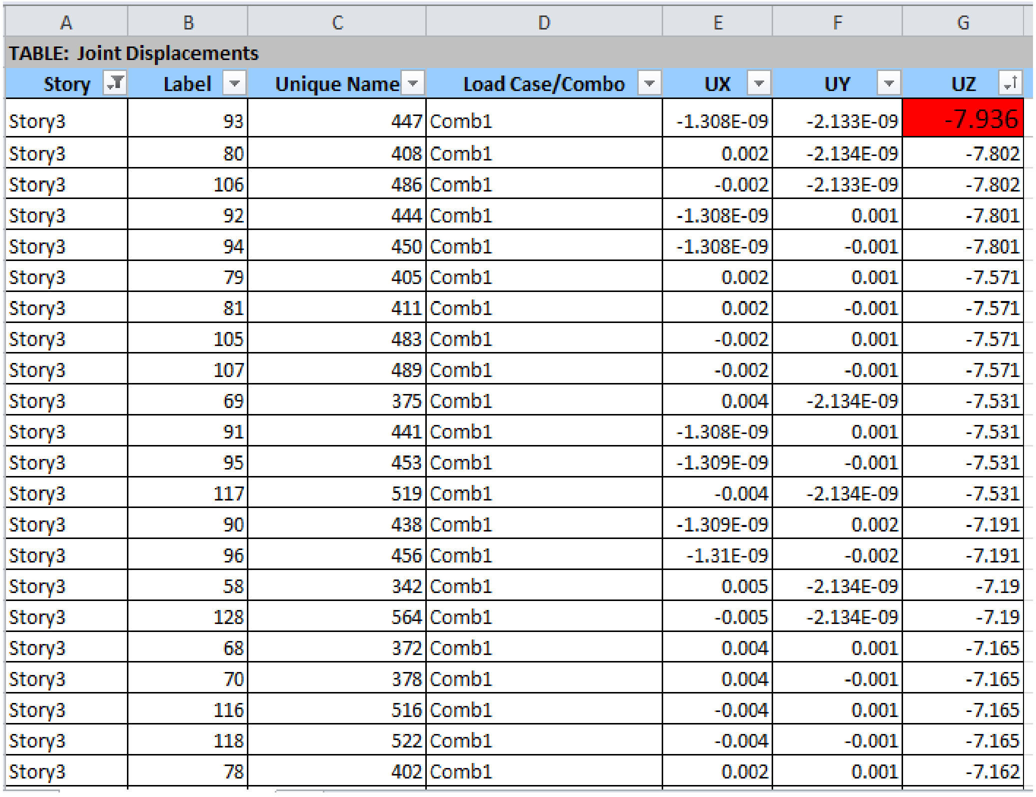


TABLE: Joint Displacements

Story	Label	Unique Name	Load Case/Combo	UX	UY	UZ
Story3	93	447	Comb1	-1.308E-09	-2.133E-09	-7.936
Story3	80	408	Comb1	0.002	-2.134E-09	-7.802
Story3	106	486	Comb1	-0.002	-2.133E-09	-7.802
Story3	92	444	Comb1	-1.308E-09	0.001	-7.801
Story3	94	450	Comb1	-1.308E-09	-0.001	-7.801
Story3	79	405	Comb1	0.002	0.001	-7.571
Story3	81	411	Comb1	0.002	-0.001	-7.571
Story3	105	483	Comb1	-0.002	0.001	-7.571
Story3	107	489	Comb1	-0.002	-0.001	-7.571
Story3	69	375	Comb1	0.004	-2.134E-09	-7.531
Story3	91	441	Comb1	-1.308E-09	0.001	-7.531
Story3	95	453	Comb1	-1.309E-09	-0.001	-7.531
Story3	117	519	Comb1	-0.004	-2.134E-09	-7.531
Story3	90	438	Comb1	-1.309E-09	0.002	-7.191
Story3	96	456	Comb1	-1.31E-09	-0.002	-7.191
Story3	58	342	Comb1	0.005	-2.134E-09	-7.19
Story3	128	564	Comb1	-0.005	-2.134E-09	-7.19
Story3	68	372	Comb1	0.004	0.001	-7.165
Story3	70	378	Comb1	0.004	-0.001	-7.165
Story3	116	516	Comb1	-0.004	0.001	-7.165
Story3	118	522	Comb1	-0.004	-0.001	-7.165
Story3	78	402	Comb1	0.002	0.001	-7.162

4.9 Selection of Optimum Model:

The Table (4.9) shows the maximum displacement values for all TSB Grid Systems GS1 and GS2 result in not acceptable displacements and are excluded.

Table (4.9): The maximum displacements of building models.

Case study	Spacing(m)	Section of beam		Maximum displacement (mm)
		Depth(mm)	Width(mm)	
GS1	2	380	230	4976(Not acceptable)
GS2	1	380	230	4063 (Not acceptable)
GS3	0.5	380	230	5.553
GS4	2	1520	230	4.145
GS5	1	760	230	7.676
CB6	1	570	230	7.936

From the Table (4.9) can be seen that minimum the displacement results in GS4 and is equal 4.145mm, therefore, for the depth of 1520mm. But this depth is very large and impractical, and GS4 is excluded. The other grid systems, resulting in safe displacements, are compared by weight, based in the material volume, as follows:

Volume per m squared for:

GS3 (depth 380mm): V_3= 2*380*230=174.800 m^3

GS5 (depth 760mm): V_5=1*760*230=174,800 m^3

GS6 (depth 570mm): V_6=1*570*230=131,100 m^3

The values above show that GS6 (depth 570mm spacing 1.0m*1.0m)) results in 25% saving in materials compared to the other two. So GS6 was considered to be the optimum grid system. For further verification this gird system was used to analyse and design a six storey building as shown in following section.

4.10 Testing Optimum Grid System:

4.10.1 Building Data and Model:

The data for the six stories building is the same as the structural data for the three storey building the validity of the optimum grid system was checked by analyzing and designing a six storeys building (6SB). The lateral stability of the model under static and dynamic wind load was also checked. The results of the analysis and design of the 6SB were presented by Santhosh et. al, 2016.

The building was analyzed and designed for different combinations of dead, live and wind loads as required codes.

The loading was as follows:

(a) Dead load:
  - Unit weight of concrete= 24kN/m^3
  - Finishes = 2kN/m^2
  - Partitions = 4.5kN/m^2

(b) Live load:

- For floor = 3kN/m^2
- For roof = 1.5kN/m^2

(c) Wind load:

The wind load coefficients were as shown in Table (4.10).

Table 4.10: Wind coefficients as per is: 875. 198.

Wind speed(vb)	44m/s
Terrain category	I I
Structure class	B
Risk coefficient k1 factor	1
Topography k3 factor	1
Windward coefficient	0.8
Leeward coefficient	0.5

The six storey's building (6SB) was idealized by a model composed of grid with 0.57m depth, 0.23m width and 1.0m*1.0m spacing. Figure (4.7) illustrates the final model of the 6SB.

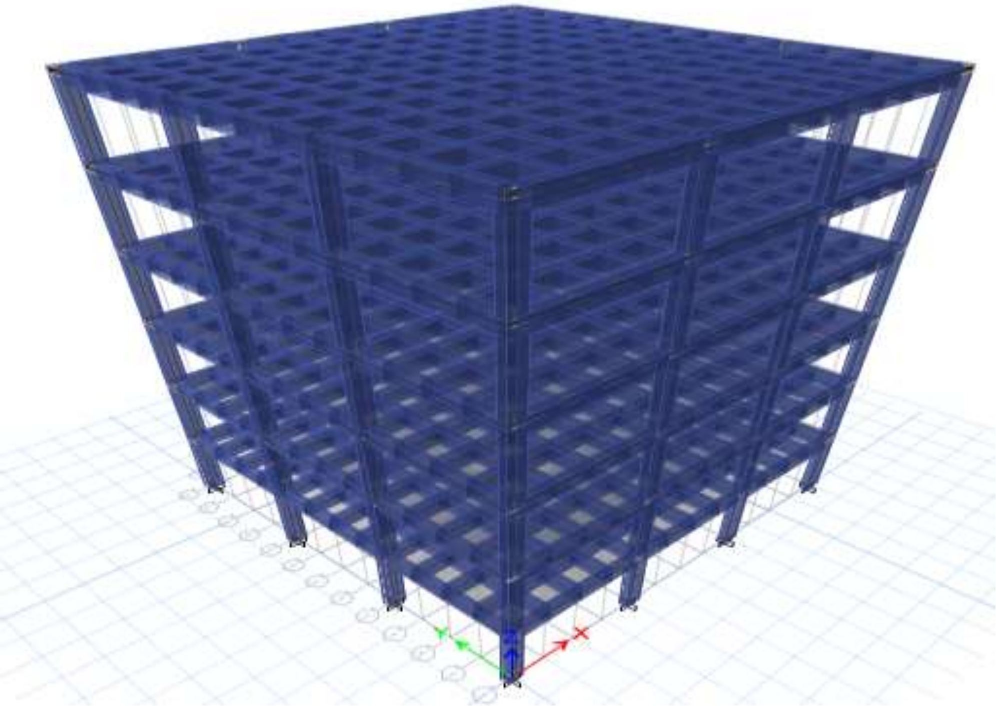
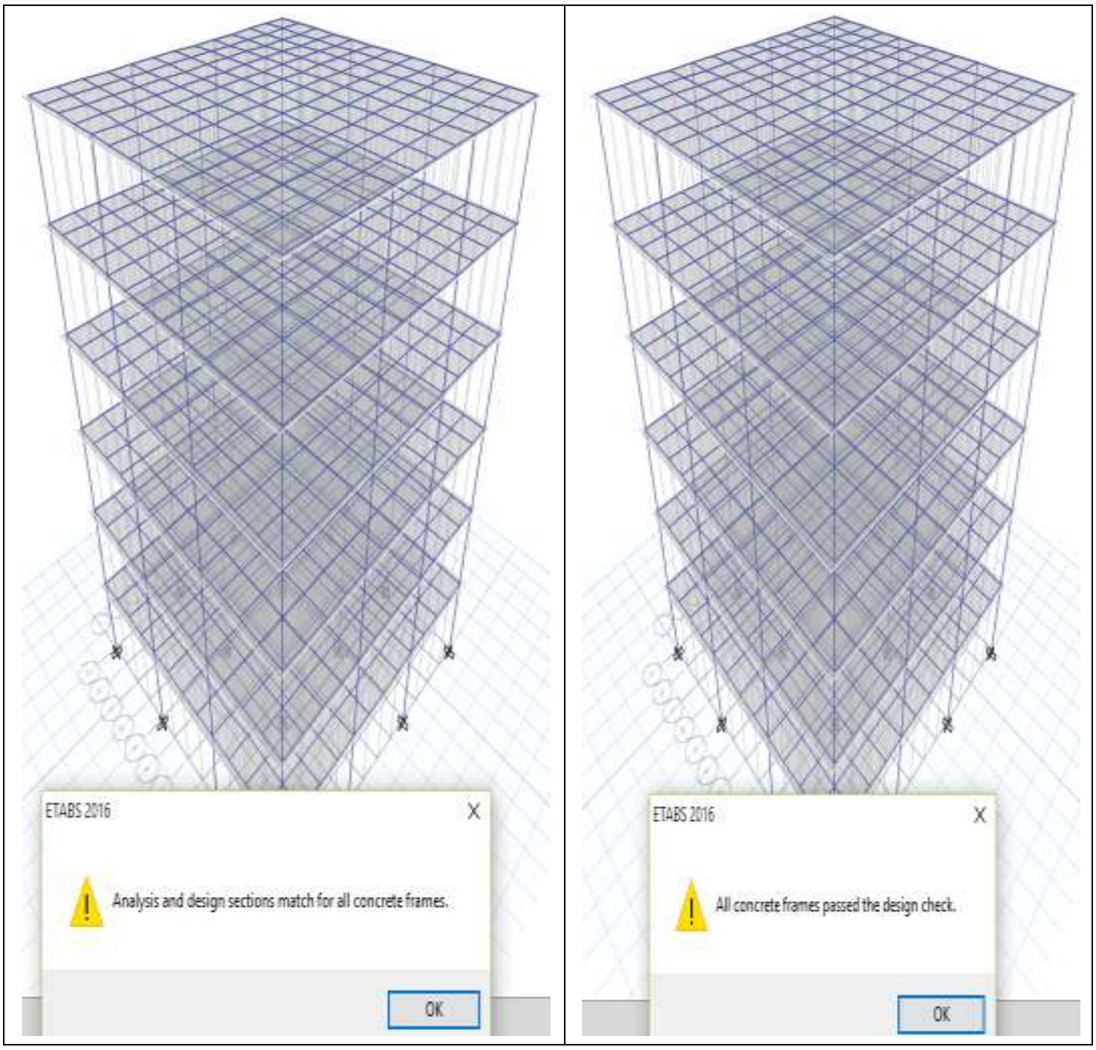


Figure 4.7: The final model of the 6SB.

4.10.2 Discussion of results:

The analysis and design results show that the building, safely, resists the applied loads. All building members (columns, beams, slabs) sections passed the design check as shown in Figure (4.8). For example Figure (4.9) shows the results of edge column C7 section design. The column was designed for (a) axial forces and biaxial moments. The section satisfied the code requirements. The section was also checked and designed for shear. As an example of beam section design, Figure (4.10) shows the results of beam B28 design. In Figure (4.11) shows the moments (Mx and My) resulting from analysis of slab. Figure (4.12) shows the slab design. All sections satisfied the design requirements.



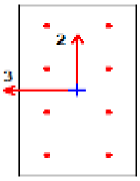
Analysis and design sections match for all concrete frames.

All concrete frames passed the design check.

Figure 4.8: All sections design check.

ETABS 2016 Concrete Frame Design

BS 8110-97 Column Section Design



Column Element Details

Level	Element	Unique Name	Section ID	Combo ID	Station Loc	Length (mm)	LLRF
Story1	C7	32	Col 230*450	DCon11	1215	3000	0.574

Section Properties

b (mm)	h (mm)	dc (mm)	Cover (Torsion) (mm)
230	450	54	30

Material Properties

E_c (MPa)	f_{cu} (MPa)	Lt.Wt Factor (Unitless)	f_y (MPa)	f_{yv} (MPa)
32000	20	1	415	215

Design Code Parameters

E_c (MPa)	f_{cu} (MPa)	Lt.Wt Factor (Unitless)
32000	20	1

Axial Force and Biaxial Moment Design For N , M_2 , M_3

Design N kN	Design M_2 kN-m	Design M_3 kN-m	Minimum M_2 kN-m	Minimum M_3 kN-m	Rebar % %	Capacity Ratio Unitless
828.5418	9.5282	12.8367	9.5282	16.5708	0.87	0.773

Axial Force and Biaxial Moment Factors

	M_i Moment kN-m	M_{add} Moment kN-m	β Factor Unitless	Length Mm
Major Bend(M3)	16.2538	5.4361	1	2430
Minor Bend(M2)	1.9319	10.6358	1	2430

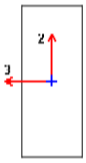
Shear Design for V_2 , V_3

	Shear V kN	Shear V_c / γ_M kN	Shear V_s / γ_M kN	Rebar A_{sv} /s mm²/m
Major, V_2	24.4937	199.8856	36.4317	492.09
Minor, V_3	3.3575	211.7782	31.6795	962.79

Figure 4.9: Column (c7- 6SB).

ETABS 2016 Concrete Frame Design

BS 8110-97 Beam Section Design



Beam Element Details

Level	Element	Unique Name	Section ID	Combo ID	Station Loc	Length (mm)	LLRF
Story6	B28	262	BEAM 230*570	DCon2	1000	1000	1

Section Properties

b (mm)	h (mm)	b_f (mm)	d_s (mm)	d_{ct} (mm)	d_{cb} (mm)
230	570	230	0	40	40

Material Properties

E_c (MPa)	f_{cu} (MPa)	Lt.Wt Factor (Unitless)	f_y (MPa)	f_{yv} (MPa)
32000	20	1	415	215

Design Code Parameters

γ_C	γ_S	γ_M
1.5	1.15	1.25

Design Moment and Flexural Reinforcement for Moment, M_3

	Design -Moment kN-m	Design +Moment kN-m	-Moment Rebar mm²	+Moment Rebar mm²	Minimum Rebar mm²	Required Rebar mm²
Top (+2 Axis)	0		0	0	0	0
Bottom (-2 Axis)		81.4648	461	461	201	0

Shear Force and Reinforcement for Shear, V_2

Shear V kN	Shear V_c / γ_M kN	Shear V_s / γ_M kN	Rebar A_{sv} /S mm²/m
5.3459	55.7074	48.76	492.09

Figure 4.10: Beam (B28-6SB).

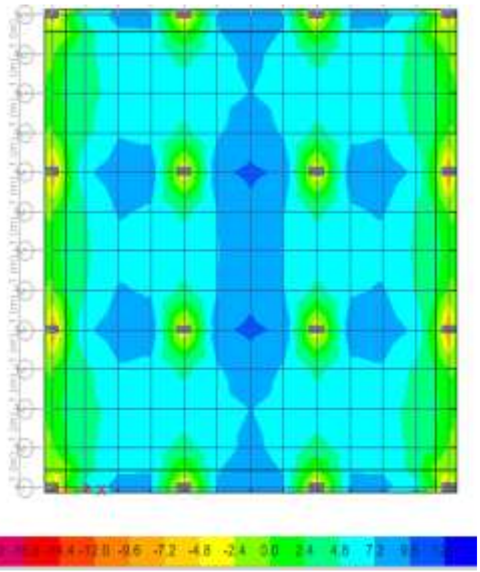


Figure 4.11.a: Slab moment at x-x direction- 6SB.

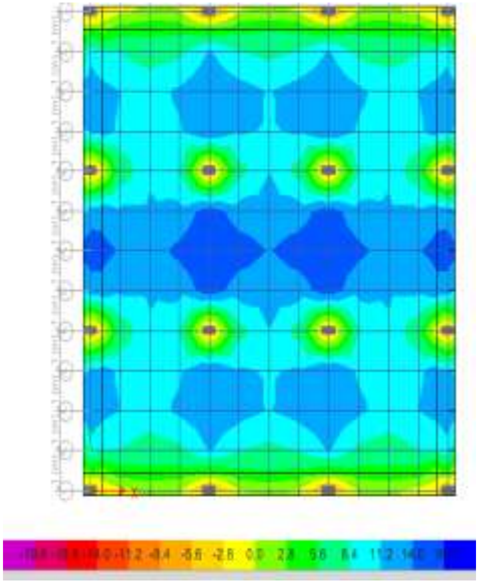
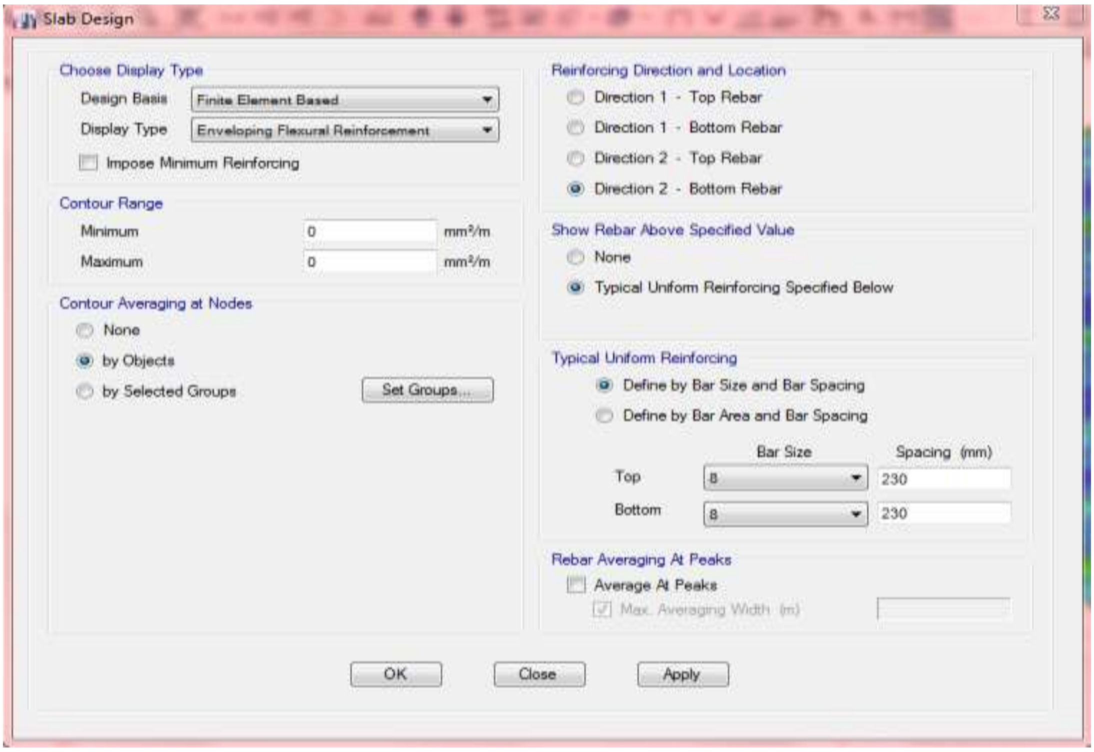


Figure 4.11.b: Slab moment at y-y direction- 6SB.



Choose Display Type

Design Basis: Finite Element Based

Display Type: Enveloping Flexural Reinforcement

☐ Impose Minimum Reinforcing

Contour Range

Minimum: 0 mm²/m

Maximum: 0 mm²/m

Contour Averaging at Nodes

○ None

● by Objects

○ by Selected Groups

Reinforcing Direction and Location

○ Direction 1 - Top Rebar

○ Direction 1 - Bottom Rebar

○ Direction 2 - Top Rebar

● Direction 2 - Bottom Rebar

Show Rebar Above Specified Value

○ None

● Typical Uniform Reinforcing Specified Below

Typical Uniform Reinforcing

● Define by Bar Size and Bar Spacing

○ Define by Bar Area and Bar Spacing

	Bar Size	Spacing (mm)
Top	8	230
Bottom	8	230

Rebar Averaging At Peaks

☐ Average At Peaks

☑ Max. Averaging Width (m)

Figure 4.12: Design of slab- 6SB.

4.10.3: Analysis of Building under lateral wind load:

`To ensure the capability of the building to resist side loads (wind load) the designed building was subjected to wind load. Static and dynamics analyses were carried out. The results obtained were compared with the results present a by (Santhosh et.al, 2016). Figure (4.13) shows the storey displacement. The maximum displacement was found to be 15.7mm which is less than the allowable displacement (H/500=36mm) and is, therefore, acceptable. Figure (4.14) shows the maximum storey drift (0.005306) is at storey6.

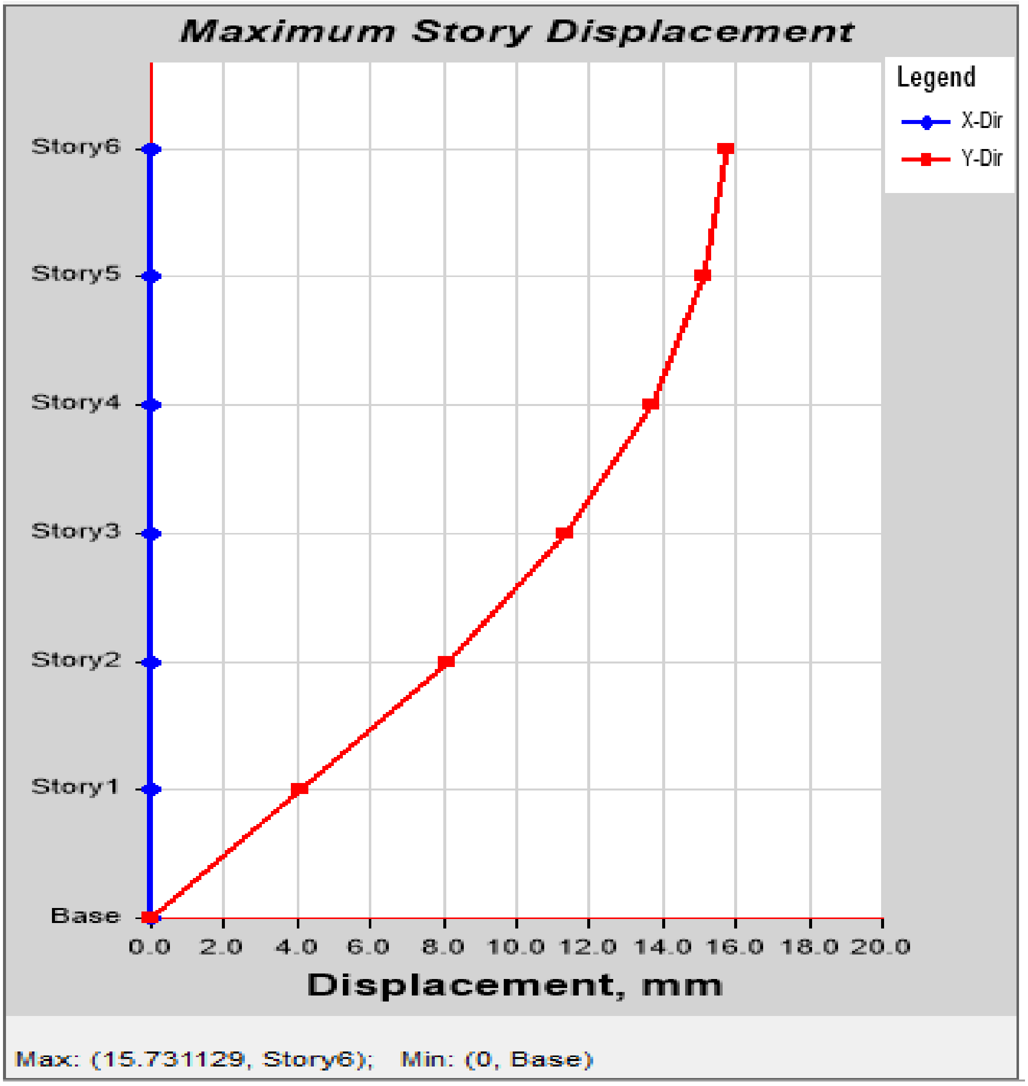


Figure 4.13: The displacement applied to the 6SB.

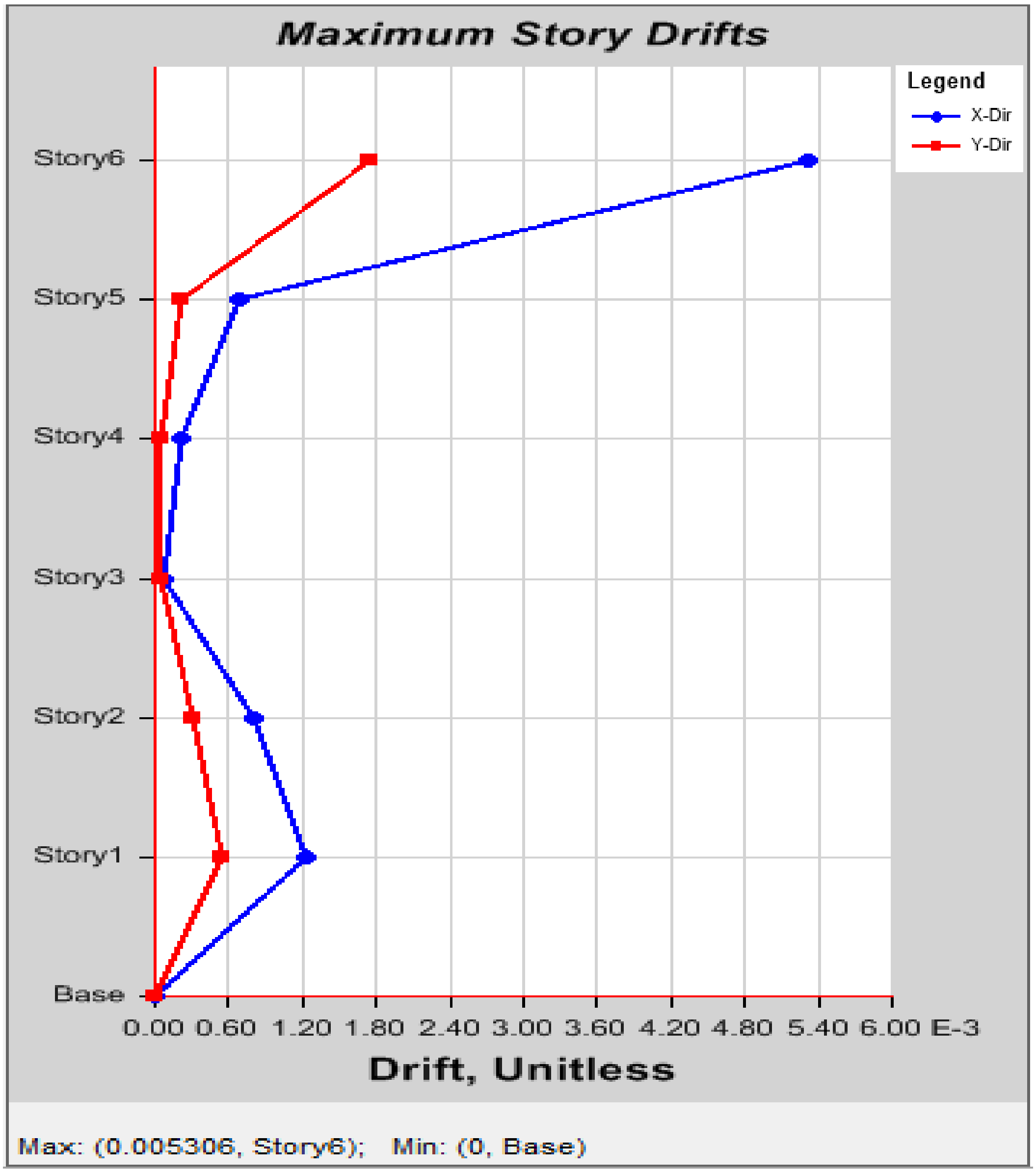
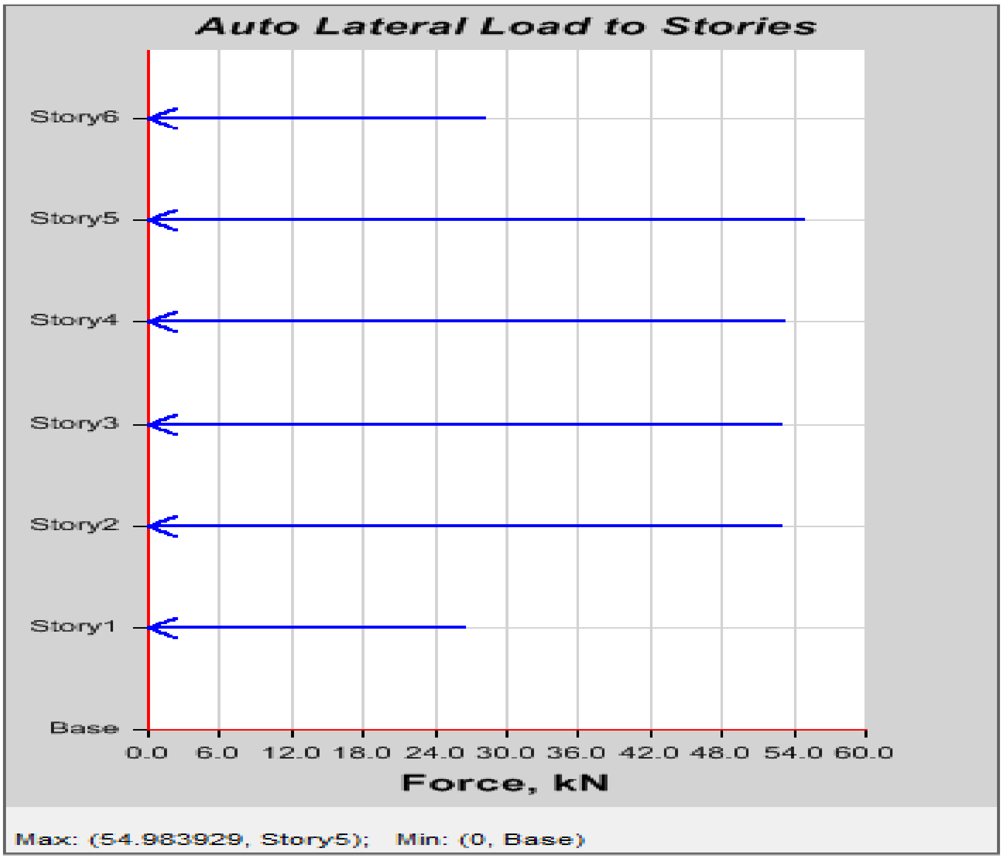


Figure 4.14: Maximum story drifts for 6SB.

The lateral loads applied to stories in x- direction were given in Table (4.11) and Figure (4.15). The maximum lateral load in storey5 is equal to (54.9839kN). Also the lateral loads applied to storey in y- direction are given in Table (4.12) and Figure (4.16). The maximum lateral load in storey5 is equal to (55.973kN).

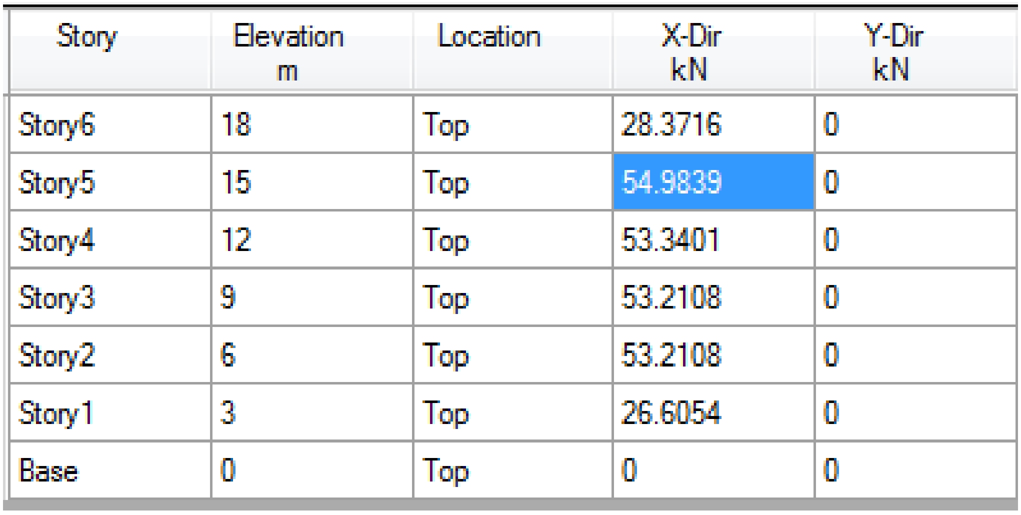
The Table (4.13) shows the maximum design reactions in the story base- 6SB, Table (4.14) shows the maximum forces in the column in story6- 6SB, Table (4.15) shows the maximum story forces were found axial force in the structure equal 23850.3kN and moment in x equal 143101.5 kN-m the Table (4.16) shows the maximum time period were found equal 3.425sec and the maximum natural frequency equal 0.273cyc/sec.



Max: (54.983929, Story5); Min: (0, Base)

Figure 4.15: Lateral load to storey in x direction-6SB.

Table4.11: Lateral load to storey in x- direction- 6SB.



Story	Elevation m	Location	X-Dir kN	Y-Dir kN
Story6	18	Top	28.3716	0
Story5	15	Top	54.9839	0
Story4	12	Top	53.3401	0
Story3	9	Top	53.2108	0
Story2	6	Top	53.2108	0
Story1	3	Top	26.6054	0
Base	0	Top	0	0

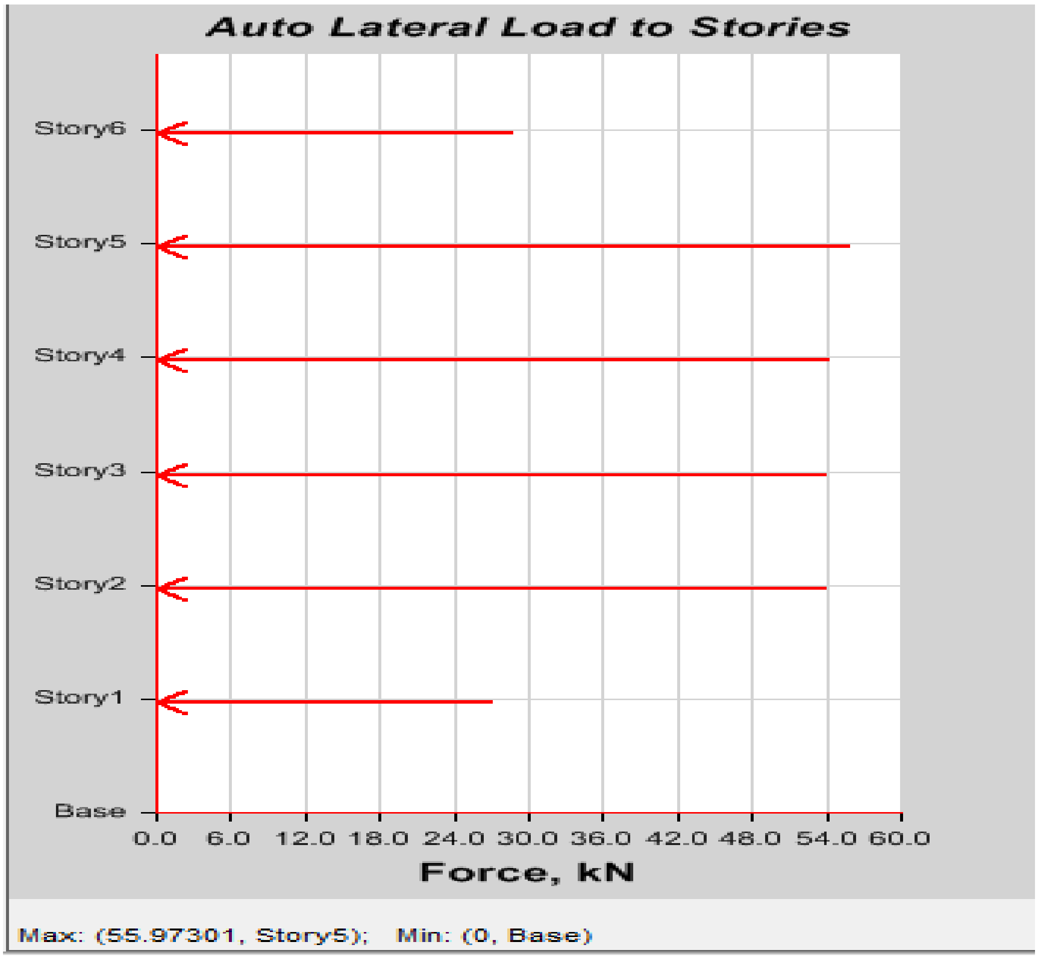
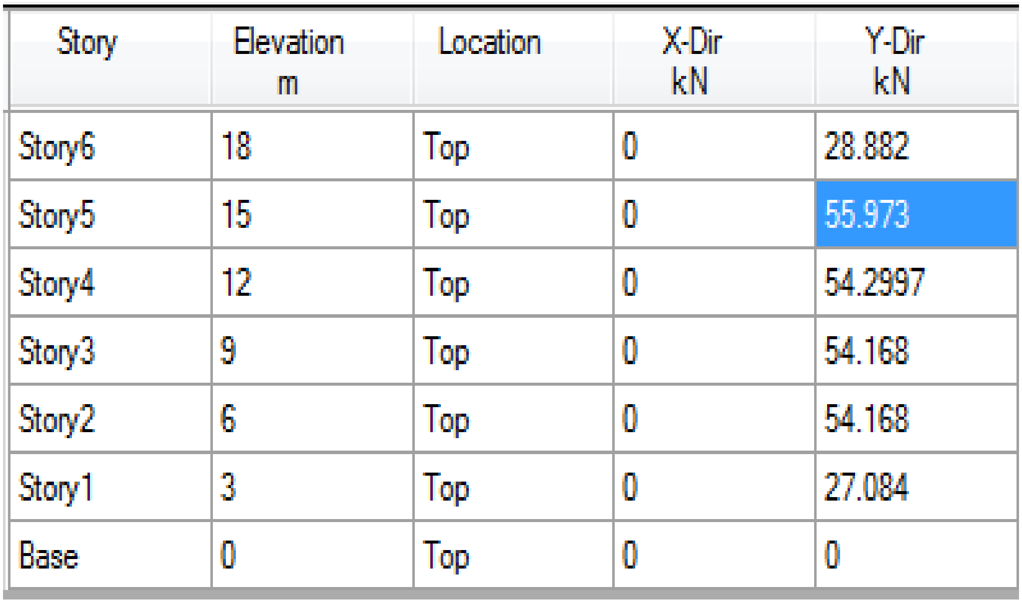


Figure 4.16: Lateral load to storey in y- direction-6SB.

Table: 4.12: Lateral load to storey in -y direction-6SB.



Story	Elevation m	Location	X-Dir kN	Y-Dir kN
Story6	18	Top	0	28.882
Story5	15	Top	0	55.973
Story4	12	Top	0	54.2997
Story3	9	Top	0	54.168
Story2	6	Top	0	54.168
Story1	3	Top	0	27.084
Base	0	Top	0	0

Table4.13: The design reactions- 6SB.

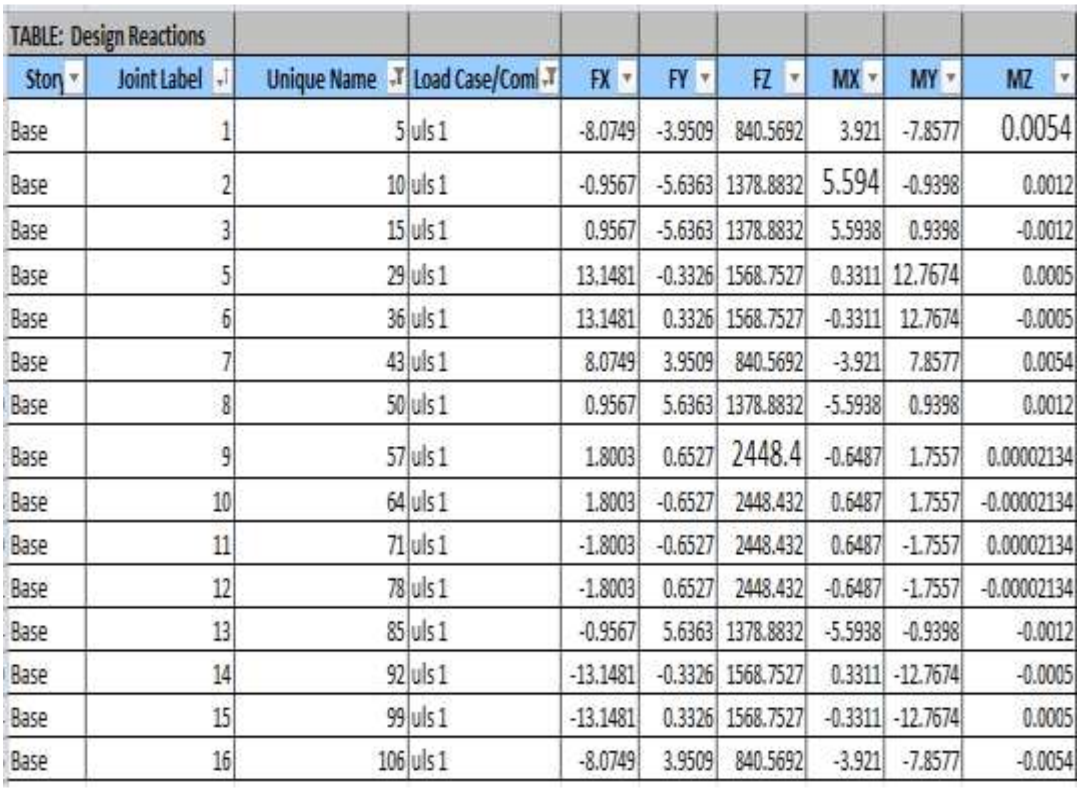


TABLE: Design Reactions

Story	Joint Label	Unique Name	Load Case/Comb	FX	FY	FZ	MX	MY	MZ
Base	1	5	uls 1	-8.0749	-3.9509	840.5692	3.921	-7.8577	0.0054
Base	2	10	uls 1	-0.9567	-5.6363	1378.8832	5.594	-0.9398	0.0012
Base	3	15	uls 1	0.9567	-5.6363	1378.8832	5.5938	0.9398	-0.0012
Base	5	29	uls 1	13.1481	-0.3326	1568.7527	0.3311	12.7674	0.0005
Base	6	36	uls 1	13.1481	0.3326	1568.7527	-0.3311	12.7674	-0.0005
Base	7	43	uls 1	8.0749	3.9509	840.5692	-3.921	7.8577	0.0054
Base	8	50	uls 1	0.9567	5.6363	1378.8832	-5.5938	0.9398	0.0012
Base	9	57	uls 1	1.8003	0.6527	2448.4	-0.6487	1.7557	0.00002134
Base	10	64	uls 1	1.8003	-0.6527	2448.432	0.6487	1.7557	-0.00002134
Base	11	71	uls 1	-1.8003	-0.6527	2448.432	0.6487	-1.7557	0.00002134
Base	12	78	uls 1	-1.8003	0.6527	2448.432	-0.6487	-1.7557	-0.00002134
Base	13	85	uls 1	-0.9567	5.6363	1378.8832	-5.5938	-0.9398	-0.0012
Base	14	92	uls 1	-13.1481	-0.3326	1568.7527	0.3311	-12.7674	-0.0005
Base	15	99	uls 1	-13.1481	0.3326	1568.7527	-0.3311	-12.7674	0.0005
Base	16	106	uls 1	-8.0749	3.9509	840.5692	-3.921	-7.8577	-0.0054

Table4.14: Forces in the column- 6SB.

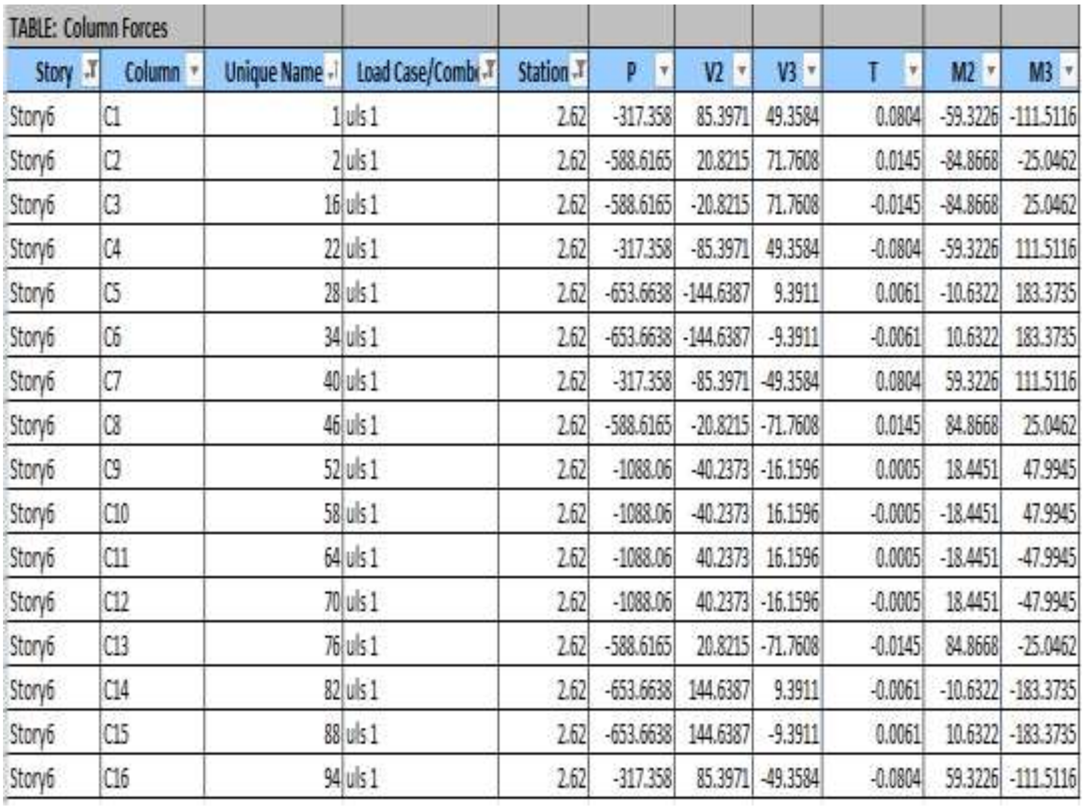


TABLE: Column Forces

Story	Column	Unique Name	Load Case/Comb	Station	P	V2	V3	T	M2	M3
Story6	C1	1	uls 1	2.62	-317.358	85.3971	49.3584	0.0804	-59.3226	-111.5116
Story6	C2	2	uls 1	2.62	-588.6165	20.8215	71.7608	0.0145	-84.8668	-25.0462
Story6	C3	16	uls 1	2.62	-588.6165	-20.8215	71.7608	-0.0145	-84.8668	25.0462
Story6	C4	22	uls 1	2.62	-317.358	-85.3971	49.3584	-0.0804	-59.3226	111.5116
Story6	C5	28	uls 1	2.62	-653.6638	-144.6387	9.3911	0.0061	-10.6322	183.3735
Story6	C6	34	uls 1	2.62	-653.6638	-144.6387	-9.3911	-0.0061	10.6322	183.3735
Story6	C7	40	uls 1	2.62	-317.358	-85.3971	-49.3584	0.0804	59.3226	111.5116
Story6	C8	46	uls 1	2.62	-588.6165	-20.8215	-71.7608	0.0145	84.8668	25.0462
Story6	C9	52	uls 1	2.62	-1088.06	-40.2373	-16.1596	0.0005	18.4451	47.9945
Story6	C10	58	uls 1	2.62	-1088.06	-40.2373	16.1596	-0.0005	-18.4451	47.9945
Story6	C11	64	uls 1	2.62	-1088.06	40.2373	16.1596	0.0005	-18.4451	-47.9945
Story6	C12	70	uls 1	2.62	-1088.06	40.2373	-16.1596	-0.0005	18.4451	-47.9945
Story6	C13	76	uls 1	2.62	-588.6165	20.8215	-71.7608	-0.0145	84.8668	-25.0462
Story6	C14	82	uls 1	2.62	-653.6638	144.6387	9.3911	-0.0061	-10.6322	-183.3735
Story6	C15	88	uls 1	2.62	-653.6638	144.6387	-9.3911	0.0061	10.6322	-183.3735
Story6	C16	94	uls 1	2.62	-317.358	85.3971	-49.3584	-0.0804	59.3226	-111.5116

Table4.15: Story - 6SB.

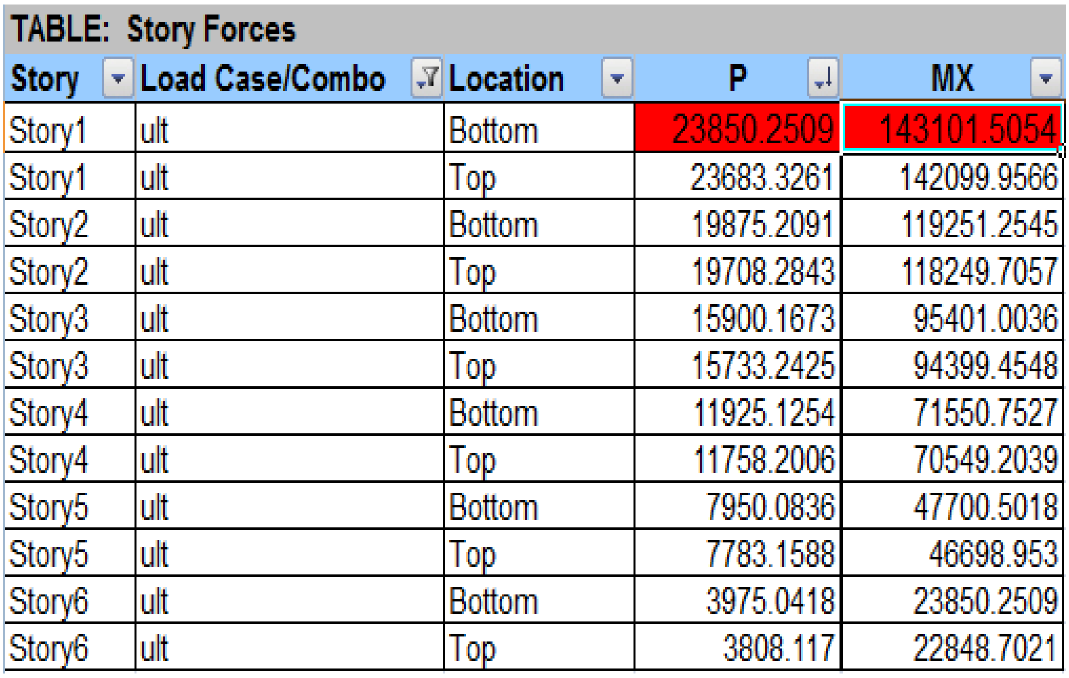


TABLE: Story Forces

Story	Load Case/Combo	Location	P	MX
Story1	ult	Bottom	23850.2509	143101.5054
Story1	ult	Top	23683.3261	142099.9566
Story2	ult	Bottom	19875.2091	119251.2545
Story2	ult	Top	19708.2843	118249.7057
Story3	ult	Bottom	15900.1673	95401.0036
Story3	ult	Top	15733.2425	94399.4548
Story4	ult	Bottom	11925.1254	71550.7527
Story4	ult	Top	11758.2006	70549.2039
Story5	ult	Bottom	7950.0836	47700.5018
Story5	ult	Top	7783.1588	46698.953
Story6	ult	Bottom	3975.0418	23850.2509
Story6	ult	Top	3808.117	22848.7021

Table4.16: Time period and the natural frequency-6SB.

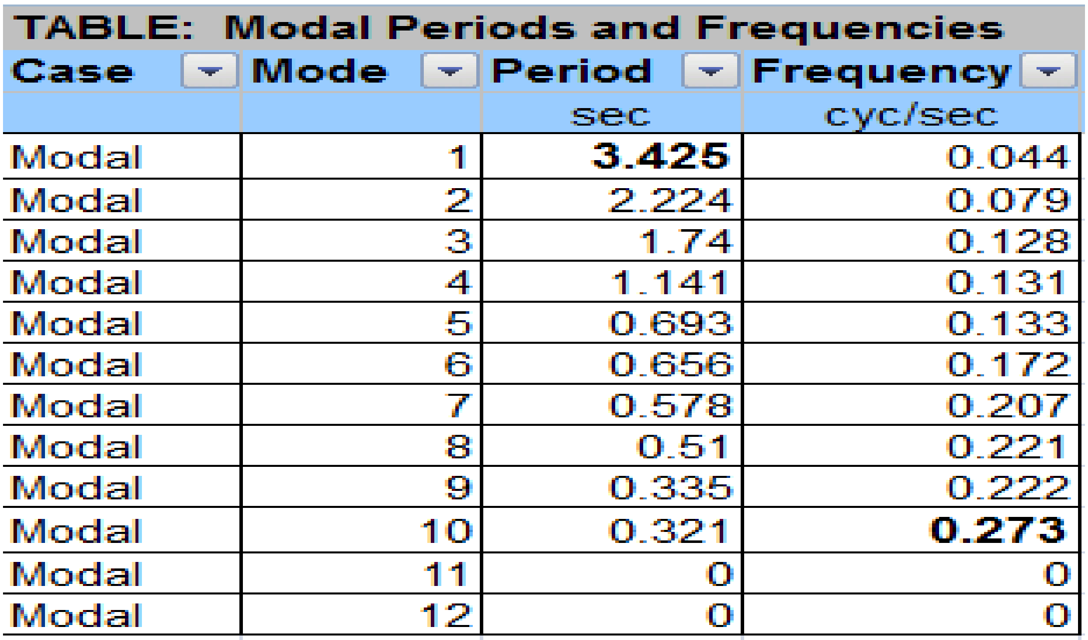


TABLE: Modal Periods and Frequencies

Case	Mode	Period	Frequency
		sec	cyc/sec
Modal	1	3.425	0.044
Modal	2	2.224	0.079
Modal	3	1.74	0.128
Modal	4	1.141	0.131
Modal	5	0.693	0.133
Modal	6	0.656	0.172
Modal	7	0.578	0.207
Modal	8	0.51	0.221
Modal	9	0.335	0.222
Modal	10	0.321	0.273
Modal	11	0	0
Modal	12	0	0

Table (4.17) shows a comparison of the results of the dynamic analysis of the six story's building -6SB model with the results of Santhosh et.al, 2016. The comparison shows that there is very close agreement between results.

Table 4.17: Comparison between Santhosh et.al, 2016, results and 6SB results for dynamic.

The description	Santhosh et.al, 2016	6SB	Difference (%)
Maximum drift	0.0077 mm	0.0053 mm	-------*
Maximum axial force in the structure	23031.36 kN	23850.25 kN	+3.5
Reinforcement ratio of column	0.874%	0.87%	+0.46
Maximum time period in the structure	3.53901 sec	3.425 sec	+3.3
the natural frequency for maximum	0.28256 cycles/sec	0.273 cycle/sec	+3.6
Design of R.C.C slab	8 dia & spacing 230mm	8 dia @ spacing 230mm	0.00

* Very small figures, thus not Suitable for comparison.

CHPTER FIVE

ANALYSIS AND DESIGN OF ALTADAMON BUILDING TOWER (ALTBT) USING OPTIMUM GRID SYSTEM

5.1 Introduction:

The optimum grid system developed in chapter four was used to analyze and design ALTBT. The steel truss floors were replaced by grid floors reinforced concrete.

5. 2 ALTBT building data and model:

Islamic Altadamon tower headquarters (Khartoum –almugran) building consisting of 19 floor overall height of 75.95 m; (two basements, ground, mezzanine, 1st, 2nd, 3rd, (height 3.1 m), 4th, 5th, 6th …18th (height 4 m) and 19th (height 4.85 m) is constructed from reinforced concrete and steel . The lateral stability of the model under static and dynamic wind load must be checked .The drawings in the appendix from Figure (5-1) to Figure (5-7) show the interfaces and horizontal sectors of the building.

Due to limited computation capacity five similar floors were taken from (ALTBT), and the steel system was changed to grid slab as shown in Figure (5-8). The validity of the grid system was checked by analyzing and designing the five storey's building (ALTBT). The lateral load stability of the model under static and dynamic wind load was also checked. The building was analyzed and designed for different combinations of dead, live and wind loads as required by codes.

The material and geometric properties of 5- story model are presented in Table (5.1).

Table 5.1: Material and geometric properties of 5-story model

Material name	concrete
Type of material	Isotropic
Density of concrete	24 kN/m^3
Poisson ratio	0.2
Grade of concrete	30 N/mm^2
Main Reinforcement grade(fy)	460 N/mm^2
Reinforcement grade(fyv)	250 N/mm^2
Thickness of slab	200mm

The loading was as follows:

(a) Dead load:

-unit weight of concrete= 24 kN/m^3

- Finishes+ partitions = 6 kN/m^2

(b) Live load:

-for office = 3 kN/m^2 (see Appendix A Table A1)

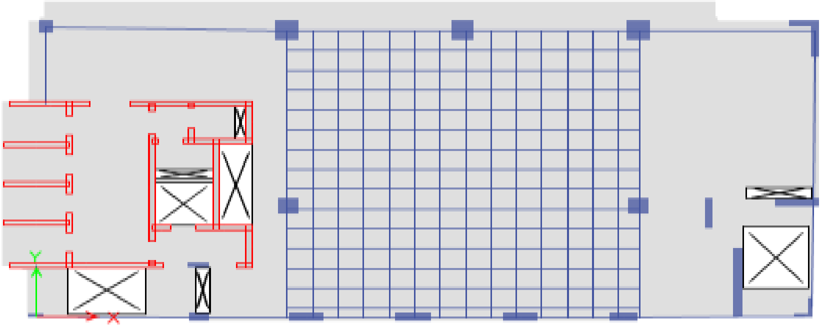
(c) Wind load: BS-6399-95

Highest wind speed in Khartoum town= 100mph (see Appendix A Table A2)

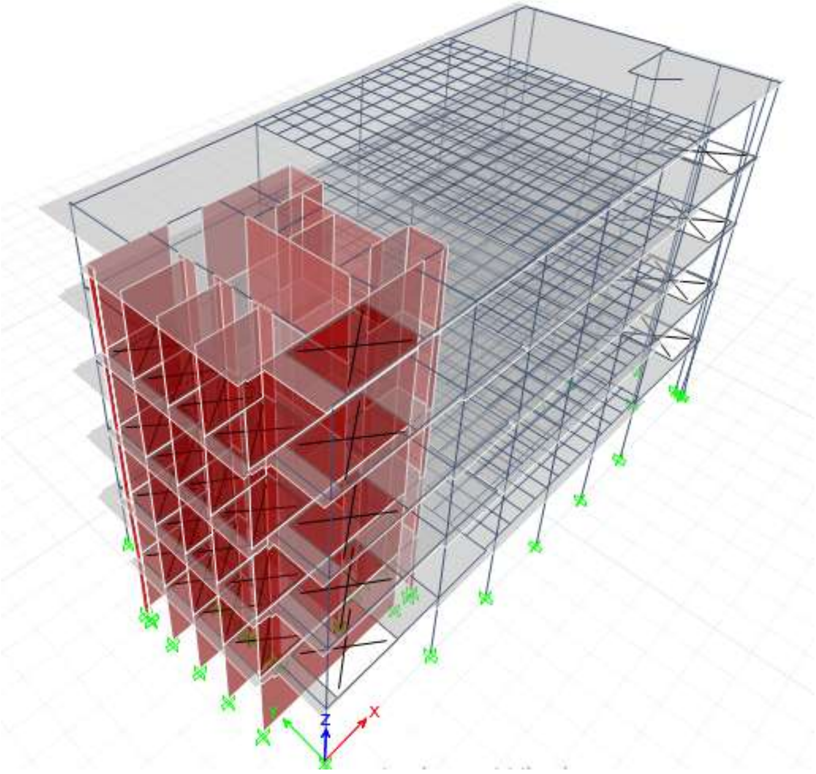
The 5- storey model was analyzed and designed using ETABS. The results of the analysis and design are presented and discussed in the following section.

5.3 Presentation and discussion of results:

The analysis and design results show that the building, safely, resists the applied loads. All building members (columns, beams, slabs) sections passed the design check of ALTBT as shown in Figure (5.9). Figure (5.10) a shows columns moments and Figure (5.10) b show axial forces in columns of ALTBT. As an example Figure (5.11) shows the results of edge column C5 in story 1 section design. The column was designed for (a) axial forces and biaxial moments. The section satisfied the code requirements. The column section was also checked and designed for shear. Figure (5.12) shows shear forces in beams and Figure (5.13) shows moments in beams of ALTBT. As an example of beams section design Figures (5.14) and (5.15) show the results of beam (31) and beam (38) design respectwely. Figure (5.16) shows the moments (Mx and My) resulting from analysis of slab. Figure (5.17) shows the slab design. All sections satisfied the design requirements as can be seen for the Figures.

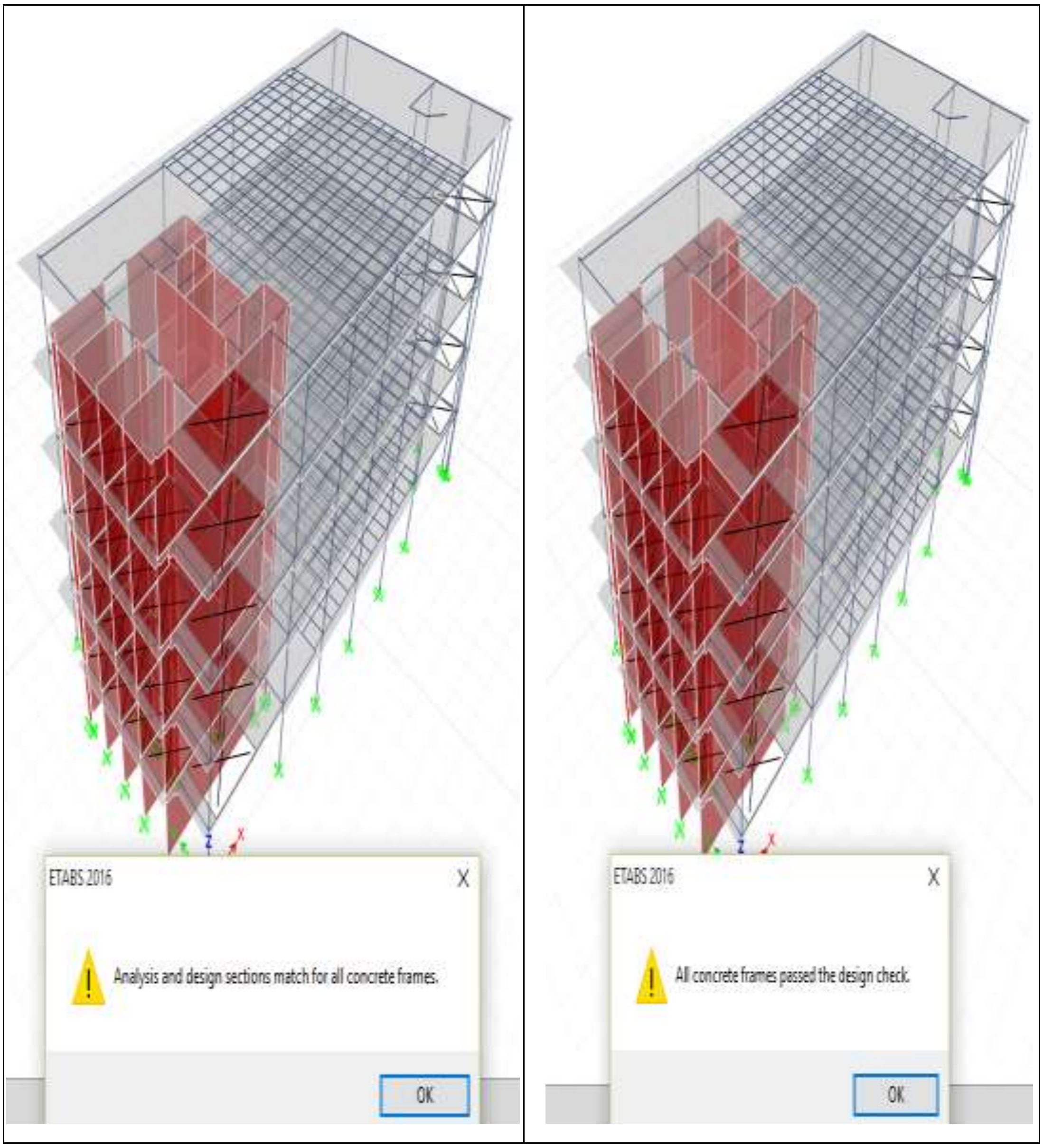


(a) Plan of model ALTBT



(b)Final model

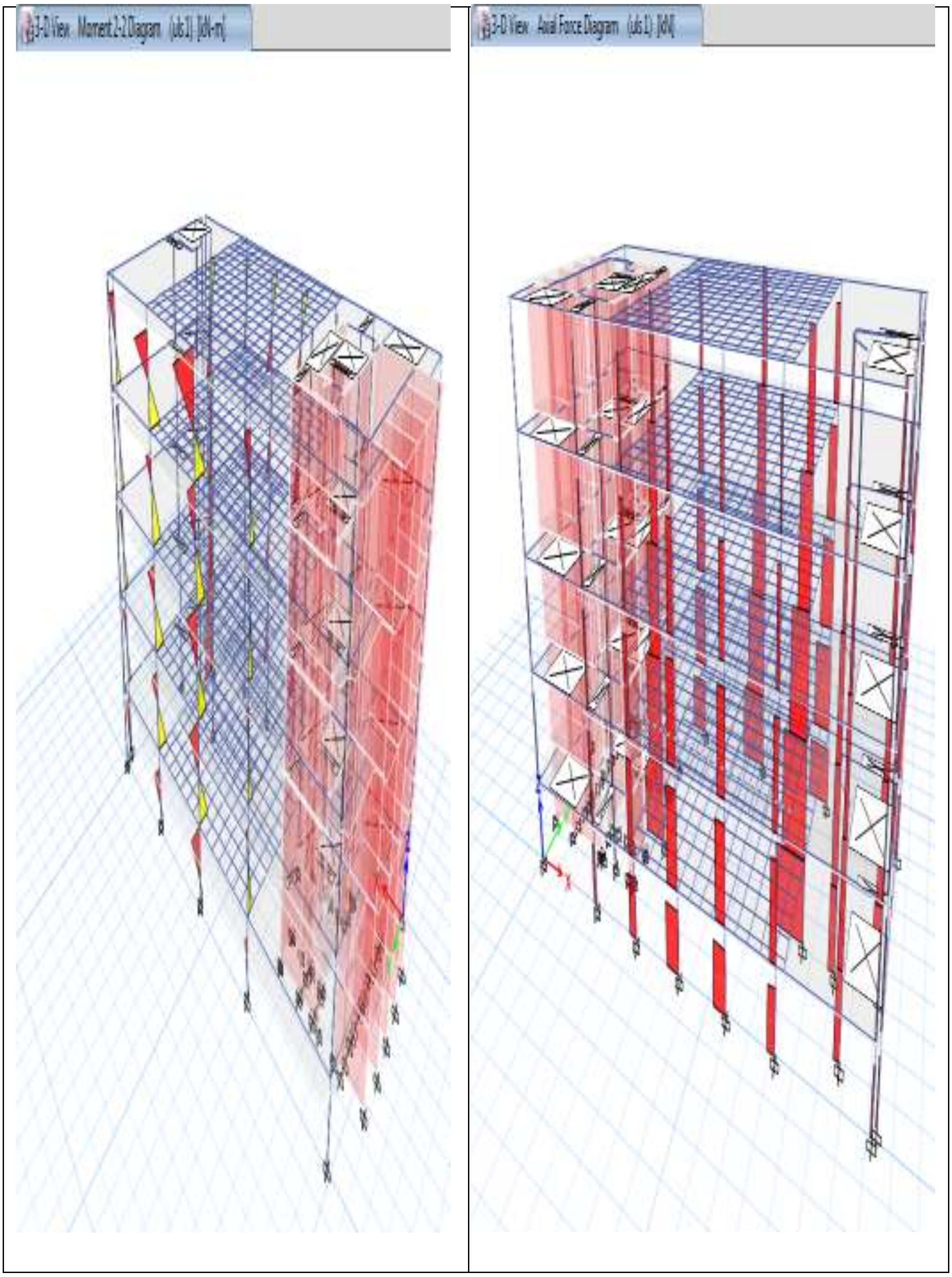
Figure 5.8: Final model of ALTBT



Analysis and design sections match for all concrete frames.

All concrete frames passed the design check.

Figure 5.9: All sections design check of ALTBT.

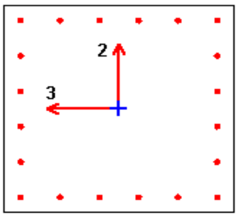


(a) Columns moments **(b) axial forces in columns**

Figure 5.10: Columns moments and axial forces in columns of ALTBT.

ETABS 2016 Concrete Frame Design

BS 8110-97 Column Section Design



Column Element Details

Level	Element	Unique Name	Section ID	Combo ID	Station Loc	Length (mm)	LLRF
Story1	C5	29	FSec6	uls 1	0	3000	0.558

Section Properties

b (mm)	h (mm)	dc (mm)	Cover (Torsion) (mm)
800	800	58	30

Material Properties

E_c (MPa)	f_{cu} (MPa)	Lt.Wt Factor (Unitless)	f_y (MPa)	f_{yv} (MPa)
24855.58	30	1	460	250

Design Code Parameters

E_c (MPa)	f_{cu} (MPa)	Lt.Wt Factor (Unitless)
24855.58	30	1

Axial Force and Biaxial Moment Design For N , M_2 , M_3

Design N kN	Design M_2 kN-m	Design M_3 kN-m	Minimum M_2 kN-m	Minimum M_3 kN-m	Rebar % %	Capacity Ratio Unitless
2010.7393	-56.6097	-42.4828	40.2148	40.2148	0.98	0.202

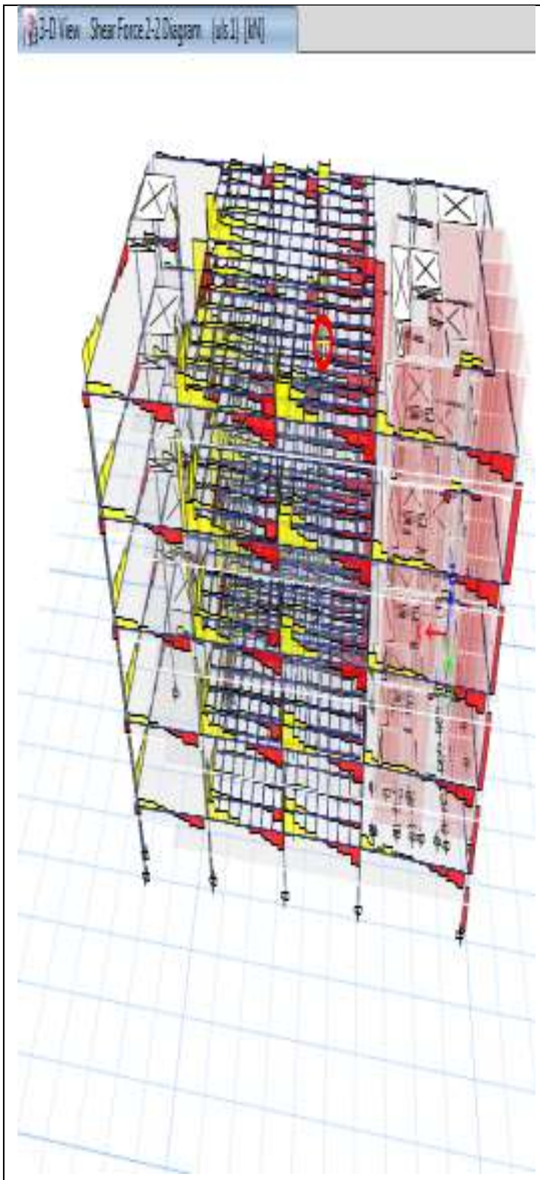
Axial Force and Biaxial Moment Factors

	M_i Moment kN-m	M_{add} Moment kN-m	β Factor Unitless	Length mm
Major Bend(M3)	-18.8623	-6.3057	1	2240
Minor Bend(M2)	26.3959	-6.3057	1	2240

Shear Design for V_2 , V_3

	Shear V kN	Shear V_c / γ_M kN	Shear V_s / γ_M kN	Rebar A_{sv} /s mm²/m
Major, V_2	19.3245	838.0349	237.4389	1472
Minor, V_3	52.5276	867.4256	237.4389	1472

Figure 5.11: Column (C5-ALTBT).



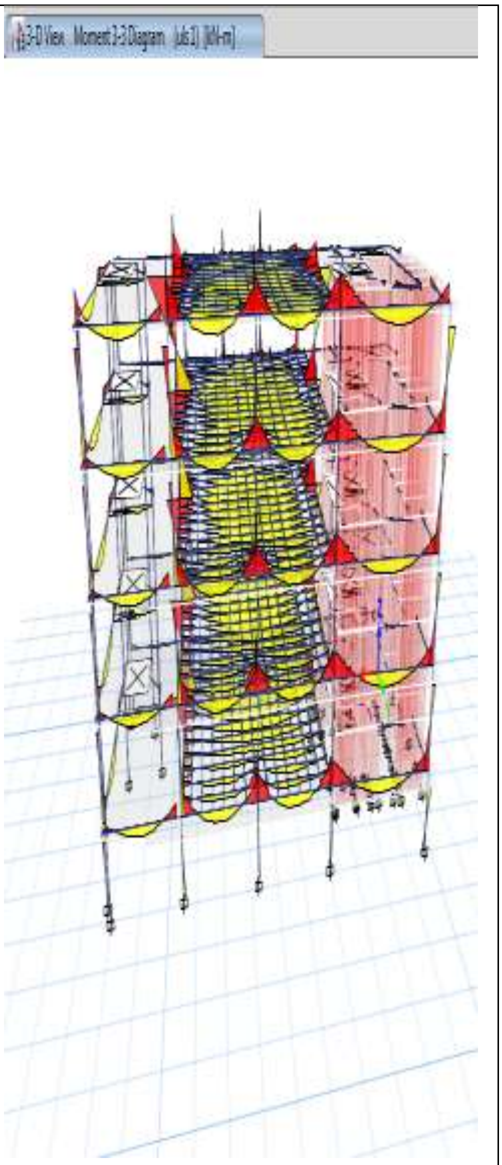
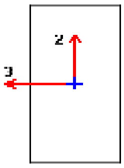


Figure 5.12: Shear forces in beams of ALTBT.

Figure 5.13: Moments in beam of ALTBT.

ETABS 2016 Concrete Frame Design

BS 8110-97 Beam Section Design



Beam Element Details

Level	Element	Unique Name	Section ID	Combo ID	Station Loc	Length (mm)	LLRF
Story5	B31	816	BEAM 230*570	uls 1	1385.9	13821.7	1

Section Properties

b (mm)	h (mm)	b_f (mm)	d_s (mm)	d_{ct} (mm)	d_{cb} (mm)
230	570	230	0	41	41

Material Properties

E_c (MPa)	f_{cu} (MPa)	Lt.Wt Factor (Unitless)	f_y (MPa)	f_{yv} (MPa)
24855.53	30	1	460	250

Design Code Parameters

γ_C	γ_S	γ_M
1.5	1.15	1.25

Design Moment and Flexural Reinforcement for Moment, M_3

	Design -Moment kN-m	Design +Moment kN-m	-Moment Rebar mm²	+Moment Rebar mm²	Minimum Rebar mm²	Required Rebar mm²
Top (+2 Axis)	-2.9183		170	0	170	15
Bottom (-2 Axis)		1.823	170	9	170	0

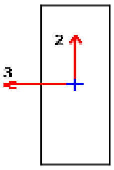
Shear Force and Reinforcement for Shear, V_2

Shear V kN	Shear V_c / γ_M kN	Shear V_s / γ_M kN	Rebar A_{sv} /S mm²/m
32.9567	43.4171	48.668	423.2

Figure 5.14: Beam (B31- ALTBT).

ETABS 2016 Concrete Frame Design

BS 8110-97 Beam Section Design



Beam Element Details

Level	Element	Unique Name	Section ID	Combo ID	Station Loc	Length (mm)	LLRF
Story5	B38	1156	B230*760	DCon1	0	1000	1

Section Properties

b (mm)	h (mm)	b_f (mm)	d_s (mm)	d_{ct} (mm)	d_{cb} (mm)
230	760	230	0	41	41

Material Properties

E_c (MPa)	f_{cu} (MPa)	Lt.Wt Factor (Unitless)	f_y (MPa)	f_{yv} (MPa)
24855.53	30	1	460	250

Design Code Parameters

γ_C	γ_S	γ_M
1.5	1.15	1.25

Design Moment and Flexural Reinforcement for Moment, M_3

	Design -Moment kN-m	Design +Moment kN-m	-Moment Rebar mm²	+Moment Rebar mm²	Minimum Rebar mm²	Required Rebar mm²
Top (+2 Axis)	-23.0756		227	0	227	84
Bottom (-2 Axis)		0	0	0	0	0

Shear Force and Reinforcement for Shear, V_2

Shear V kN	Shear V_c / γ_M kN	Shear V_s / γ_M kN	Rebar A_{sv} /S mm²/m
90.8023	59.0111	66.148	423.2

Figure 5.15: Beam (B38- ALTBT).

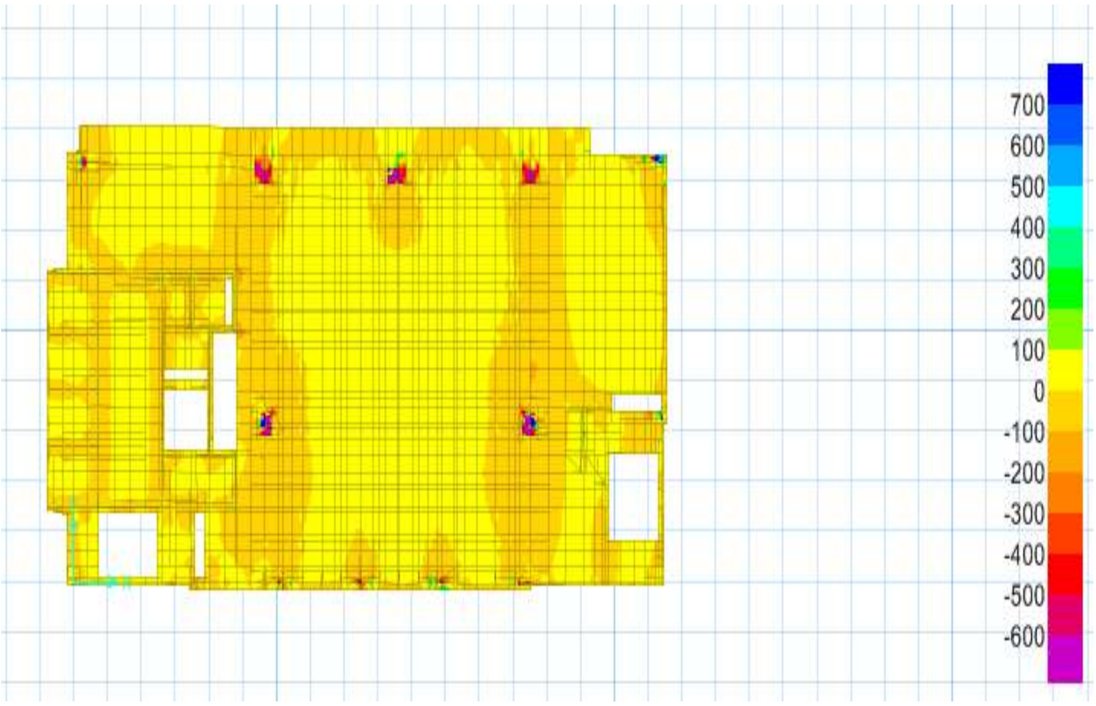


Figure 5.16.a: Slab moment at(x-x) direction- ALTBT.

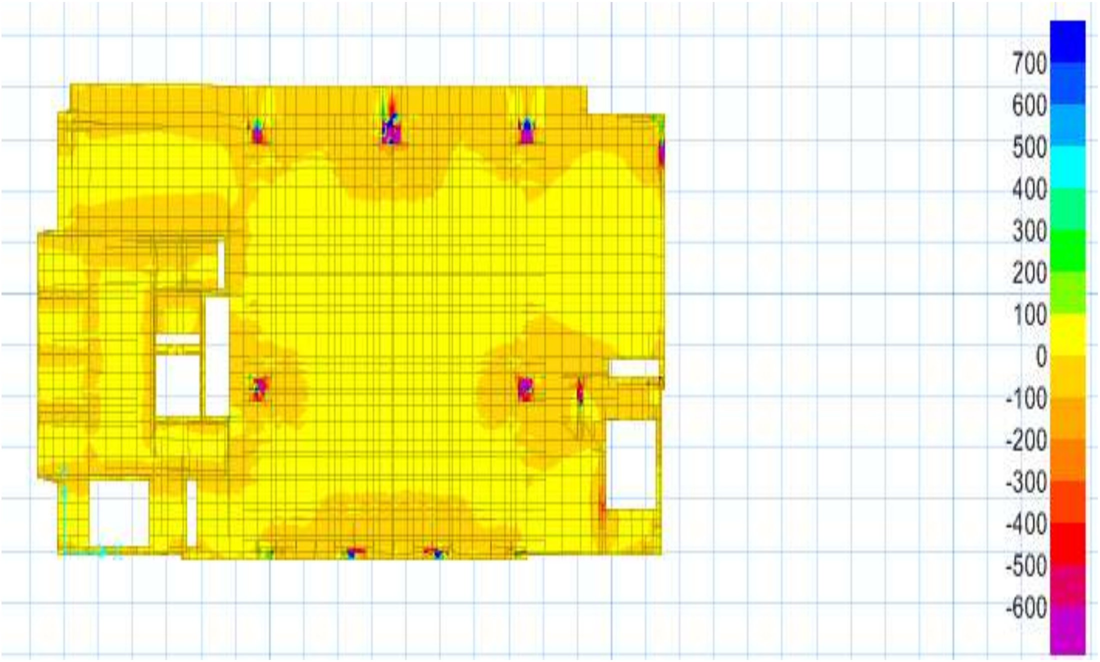
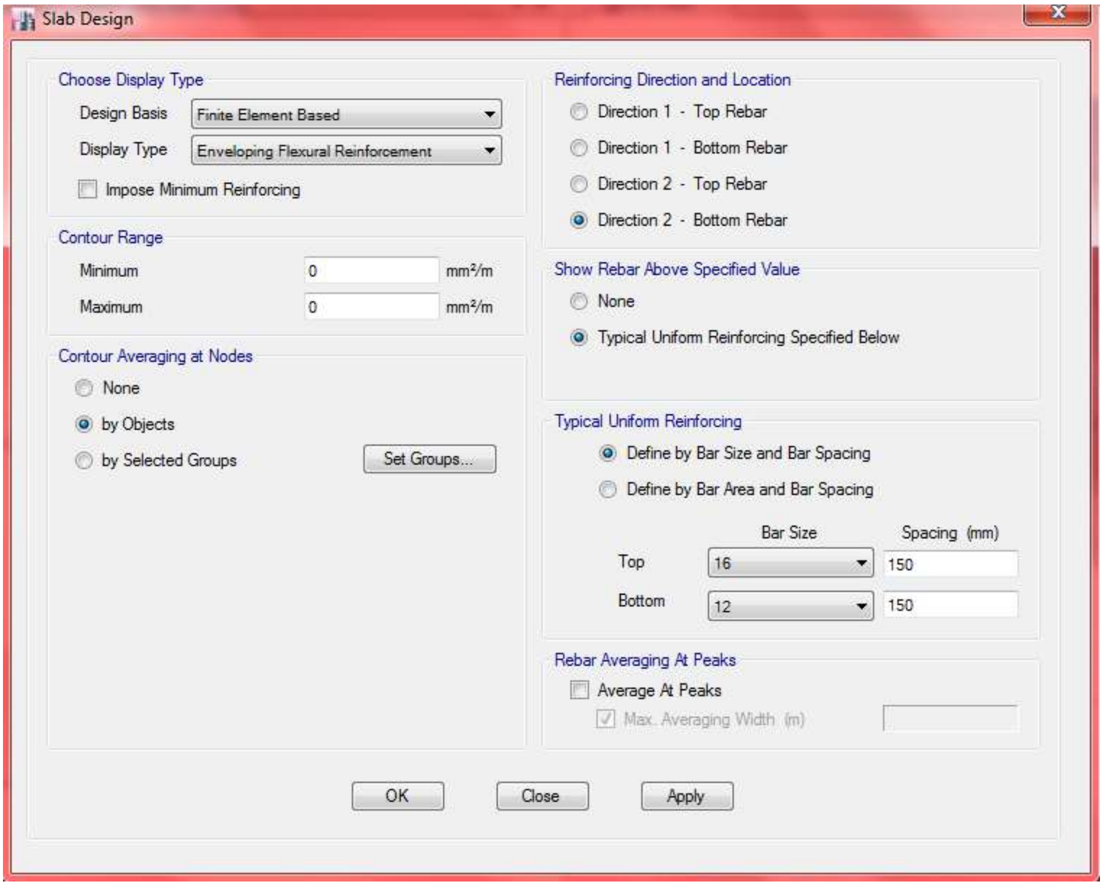


Figure 5.16.b: Slab moment at(y-y) direction- ALTBT.



Slab Design

Choose Display Type

Design Basis: Finite Element Based

Display Type: Enveloping Flexural Reinforcement

☐ Impose Minimum Reinforcing

Contour Range

Minimum: 0 mm²/m

Maximum: 0 mm²/m

Contour Averaging at Nodes

○ None

● by Objects

○ by Selected Groups

Reinforcing Direction and Location

○ Direction 1 - Top Rebar

○ Direction 1 - Bottom Rebar

○ Direction 2 - Top Rebar

● Direction 2 - Bottom Rebar

Show Rebar Above Specified Value

○ None

● Typical Uniform Reinforcing Specified Below

Typical Uniform Reinforcing

● Define by Bar Size and Bar Spacing

○ Define by Bar Area and Bar Spacing

	Bar Size	Spacing (mm)
Top	16	150
Bottom	12	150

Rebar Averaging At Peaks

☐ Average At Peaks

☑ Max. Averaging Width (m)

Figure 5.17.a: Design slab-ALTBT.

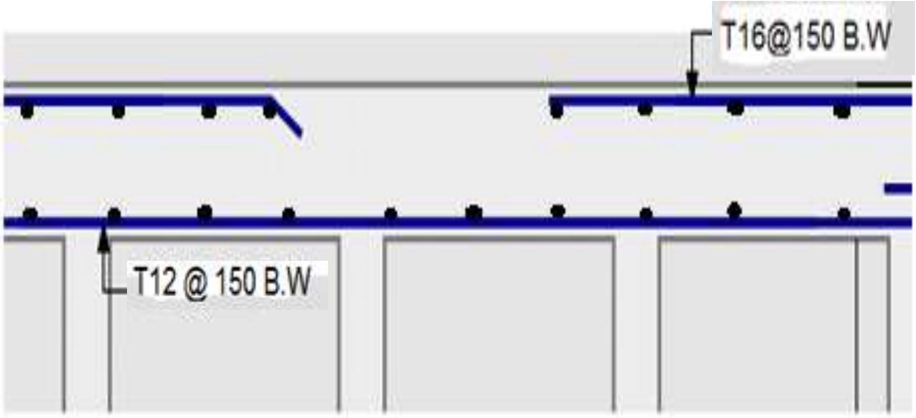


Figure 5.17.b: Reinforcement for two way slab –ALTBT.

5.4 Analysis of ALTBT Building under lateral wind load:

To ensure the capability of the building to resist side loads (wind load) the designed building was subjected to wind load. Static and dynamics analyses were carried out. Table (5.2) and Figure (5.18) show the storey displacement. The maximum displacement was found to be 5.613mm which is less than the allowable displacement (H/500=40mm) and is, therefore acceptable.

Table (5.3) and Figure (5.19) show the storey drifts- ALTBT. The maximum storey drift equal to 0.000359mm is at storey4.

Table 5.2: Maximum displacement of storys-ALTBT.

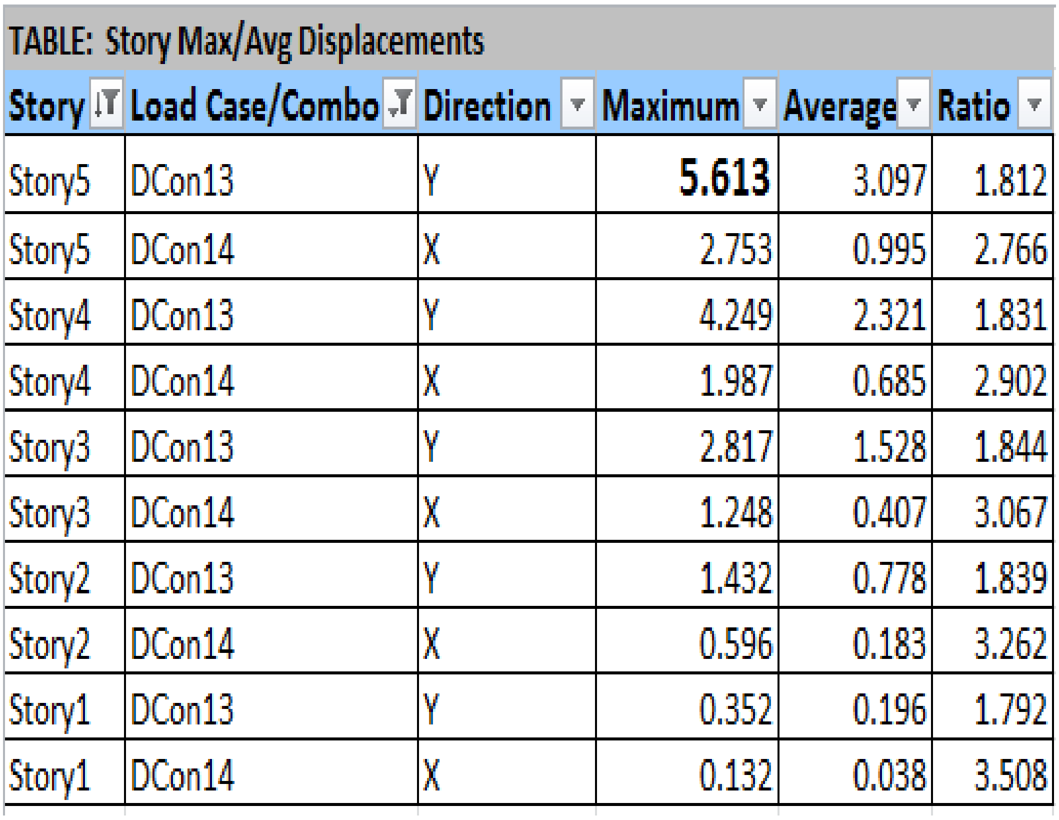


TABLE: Story Max/Avg Displacements

Story	Load Case/Combo	Direction	Maximum	Average	Ratio
Story5	DCon13	Y	**5.613**	3.097	1.812
Story5	DCon14	X	2.753	0.995	2.766
Story4	DCon13	Y	4.249	2.321	1.831
Story4	DCon14	X	1.987	0.685	2.902
Story3	DCon13	Y	2.817	1.528	1.844
Story3	DCon14	X	1.248	0.407	3.067
Story2	DCon13	Y	1.432	0.778	1.839
Story2	DCon14	X	0.596	0.183	3.262
Story1	DCon13	Y	0.352	0.196	1.792
Story1	DCon14	X	0.132	0.038	3.508

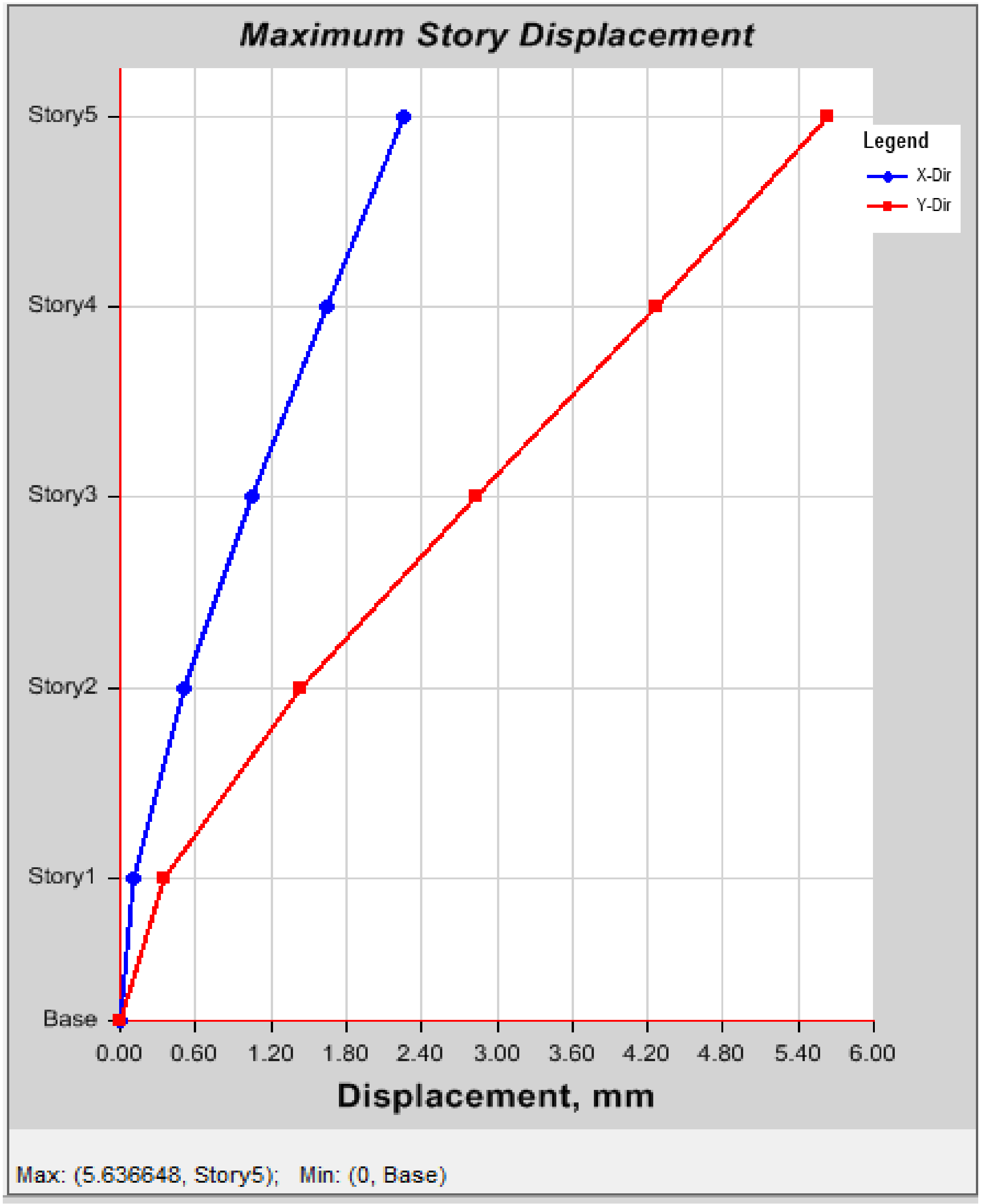


Figure5.18: The maximum displacement- ALTBT.

Table 5.3: Storey drifts of ALTBT.

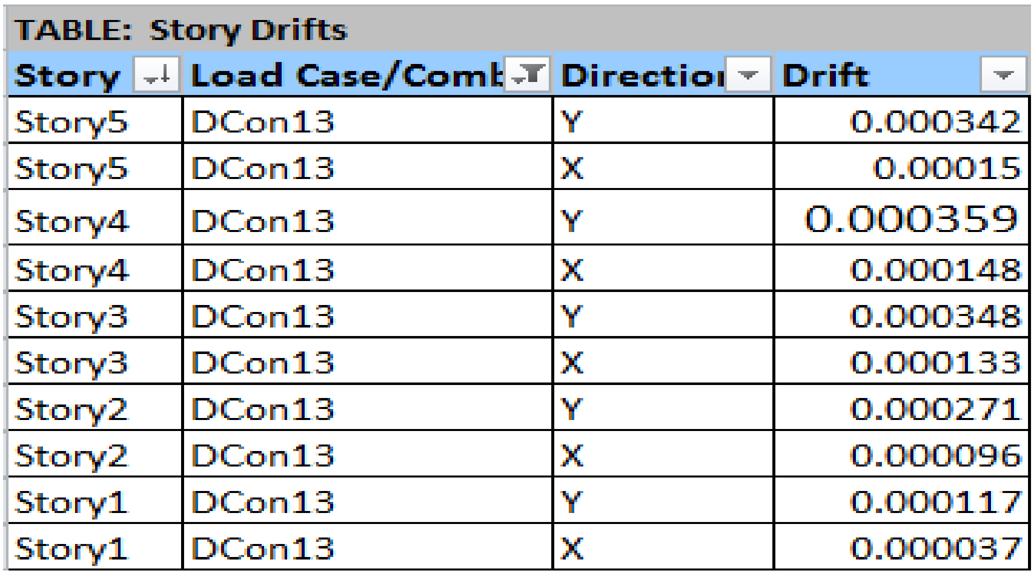


TABLE: Story Drifts

Story	Load Case/Comb	Directio	Drift
Story5	DCon13	Y	0.000342
Story5	DCon13	X	0.00015
Story4	DCon13	Y	0.000359
Story4	DCon13	X	0.000148
Story3	DCon13	Y	0.000348
Story3	DCon13	X	0.000133
Story2	DCon13	Y	0.000271
Story2	DCon13	X	0.000096
Story1	DCon13	Y	0.000117
Story1	DCon13	X	0.000037

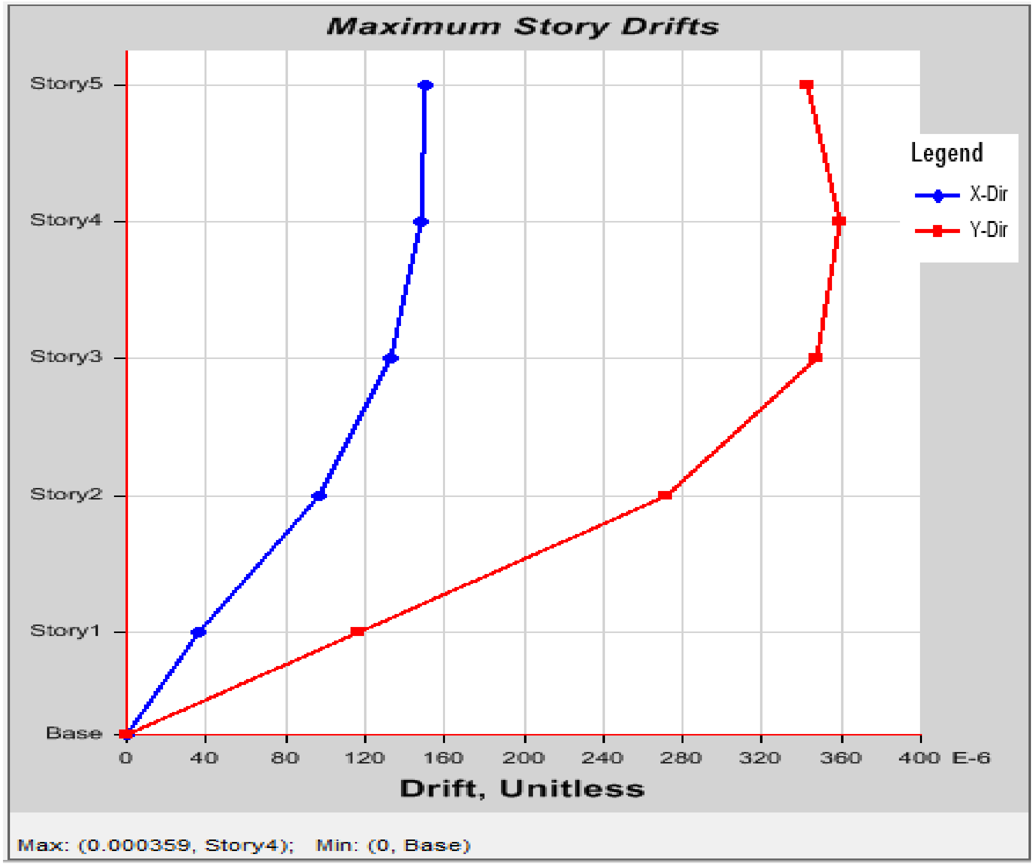


Figure 5.19: Maximum story drifts-ALTBT.

The lateral loads applied to stories in x- direction were given in Table (5.4) and Figure (5.20). The maximum lateral load in storey2 is equal to (93.619kN). Also the lateral loads applied to storey in y- direction are given in Table (5.5) and Figure (5.21). The maximum lateral load in storey2 is equal to (186.122kN).Table (5.6) shows the maximum time period equal 4.842sec and the natural frequency for maximum equal .0297 cyc/sec.

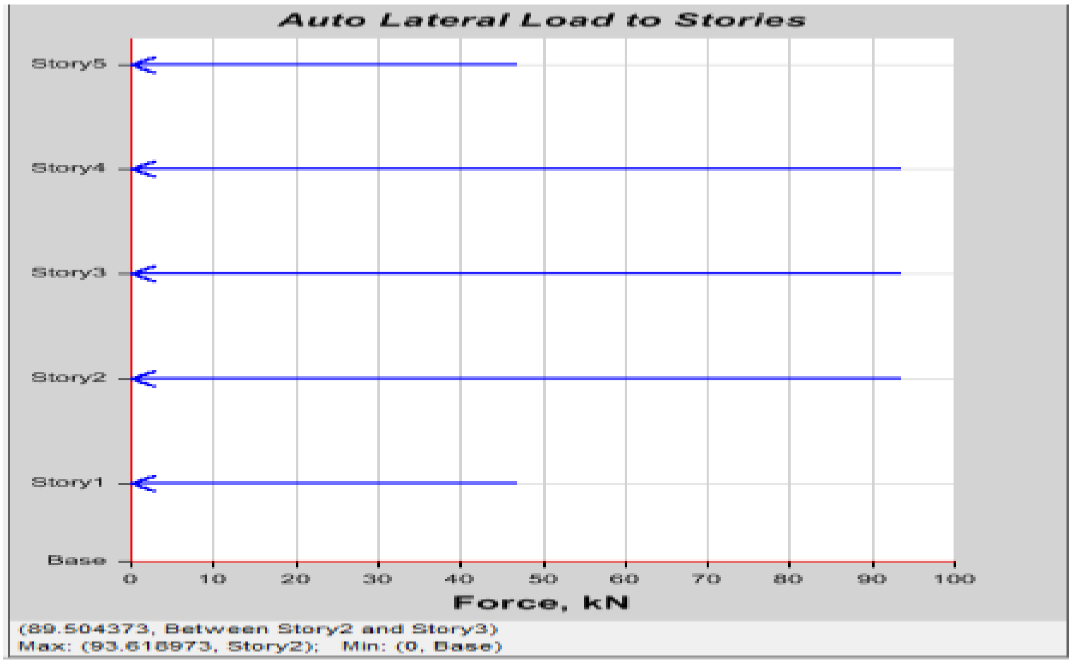
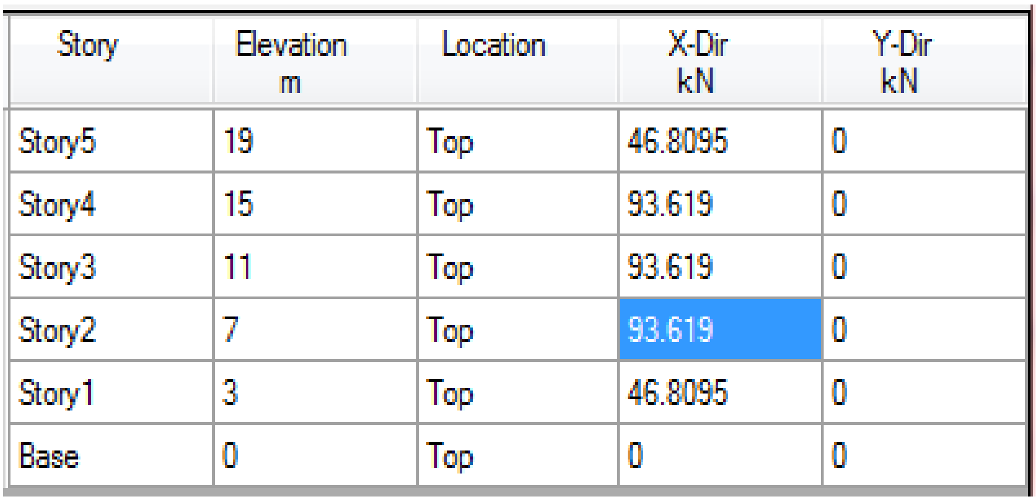


Figure 5.20: Lateral load to storey in x-direction-ALTBT.

Table 5.4: Lateral load to storey in x-direction- ALTBT.



Story	Elevation m	Location	X-Dir kN	Y-Dir kN
Story5	19	Top	46.8095	0
Story4	15	Top	93.619	0
Story3	11	Top	93.619	0
Story2	7	Top	93.619	0
Story1	3	Top	46.8095	0
Base	0	Top	0	0

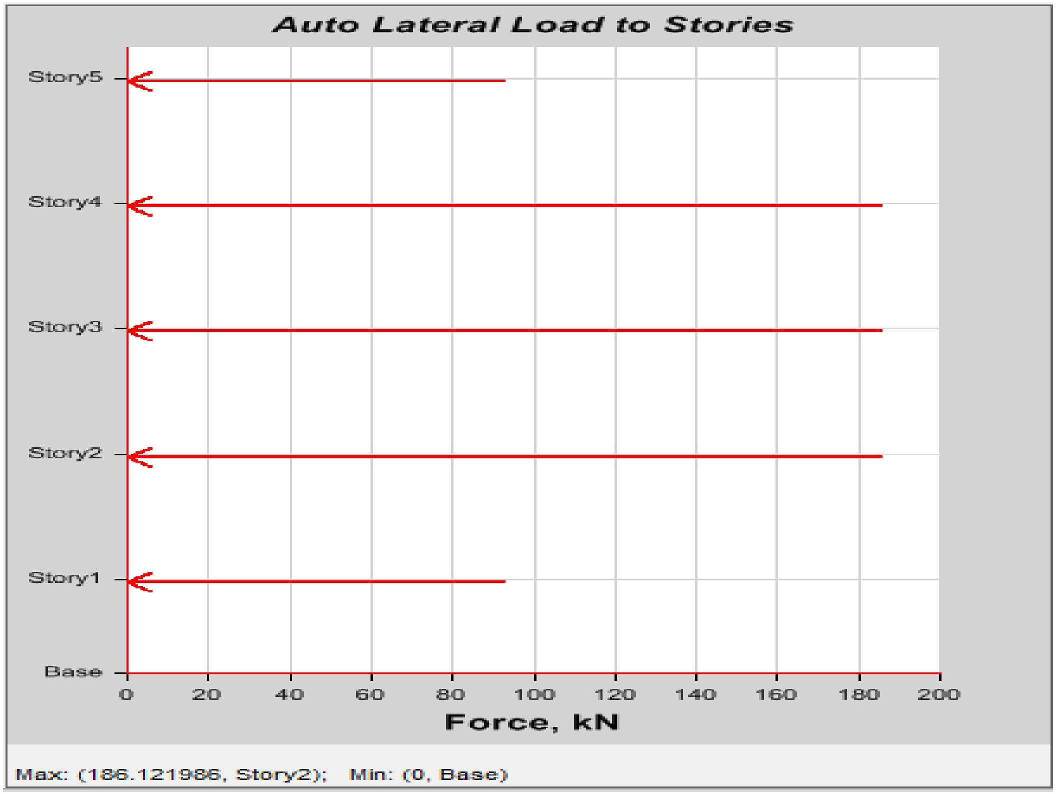
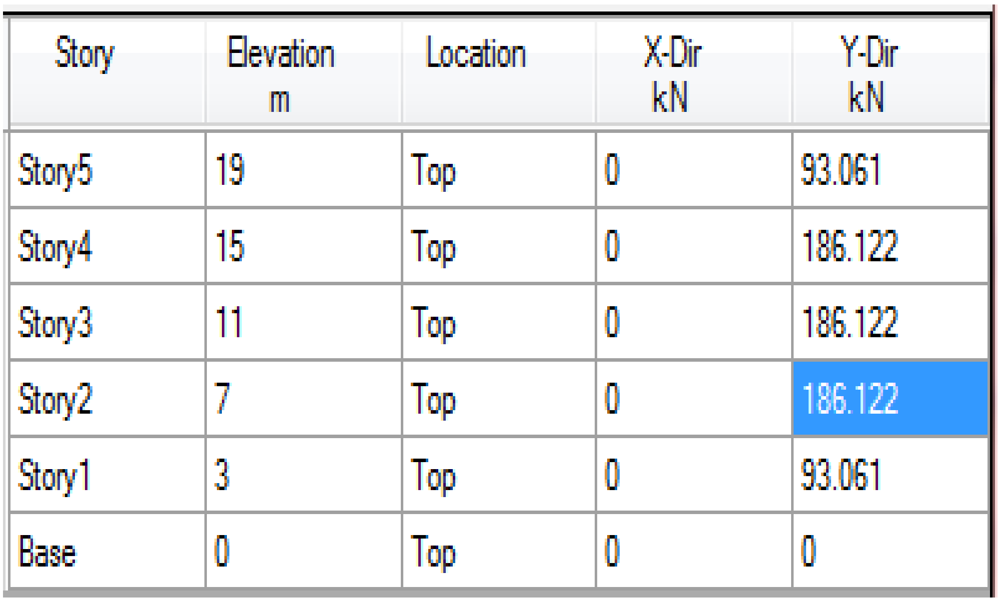


Figure 5.21: Lateral load to storey in-y direction-ALTBT.

Table5.5: Lateral load to storey in y- direction- ALTBT.



Story	Elevation m	Location	X-Dir kN	Y-Dir kN
Story5	19	Top	0	93.061
Story4	15	Top	0	186.122
Story3	11	Top	0	186.122
Story2	7	Top	0	186.122
Story1	3	Top	0	93.061
Base	0	Top	0	0

Table5.6: Time period and the natural frequency- ALTBT.

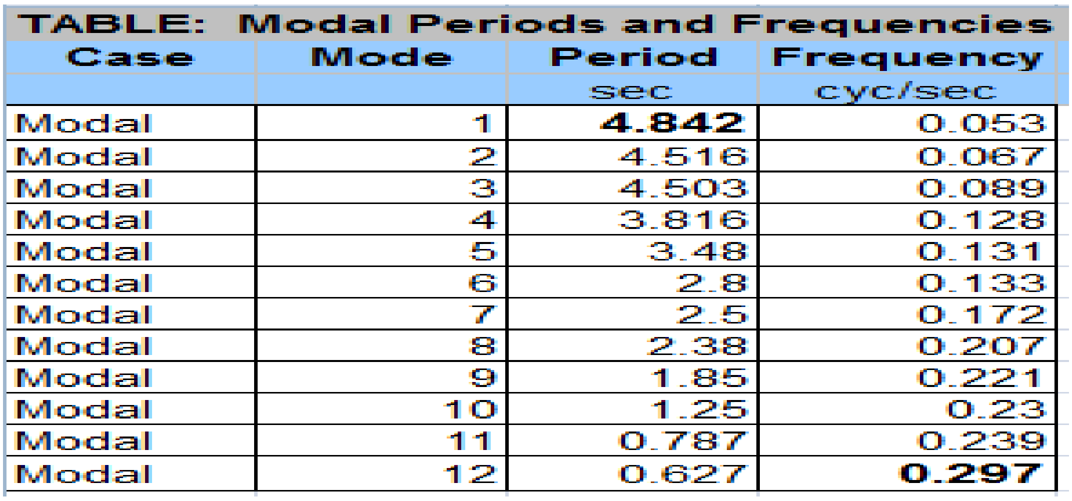


TABLE: Modal Periods and Frequencies

Case	Mode	Period	Frequency
		sec	cyc/sec
Modal	1	**4.842**	0.053
Modal	2	4.516	0.067
Modal	3	4.503	0.089
Modal	4	3.816	0.128
Modal	5	3.48	0.131
Modal	6	2.8	0.133
Modal	7	2.5	0.172
Modal	8	2.38	0.207
Modal	9	1.85	0.221
Modal	10	1.25	0.23
Modal	11	0.787	0.239
Modal	12	0.627	**0.297**

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions:

1- The parametric study of grid systems with different combinations of depth and spacing showed that from the grid system resultting in safe displacement and reasonable depth, is the 570mm depth, 230mm width and 1.0m*1.0m spacing (optimum grid system) gives the largest saving in weight(25%). This compared to the other two safe systems.

2- .There is very close agreement between the optimum grid system results and known published results, which confirms the validity of the use of the optimum grid system

3- The percentage difference between the results are as follows:(Table 4.17)

  - +3.5% for maximum axial force
  - +0.46% for reinforcement ratio
  - +3.3% for mximum time period
  - +3.6% for the maximum natural frequency
  - 0.00% for reinforcement ratio

4- For Altadamon towr (ALTBT), the steel truss system was repleced by the optimum grid system. Five storeys of the building were analyzed and designed using (ETABS). The validity of the results was verified according to BS8110 requirements thus, confirming the validity of the use of the grid slab system for large span slabs.

6.2 Recommendations:

- As aresult of this study it is recommended to use:

1- The concrete grid slab for large span floors of residential building .
2- The optimum model (570mm depth, 380mm width and 1.0m*1.0m spacing grid for large span residential and commercial building.
3- Grids slabs systems instead of the steel truss systems.
4- For industiral building structural analysis program (ETABS) in the analysis and design to ensure the efficiency and stability of the building.

- For further studies it is recommended to:

1- Study the analysis and design of the Altadamon grid slab system building under the influence of earthquakes.
2- Study the effect of replacing all floors of Altadamon tower by the optimum grid system.
3- Study the use of pre-stressed ribbed beams and compare with the grid system.

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APPENDIX (A)

ALTBT Structural Summary Sheets and Design Tables

Figure 5.1: interfaces of ALTBT.

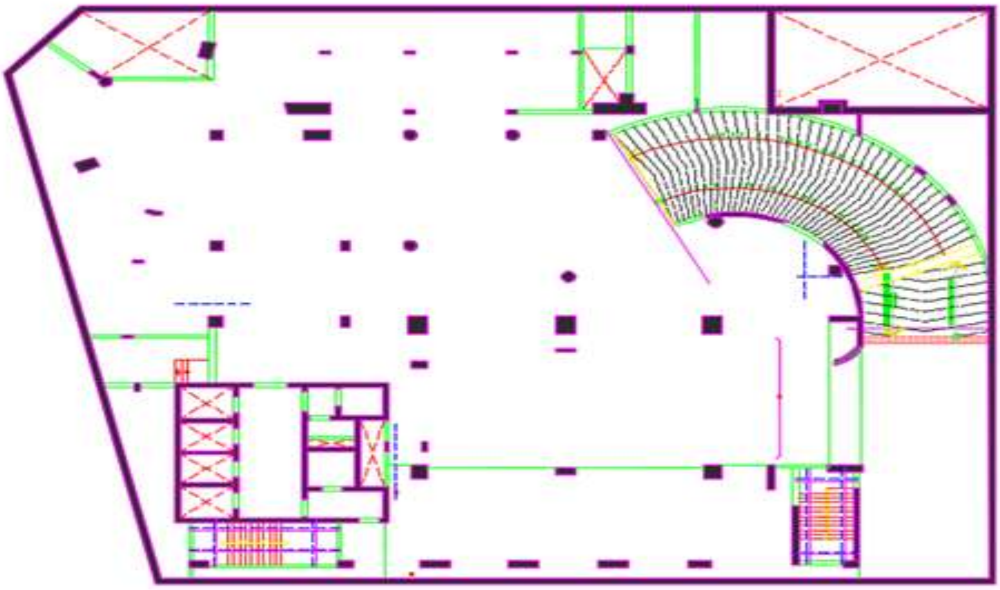


Figure 5.2: basement of ALTBT.

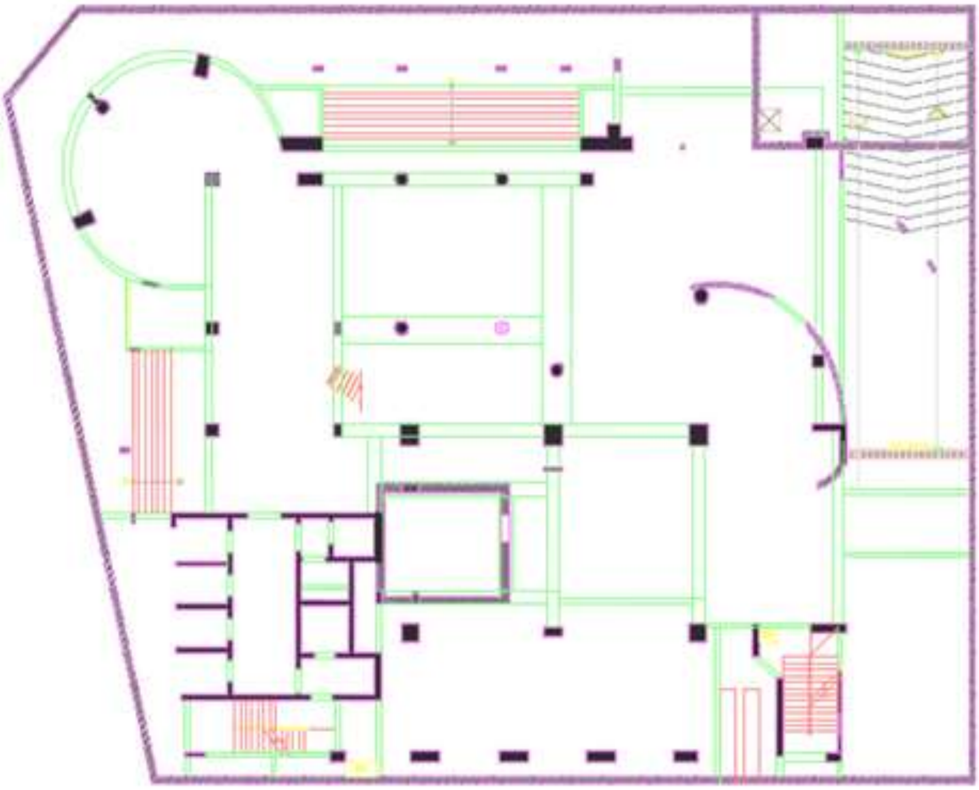


Figure 5.3: ground floor slab of ALTBT.

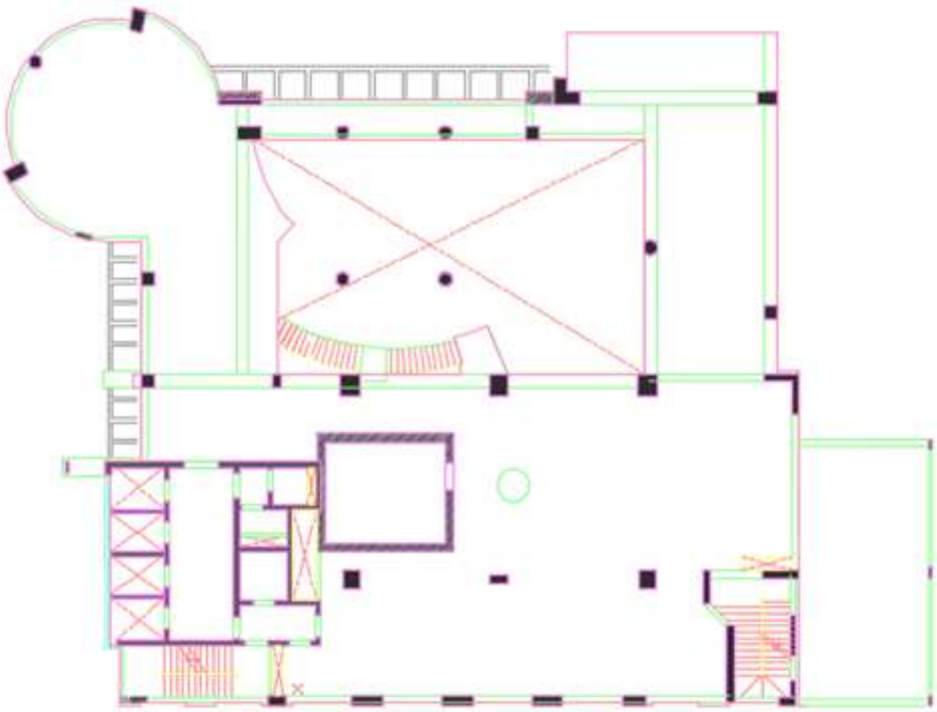


Figure 5.4: mezzanine floor slab of ALTBT.

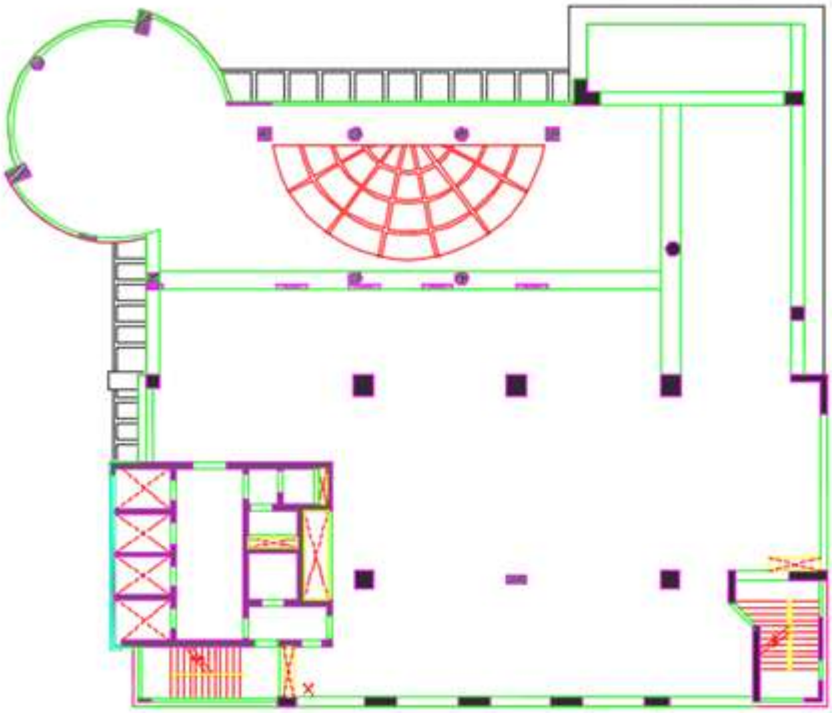


Figure 5.5: first floor slab of ALTBT.

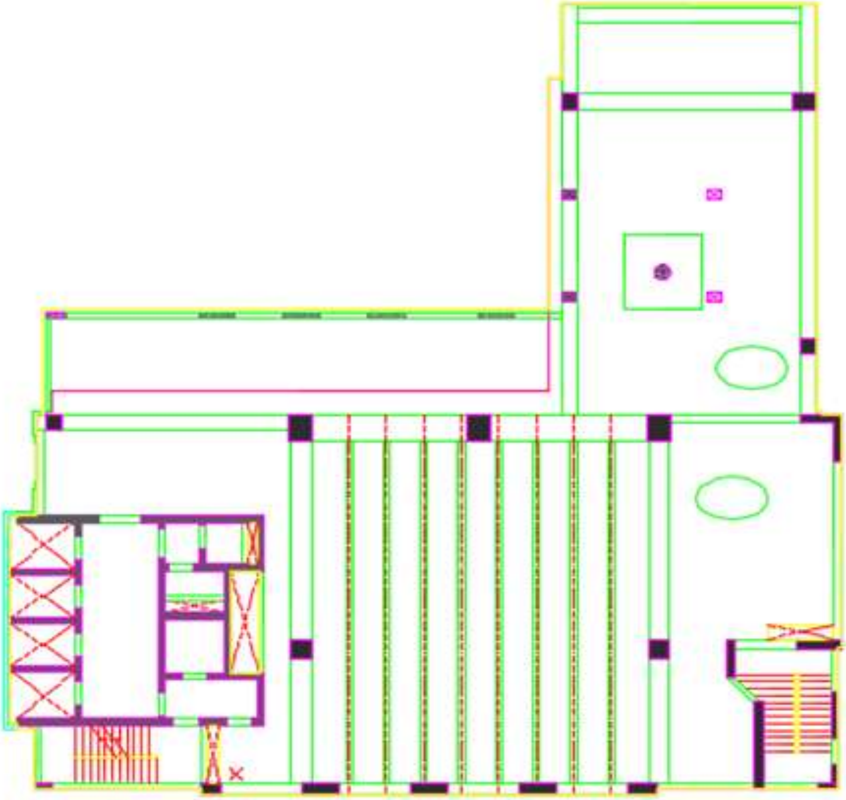


Figure 5.6: 2nd floor slab and 3rd floor slab of ALTBT.

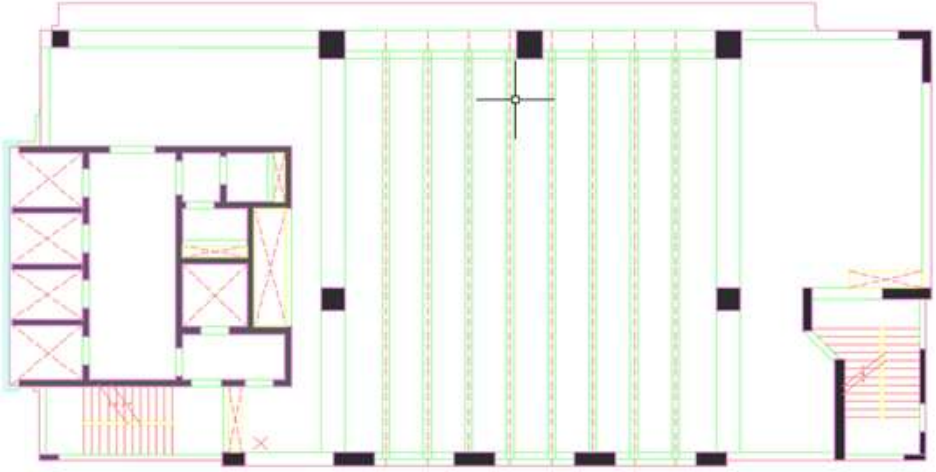


Figure 5.7: typical floors slab of ALTBT.

Table A1: imposed floor loads (BS6399:part1:1996, loading for buildings, part1: code of practice for dead and imposed loads)

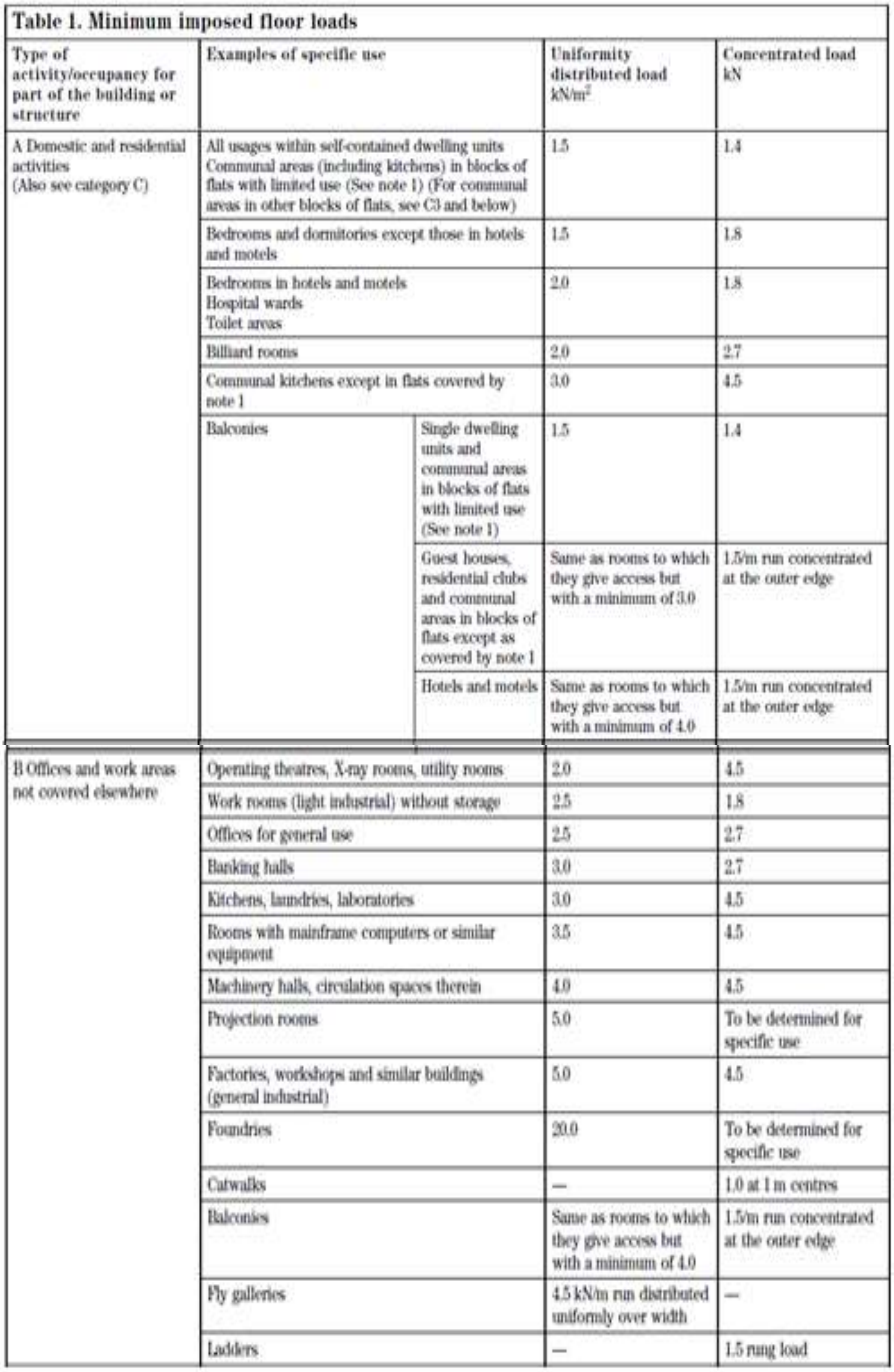


Table 1. Minimum imposed floor loads

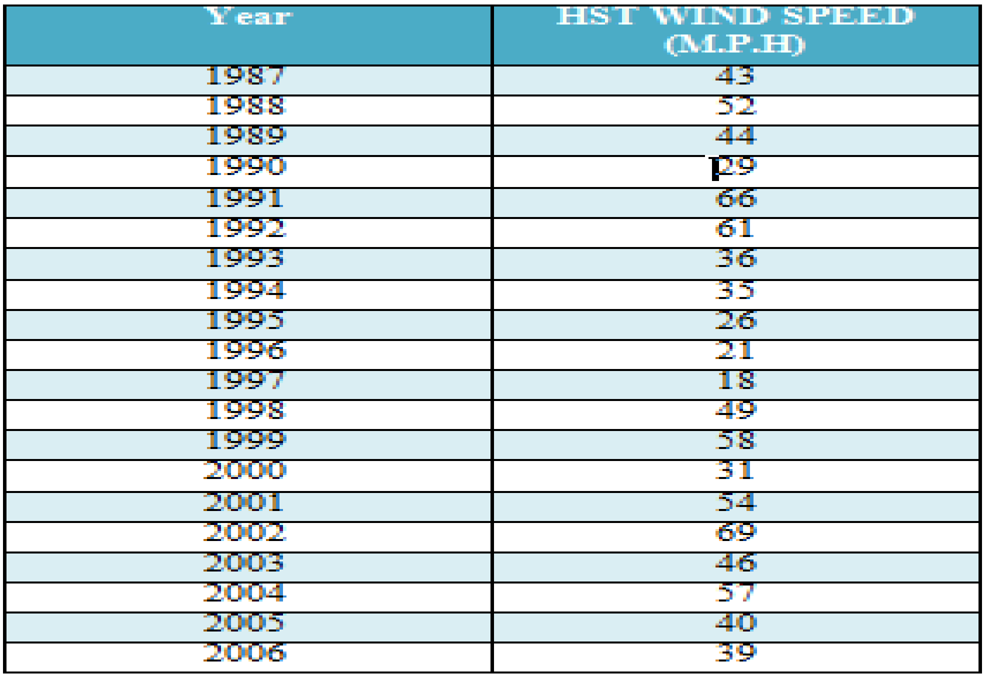
Type of activity/occupancy for part of the building or structure	**Examples of specific use**		**Uniformity distributed load** kN/m²	**Concentrated load** kN
A Domestic and residential activities (Also see category C)	All usages within self-contained dwelling units Communal areas (including kitchens) in blocks of flats with limited use (See note 1) (For communal areas in other blocks of flats, see C3 and below)		1.5	1.4
	Bedrooms and dormitories except those in hotels and motels		1.5	1.8
	Bedrooms in hotels and motels Hospital wards Toilet areas		2.0	1.8
	Billiard rooms		2.0	2.7
	Communal kitchens except in flats covered by note 1		3.0	4.5
	Balconies	Single dwelling units and communal areas in blocks of flats with limited use (See note 1)	1.5	1.4
		Guest houses, residential clubs and communal areas in blocks of flats except as covered by note 1	Same as rooms to which they give access but with a minimum of 3.0	1.5/m run concentrated at the outer edge
		Hotels and motels	Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
B Offices and work areas not covered elsewhere	Operating theatres, X-ray rooms, utility rooms		2.0	4.5
	Work rooms (light industrial) without storage		2.5	1.8
	Offices for general use		2.5	2.7
	Banking halls		3.0	2.7
	Kitchens, laundries, laboratories		3.0	4.5
	Rooms with mainframe computers or similar equipment		3.5	4.5
	Machinery halls, circulation spaces therein		4.0	4.5
	Projection rooms		5.0	To be determined for specific use
	Factories, workshops and similar buildings (general industrial)		5.0	4.5
	Foundries		20.0	To be determined for specific use
	Catwalks		—	1.0 at 1 m centres
	Balconies		Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
	Fly galleries		4.5 kN/m run distributed uniformly over width	—
	Ladders		—	1.5 rung load

Table A2: wind speed in the area:

Ministry of Science and Technology- Meteorological Authority- Khartoum

LAT: 1536 NLONG: 3233ALT: - 38M ABOVE M.S.L

TYPE OF DATE: - ANNUL HIGEST WIND SPEED (GUST) M.P.H



Year	HST WIND SPEED (M.P.H)
1987	43
1988	52
1989	44
1990	29
1991	66
1992	61
1993	36
1994	35
1995	26
1996	21
1997	18
1998	49
1999	58
2000	31
2001	54
2002	69
2003	46
2004	57
2005	40
2006	39

TableA3: building- type factor Kb (BS6399-2:1997, loading for buildings, part2:section1, code of practice for wind load).

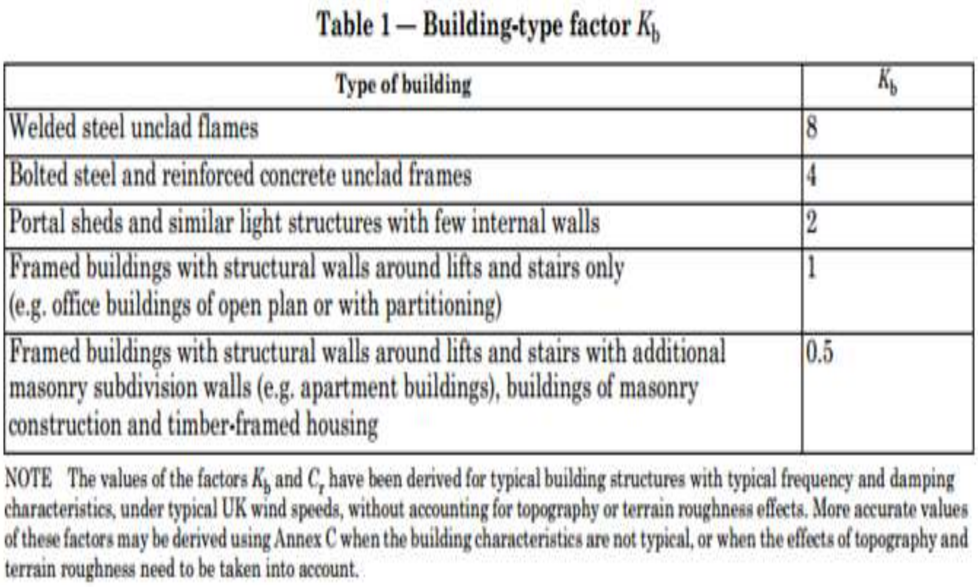


Table 1 — Building-type factor K_b

Type of building	K_b
Welded steel unclad flames	8
Bolted steel and reinforced concrete unclad frames	4
Portal sheds and similar light structures with few internal walls	2
Framed buildings with structural walls around lifts and stairs only (e.g. office buildings of open plan or with partitioning)	1
Framed buildings with structural walls around lifts and stairs with additional masonry subdivision walls (e.g. apartment buildings), buildings of masonry construction and timber-framed housing	0.5

NOTE The values of the factors K_b and C_r have been derived for typical building structures with typical frequency and damping characteristics, under typical UK wind speeds, without accounting for topography or terrain roughness effects. More accurate values of these factors may be derived using Annex C when the building characteristics are not typical, or when the effects of topography and terrain roughness need to be taken into account.

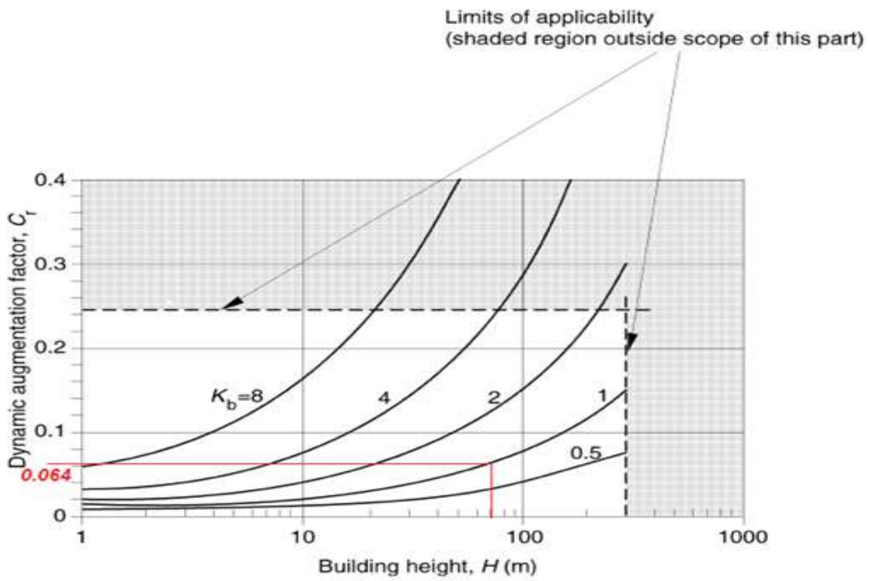


Figure 3 — Dynamic augmentation factor C_r

Figure A1: dynamic augmentation factor Cr (BS6399-2:1997, loading for buildings, part2: section1, code of practice for wind load).

Table A4: values of direction factor Sd (BS6399-2:1997, loading for buildings, part2: section2, code of practice for wind load)

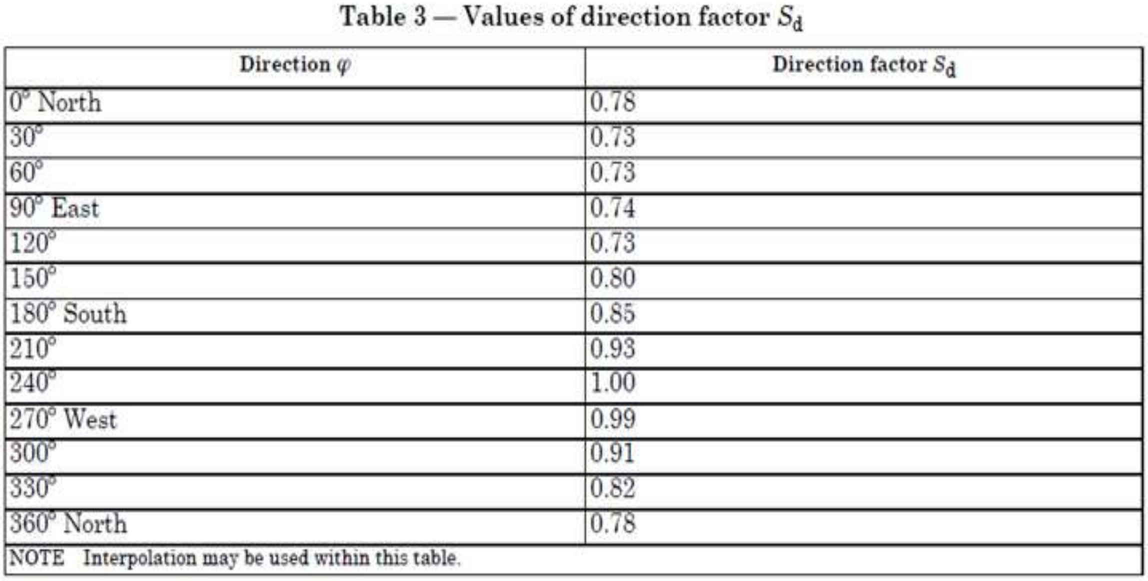


Table 3 — Values of direction factor S_d

Direction φ	Direction factor S_d
0° North	0.78
30°	0.73
60°	0.73
90° East	0.74
120°	0.73
150°	0.80
180° South	0.85
210°	0.93
240°	1.00
270° West	0.99
300°	0.91
330°	0.82
360° North	0.78
NOTE Interpolation may be used within this table.	

TableA5: Factor Sb for standard method (BS6399-2:1997, loading for buildings, part2: section2, code of practice for wind load).

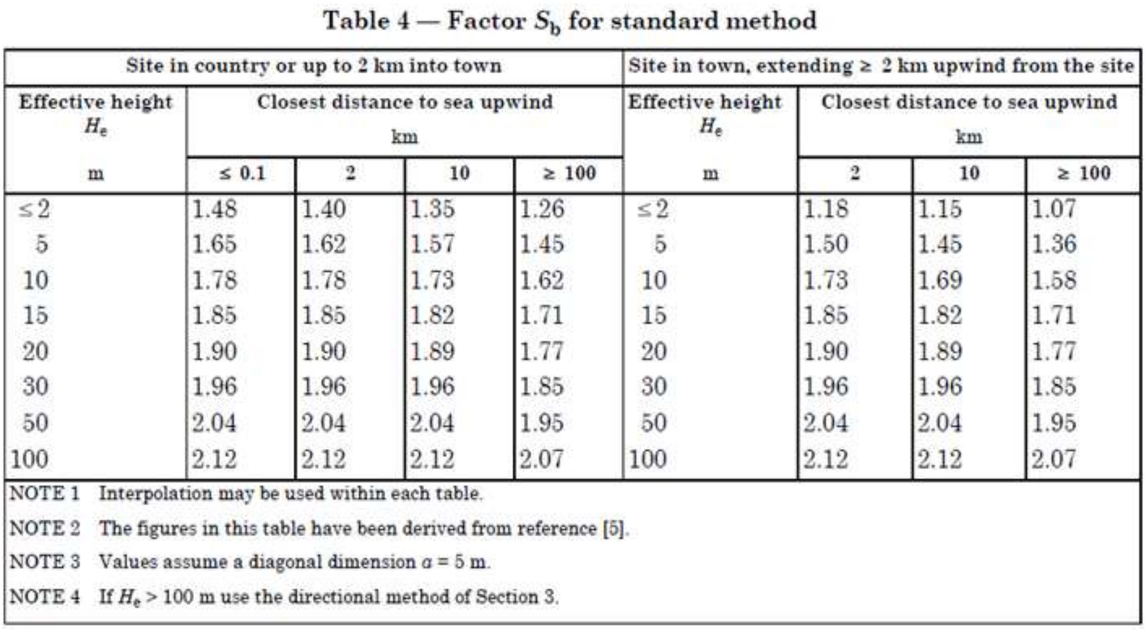


Table 4 — Factor S_b for standard method

Site in country or up to 2 km into town					Site in town, extending ≥ 2 km upwind from the site			
Effective height H_e m	Closest distance to sea upwind km				Effective height H_e m	Closest distance to sea upwind km		
	≤ 0.1	2	10	≥ 100		2	10	≥ 100
≤2	1.48	1.40	1.35	1.26	≤2	1.18	1.15	1.07
5	1.65	1.62	1.57	1.45	5	1.50	1.45	1.36
10	1.78	1.78	1.73	1.62	10	1.73	1.69	1.58
15	1.85	1.85	1.82	1.71	15	1.85	1.82	1.71
20	1.90	1.90	1.89	1.77	20	1.90	1.89	1.77
30	1.96	1.96	1.96	1.85	30	1.96	1.96	1.85
50	2.04	2.04	2.04	1.95	50	2.04	2.04	1.95
100	2.12	2.12	2.12	2.07	100	2.12	2.12	2.07

NOTE 1 Interpolation may be used within each table.

NOTE 2 The figures in this table have been derived from reference [5].

NOTE 3 Values assume a diagonal dimension a = 5 m.

NOTE 4 If H_e > 100 m use the directional method of Section 3.

Table A6: internal pressure coefficients Cpi for enclosed buildings (BS6399-2:1997, loading for buildings, part2: section2, code of practice for wind load)

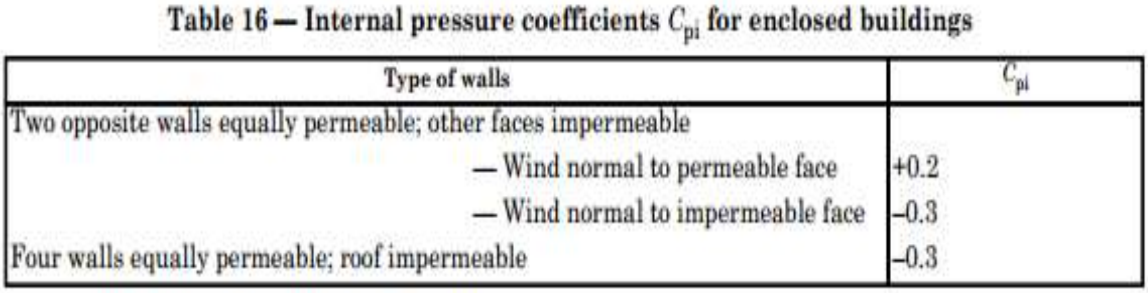


Table 16 — Internal pressure coefficients C_{pi} for enclosed buildings

Type of walls	C_{pi}
Two opposite walls equally permeable; other faces impermeable	
— Wind normal to permeable face	+0.2
— Wind normal to impermeable face	–0.3
Four walls equally permeable; roof impermeable	–0.3

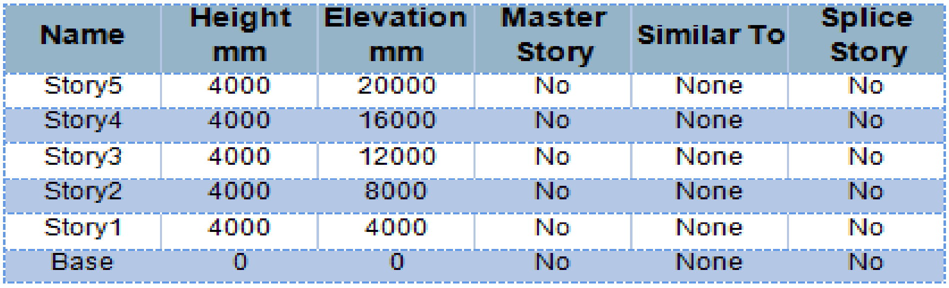
APPENDIX (B)

ETABS Summary Report

ETABS® 2016
Integrated Building Design Software

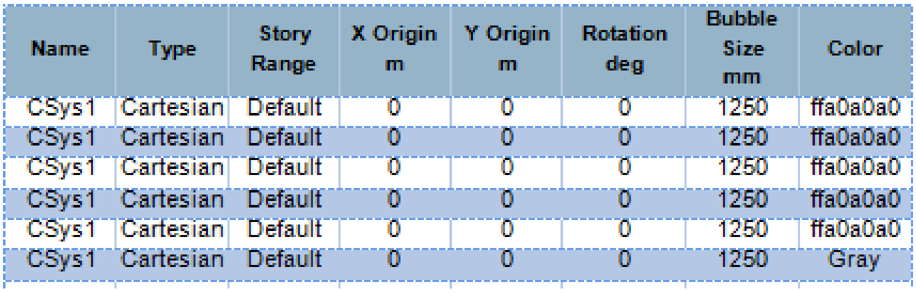
Summary Report

Table 1.1 - Story Data



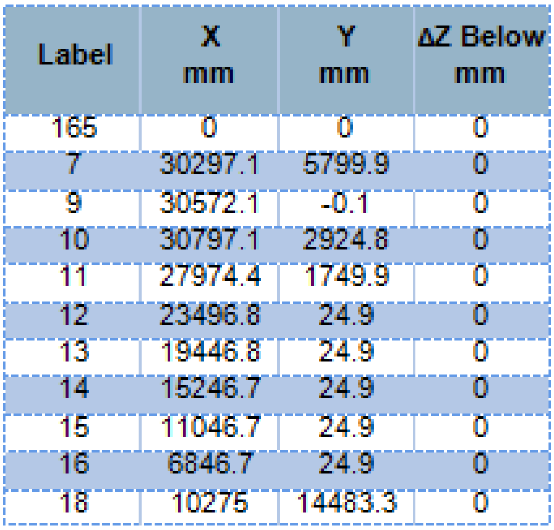
Name	Height mm	Elevation mm	Master Story	Similar To	Splice Story
Story5	4000	20000	No	None	No
Story4	4000	16000	No	None	No
Story3	4000	12000	No	None	No
Story2	4000	8000	No	None	No
Story1	4000	4000	No	None	No
Base	0	0	No	None	No

Table 1.2 - Grid Systems



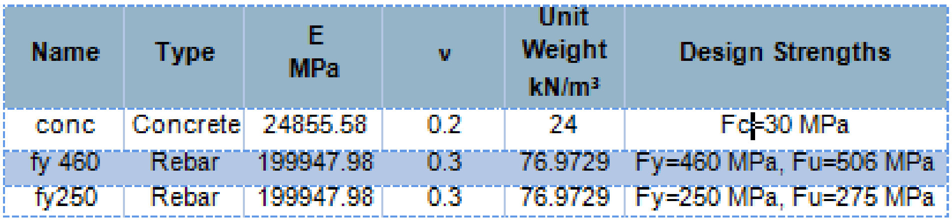
Name	Type	Story Range	X Origin m	Y Origin m	Rotation deg	Bubble Size mm	Color
CSys1	Cartesian	Default	0	0	0	1250	ffa0a0a0
CSys1	Cartesian	Default	0	0	0	1250	ffa0a0a0
CSys1	Cartesian	Default	0	0	0	1250	ffa0a0a0
CSys1	Cartesian	Default	0	0	0	1250	ffa0a0a0
CSys1	Cartesian	Default	0	0	0	1250	ffa0a0a0
CSys1	Cartesian	Default	0	0	0	1250	Gray

Table 1.3 - Joint Coordinates Data



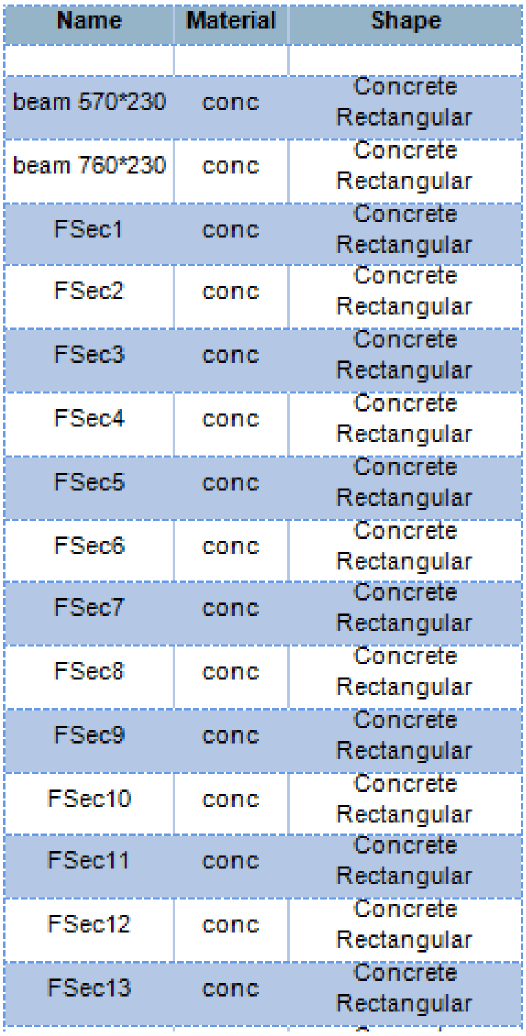
Label	X mm	Y mm	ΔZ Below mm
165	0	0	0
7	30297.1	5799.9	0
9	30572.1	-0.1	0
10	30797.1	2924.8	0
11	27974.4	1749.9	0
12	23496.8	24.9	0
13	19446.8	24.9	0
14	15246.7	24.9	0
15	11046.7	24.9	0
16	6846.7	24.9	0
18	10275	14483.3	0

Table 2.1 - Material Properties - Summary



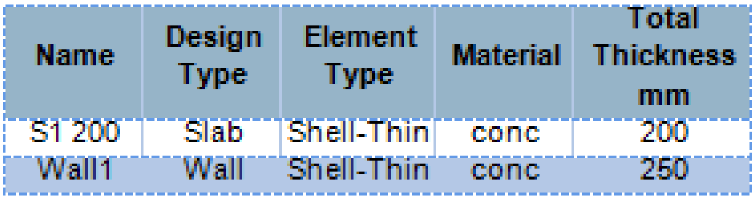
Name	Type	E MPa	v	Unit Weight kN/m³	Design Strengths
conc	Concrete	24855.58	0.2	24	Fc=30 MPa
fy 460	Rebar	199947.98	0.3	76.9729	Fy=460 MPa, Fu=506 MPa
fy250	Rebar	199947.98	0.3	76.9729	Fy=250 MPa, Fu=275 MPa

Table 2.2 - Frame Sections - Summary



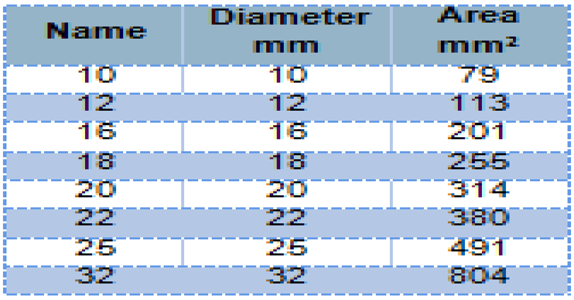
Name	Material	Shape
beam 570*230	conc	Concrete Rectangular
beam 760*230	conc	Concrete Rectangular
FSec1	conc	Concrete Rectangular
FSec2	conc	Concrete Rectangular
FSec3	conc	Concrete Rectangular
FSec4	conc	Concrete Rectangular
FSec5	conc	Concrete Rectangular
FSec6	conc	Concrete Rectangular
FSec7	conc	Concrete Rectangular
FSec8	conc	Concrete Rectangular
FSec9	conc	Concrete Rectangular
FSec10	conc	Concrete Rectangular
FSec11	conc	Concrete Rectangular
FSec12	conc	Concrete Rectangular
FSec13	conc	Concrete Rectangular

Table 2.3 - Shell Sections - Summary



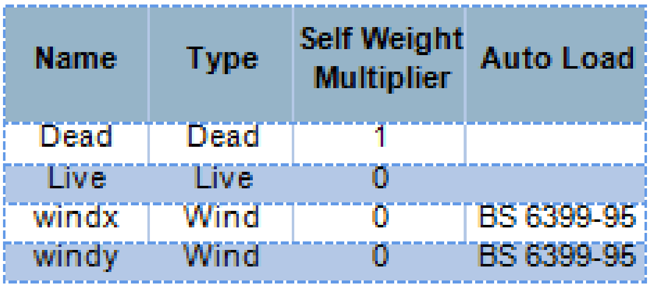
Name	Design Type	Element Type	Material	Total Thickness mm
S1 200	Slab	Shell-Thin	conc	200
Wall1	Wall	Shell-Thin	conc	250

Table 2.4 - Reinforcing Bar Sizes



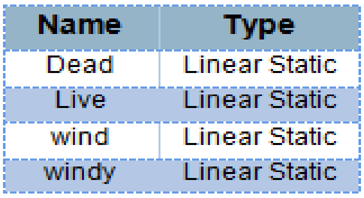
Name	Diameter mm	Area mm²
10	10	79
12	12	113
16	16	201
18	18	255
20	20	314
22	22	380
25	25	491
32	32	804

Table 4.1 - Load Patterns



Name	Type	Self Weight Multiplier	Auto Load
Dead	Dead	1	
Live	Live	0	
windx	Wind	0	BS 6399-95
windy	Wind	0	BS 6399-95

Table 4.5 - Load Cases - Summary



Name	Type
Dead	Linear Static
Live	Linear Static
wind	Linear Static
windy	Linear Static

Table 4.6 - Load Combinations

Name	Load Case/Combo	Scale Factor	Type	Auto
ult	Dead	1.4	Linear Add	No
ult	Live	1.6		No
1.2D+1.2L+1.2W	Dead	1.2	Linear Add	No
1.2D+1.2L+1.2W	Live	1.2		No
1.2D+1.2L+1.2W	wind	1.2		No
WALL ULT	Dead	1.4	Linear Add	No
WALL ULT	Live	1.6		No
WALL 1.2 D+1.2L+1.2W	Dead	1.2	Linear Add	No
WALL 1.2 D+1.2L+1.2W	Live	1.2		No
WALL 1.2 D+1.2L+1.2W	wind	1.2		No
ser	Dead	1	Linear Add	No
ser	Live	1		No
stability	Dead	0.9	Linear Add	No
stability	wind	1.6		No
DCon1	Dead	1.4	Linear Add	Yes
DCon2	Dead	1.4	Linear Add	Yes
DCon2	Live	1.6		No
DCon3	Dead	1.2	Linear Add	Yes
DCon3	Live	1.2		No
DCon3	wind	1.2		No
DCon4	Dead	1.2	Linear Add	Yes
DCon4	Live	1.2		No
DCon4	wind	-1.2		No
DCon5	Dead	1.2	Linear Add	Yes
DCon5	Live	1.2		No
DCon5	windy	1.2		No
DCon6	Dead	1.2	Linear Add	Yes
DCon5	Dead	1.2	Linear Add	Yes
DCon5	Live	1.2		No
DCon5	windy	1.2		No
DCon6	Dead	1.2	Linear Add	Yes
DCon6	Live	1.2		No
DCon6	windy	-1.2		No
DCon7	Dead	1.4	Linear Add	Yes
DCon7	wind	1.4		No

APPENDIX (C)

SIMPLE RESULTS

Table C1: story max/ avg displacement

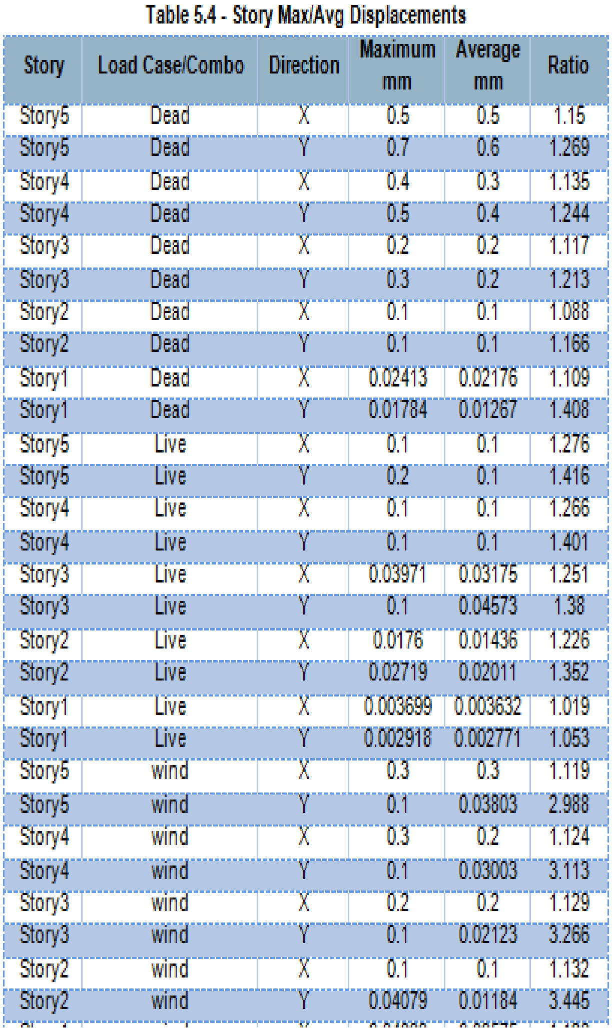
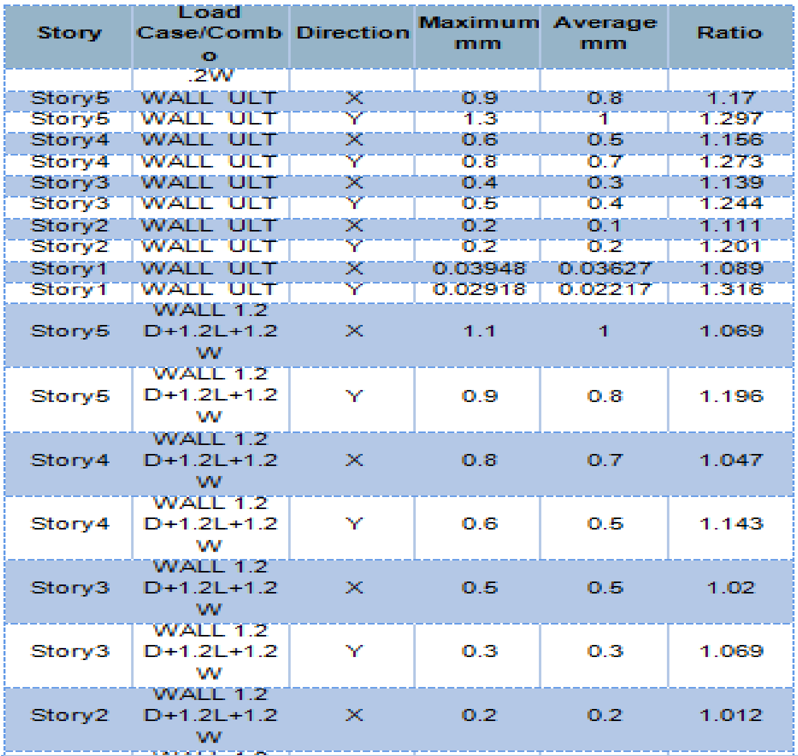
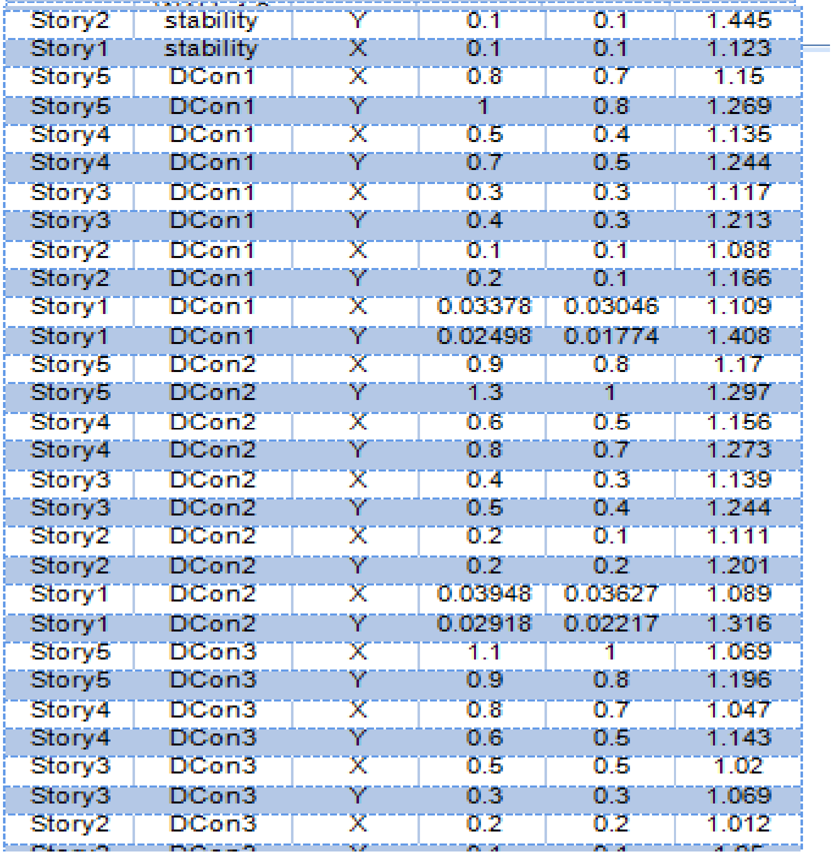


Table 5.4 - Story Max/Avg Displacements

Story	Load Case/Combo	Direction	Maximum mm	Average mm	Ratio
Story5	Dead	X	0.5	0.5	1.15
Story5	Dead	Y	0.7	0.6	1.269
Story4	Dead	X	0.4	0.3	1.135
Story4	Dead	Y	0.5	0.4	1.244
Story3	Dead	X	0.2	0.2	1.117
Story3	Dead	Y	0.3	0.2	1.213
Story2	Dead	X	0.1	0.1	1.088
Story2	Dead	Y	0.1	0.1	1.166
Story1	Dead	X	0.02413	0.02176	1.109
Story1	Dead	Y	0.01784	0.01267	1.408
Story5	Live	X	0.1	0.1	1.276
Story5	Live	Y	0.2	0.1	1.416
Story4	Live	X	0.1	0.1	1.266
Story4	Live	Y	0.1	0.1	1.401
Story3	Live	X	0.03971	0.03175	1.251
Story3	Live	Y	0.1	0.04573	1.38
Story2	Live	X	0.0176	0.01436	1.226
Story2	Live	Y	0.02719	0.02011	1.352
Story1	Live	X	0.003699	0.003632	1.019
Story1	Live	Y	0.002918	0.002771	1.053
Story5	wind	X	0.3	0.3	1.119
Story5	wind	Y	0.1	0.03803	2.988
Story4	wind	X	0.3	0.2	1.124
Story4	wind	Y	0.1	0.03003	3.113
Story3	wind	X	0.2	0.2	1.129
Story3	wind	Y	0.1	0.02123	3.266
Story2	wind	X	0.1	0.1	1.132
Story2	wind	Y	0.04079	0.01184	3.445





Story	Load Case/Combo	Direction	Maximum mm	Average mm	Ratio
	.2W				
Story5	WALL ULT	X	0.9	0.8	1.17
Story5	WALL ULT	Y	1.3	1	1.297
Story4	WALL ULT	X	0.6	0.5	1.156
Story4	WALL ULT	Y	0.8	0.7	1.273
Story3	WALL ULT	X	0.4	0.3	1.139
Story3	WALL ULT	Y	0.5	0.4	1.244
Story2	WALL ULT	X	0.2	0.1	1.111
Story2	WALL ULT	Y	0.2	0.2	1.201
Story1	WALL ULT	X	0.03948	0.03627	1.089
Story1	WALL ULT	Y	0.02918	0.02217	1.316
Story5	WALL 1.2 D+1.2L+1.2 W	X	1.1	1	1.069
Story5	WALL 1.2 D+1.2L+1.2 W	Y	0.9	0.8	1.196
Story4	WALL 1.2 D+1.2L+1.2 W	X	0.8	0.7	1.047
Story4	WALL 1.2 D+1.2L+1.2 W	Y	0.6	0.5	1.143
Story3	WALL 1.2 D+1.2L+1.2 W	X	0.5	0.5	1.02
Story3	WALL 1.2 D+1.2L+1.2 W	Y	0.3	0.3	1.069
Story2	WALL 1.2 D+1.2L+1.2 W	X	0.2	0.2	1.012
Story2	stability	Y	0.1	0.1	1.445
Story1	stability	X	0.1	0.1	1.123
Story5	DCon1	X	0.8	0.7	1.15
Story5	DCon1	Y	1	0.8	1.269
Story4	DCon1	X	0.5	0.4	1.135
Story4	DCon1	Y	0.7	0.5	1.244
Story3	DCon1	X	0.3	0.3	1.117
Story3	DCon1	Y	0.4	0.3	1.213
Story2	DCon1	X	0.1	0.1	1.088
Story2	DCon1	Y	0.2	0.1	1.166
Story1	DCon1	X	0.03378	0.03046	1.109
Story1	DCon1	Y	0.02498	0.01774	1.408
Story5	DCon2	X	0.9	0.8	1.17
Story5	DCon2	Y	1.3	1	1.297
Story4	DCon2	X	0.6	0.5	1.156
Story4	DCon2	Y	0.8	0.7	1.273
Story3	DCon2	X	0.4	0.3	1.139
Story3	DCon2	Y	0.5	0.4	1.244
Story2	DCon2	X	0.2	0.1	1.111
Story2	DCon2	Y	0.2	0.2	1.201
Story1	DCon2	X	0.03948	0.03627	1.089
Story1	DCon2	Y	0.02918	0.02217	1.316
Story5	DCon3	X	1.1	1	1.069
Story5	DCon3	Y	0.9	0.8	1.196
Story4	DCon3	X	0.8	0.7	1.047
Story4	DCon3	Y	0.6	0.5	1.143
Story3	DCon3	X	0.5	0.5	1.02
Story3	DCon3	Y	0.3	0.3	1.069
Story2	DCon3	X	0.2	0.2	1.012

Table C2: story drifts

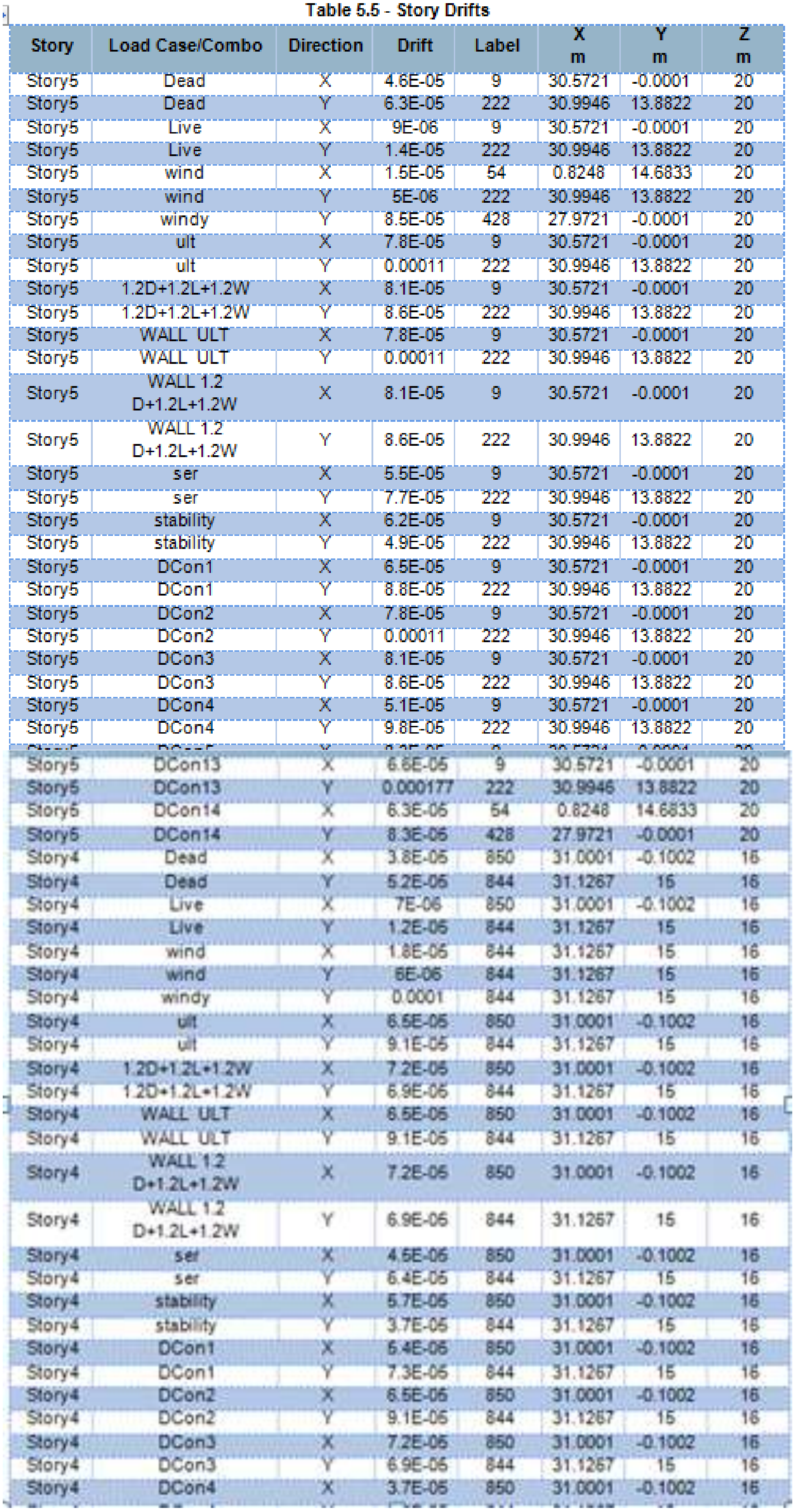
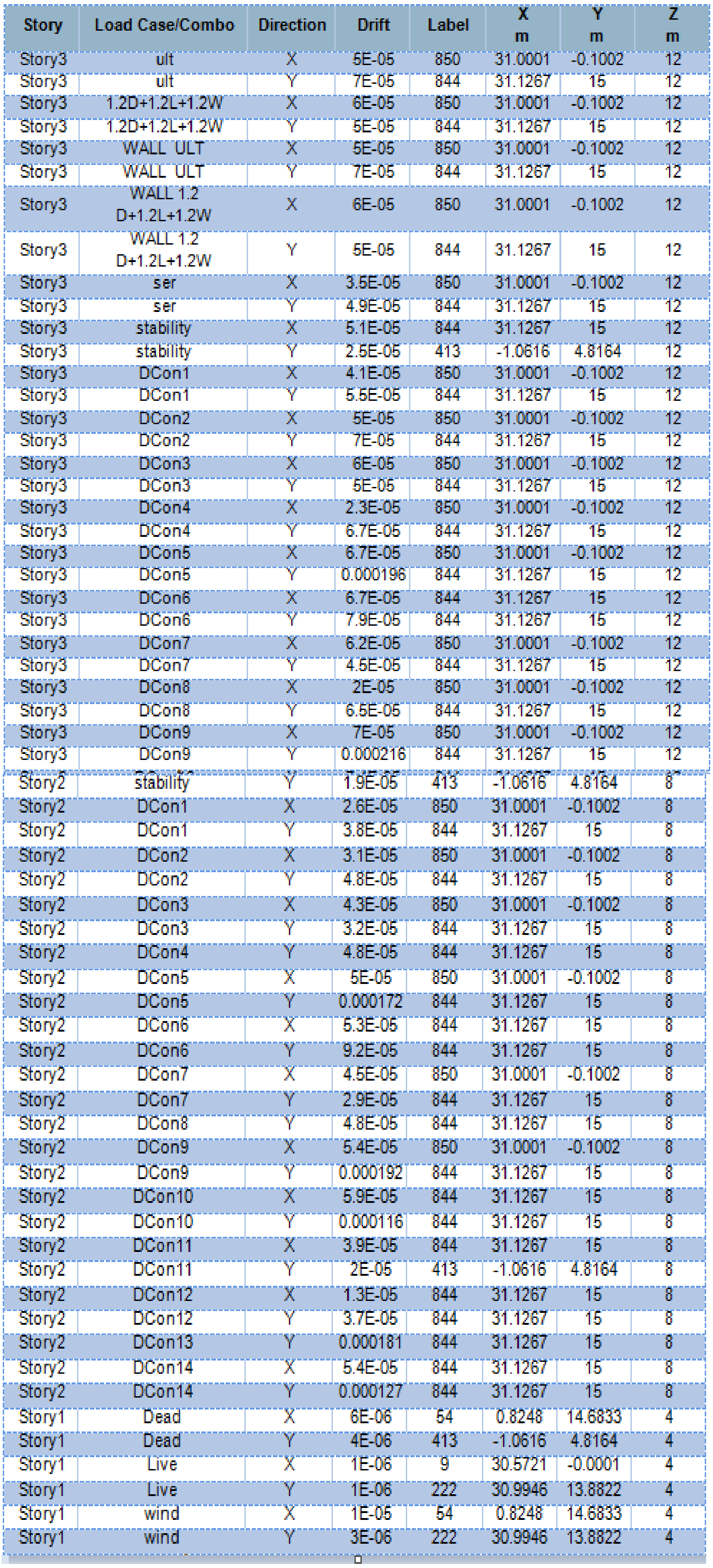


Table 5.5 - Story Drifts

Story	Load Case/Combo	Direction	Drift	Label	X m	Y m	Z m
Story5	Dead	X	4.6E-05	9	30.5721	-0.0001	20
Story5	Dead	Y	6.3E-05	222	30.9946	13.8822	20
Story5	Live	X	9E-06	9	30.5721	-0.0001	20
Story5	Live	Y	1.4E-05	222	30.9946	13.8822	20
Story5	wind	X	1.5E-05	54	0.8248	14.6833	20
Story5	wind	Y	5E-06	222	30.9946	13.8822	20
Story5	windy	Y	8.5E-05	428	27.9721	-0.0001	20
Story5	ult	X	7.8E-05	9	30.5721	-0.0001	20
Story5	ult	Y	0.00011	222	30.9946	13.8822	20
Story5	1.2D+1.2L+1.2W	X	8.1E-05	9	30.5721	-0.0001	20
Story5	1.2D+1.2L+1.2W	Y	8.6E-05	222	30.9946	13.8822	20
Story5	WALL ULT	X	7.8E-05	9	30.5721	-0.0001	20
Story5	WALL ULT	Y	0.00011	222	30.9946	13.8822	20
Story5	WALL 1.2 D+1.2L+1.2W	X	8.1E-05	9	30.5721	-0.0001	20
Story5	WALL 1.2 D+1.2L+1.2W	Y	8.6E-05	222	30.9946	13.8822	20
Story5	ser	X	5.5E-05	9	30.5721	-0.0001	20
Story5	ser	Y	7.7E-05	222	30.9946	13.8822	20
Story5	stability	X	6.2E-05	9	30.5721	-0.0001	20
Story5	stability	Y	4.9E-05	222	30.9946	13.8822	20
Story5	DCon1	X	6.5E-05	9	30.5721	-0.0001	20
Story5	DCon1	Y	8.8E-05	222	30.9946	13.8822	20
Story5	DCon2	X	7.8E-05	9	30.5721	-0.0001	20
Story5	DCon2	Y	0.00011	222	30.9946	13.8822	20
Story5	DCon3	X	8.1E-05	9	30.5721	-0.0001	20
Story5	DCon3	Y	8.6E-05	222	30.9946	13.8822	20
Story5	DCon4	X	5.1E-05	9	30.5721	-0.0001	20
Story5	DCon4	Y	9.8E-05	222	30.9946	13.8822	20
Story5	DCon13	X	6.6E-05	9	30.5721	-0.0001	20
Story5	DCon13	Y	0.000177	222	30.9946	13.8822	20
Story5	DCon14	X	6.3E-05	54	0.8248	14.6833	20
Story5	DCon14	Y	8.3E-05	428	27.9721	-0.0001	20
Story4	Dead	X	3.8E-05	850	31.0001	-0.1002	16
Story4	Dead	Y	5.2E-05	844	31.1267	15	16
Story4	Live	X	7E-06	850	31.0001	-0.1002	16
Story4	Live	Y	1.2E-05	844	31.1267	15	16
Story4	wind	X	1.8E-05	844	31.1267	15	16
Story4	wind	Y	6E-06	844	31.1267	15	16
Story4	windy	Y	0.0001	844	31.1267	15	16
Story4	ult	X	6.5E-05	850	31.0001	-0.1002	16
Story4	ult	Y	9.1E-05	844	31.1267	15	16
Story4	1.2D+1.2L+1.2W	X	7.2E-05	850	31.0001	-0.1002	16
Story4	1.2D+1.2L+1.2W	Y	6.9E-05	844	31.1267	15	16
Story4	WALL ULT	X	6.5E-05	850	31.0001	-0.1002	16
Story4	WALL ULT	Y	9.1E-05	844	31.1267	15	16
Story4	WALL 1.2 D+1.2L+1.2W	X	7.2E-05	850	31.0001	-0.1002	16
Story4	WALL 1.2 D+1.2L+1.2W	Y	6.9E-05	844	31.1267	15	16
Story4	ser	X	4.5E-05	850	31.0001	-0.1002	16
Story4	ser	Y	6.4E-05	844	31.1267	15	16
Story4	stability	X	5.7E-05	850	31.0001	-0.1002	16
Story4	stability	Y	3.7E-05	844	31.1267	15	16
Story4	DCon1	X	5.4E-05	850	31.0001	-0.1002	16
Story4	DCon1	Y	7.3E-05	844	31.1267	15	16
Story4	DCon2	X	6.5E-05	850	31.0001	-0.1002	16
Story4	DCon2	Y	9.1E-05	844	31.1267	15	16
Story4	DCon3	X	7.2E-05	850	31.0001	-0.1002	16
Story4	DCon3	Y	6.9E-05	844	31.1267	15	16
Story4	DCon4	X	3.7E-05	850	31.0001	-0.1002	16



Story	Load Case/Combo	Direction	Drift	Label	X m	Y m	Z m
Story3	ult	X	5E-05	850	31.0001	-0.1002	12
Story3	ult	Y	7E-05	844	31.1267	15	12
Story3	1.2D+1.2L+1.2W	X	6E-05	850	31.0001	-0.1002	12
Story3	1.2D+1.2L+1.2W	Y	5E-05	844	31.1267	15	12
Story3	WALL ULT	X	5E-05	850	31.0001	-0.1002	12
Story3	WALL ULT	Y	7E-05	844	31.1267	15	12
Story3	WALL 1.2 D+1.2L+1.2W	X	6E-05	850	31.0001	-0.1002	12
Story3	WALL 1.2 D+1.2L+1.2W	Y	5E-05	844	31.1267	15	12
Story3	ser	X	3.5E-05	850	31.0001	-0.1002	12
Story3	ser	Y	4.9E-05	844	31.1267	15	12
Story3	stability	X	5.1E-05	844	31.1267	15	12
Story3	stability	Y	2.5E-05	413	-1.0616	4.8164	12
Story3	DCon1	X	4.1E-05	850	31.0001	-0.1002	12
Story3	DCon1	Y	5.5E-05	844	31.1267	15	12
Story3	DCon2	X	5E-05	850	31.0001	-0.1002	12
Story3	DCon2	Y	7E-05	844	31.1267	15	12
Story3	DCon3	X	6E-05	850	31.0001	-0.1002	12
Story3	DCon3	Y	5E-05	844	31.1267	15	12
Story3	DCon4	X	2.3E-05	850	31.0001	-0.1002	12
Story3	DCon4	Y	6.7E-05	844	31.1267	15	12
Story3	DCon5	X	6.7E-05	850	31.0001	-0.1002	12
Story3	DCon5	Y	0.000196	844	31.1267	15	12
Story3	DCon6	X	6.7E-05	844	31.1267	15	12
Story3	DCon6	Y	7.9E-05	844	31.1267	15	12
Story3	DCon7	X	6.2E-05	850	31.0001	-0.1002	12
Story3	DCon7	Y	4.5E-05	844	31.1267	15	12
Story3	DCon8	X	2E-05	850	31.0001	-0.1002	12
Story3	DCon8	Y	6.5E-05	844	31.1267	15	12
Story3	DCon9	X	7E-05	850	31.0001	-0.1002	12
Story3	DCon9	Y	0.000216	844	31.1267	15	12
Story2	stability	Y	1.9E-05	413	-1.0616	4.8164	8
Story2	DCon1	X	2.6E-05	850	31.0001	-0.1002	8
Story2	DCon1	Y	3.8E-05	844	31.1267	15	8
Story2	DCon2	X	3.1E-05	850	31.0001	-0.1002	8
Story2	DCon2	Y	4.8E-05	844	31.1267	15	8
Story2	DCon3	X	4.3E-05	850	31.0001	-0.1002	8
Story2	DCon3	Y	3.2E-05	844	31.1267	15	8
Story2	DCon4	Y	4.8E-05	844	31.1267	15	8
Story2	DCon5	X	5E-05	850	31.0001	-0.1002	8
Story2	DCon5	Y	0.000172	844	31.1267	15	8
Story2	DCon6	X	5.3E-05	844	31.1267	15	8
Story2	DCon6	Y	9.2E-05	844	31.1267	15	8
Story2	DCon7	X	4.5E-05	850	31.0001	-0.1002	8
Story2	DCon7	Y	2.9E-05	844	31.1267	15	8
Story2	DCon8	Y	4.8E-05	844	31.1267	15	8
Story2	DCon9	X	5.4E-05	850	31.0001	-0.1002	8
Story2	DCon9	Y	0.000192	844	31.1267	15	8
Story2	DCon10	X	5.9E-05	844	31.1267	15	8
Story2	DCon10	Y	0.000116	844	31.1267	15	8
Story2	DCon11	X	3.9E-05	844	31.1267	15	8
Story2	DCon11	Y	2E-05	413	-1.0616	4.8164	8
Story2	DCon12	X	1.3E-05	844	31.1267	15	8
Story2	DCon12	Y	3.7E-05	844	31.1267	15	8
Story2	DCon13	Y	0.000181	844	31.1267	15	8
Story2	DCon14	X	5.4E-05	844	31.1267	15	8
Story2	DCon14	Y	0.000127	844	31.1267	15	8
Story1	Dead	X	6E-06	54	0.8248	14.6833	4
Story1	Dead	Y	4E-06	413	-1.0616	4.8164	4
Story1	Live	X	1E-06	9	30.5721	-0.0001	4
Story1	Live	Y	1E-06	222	30.9946	13.8822	4
Story1	wind	X	1E-05	54	0.8248	14.6833	4
Story1	wind	Y	3E-06	222	30.9946	13.8822	4

Table C3: storv forces

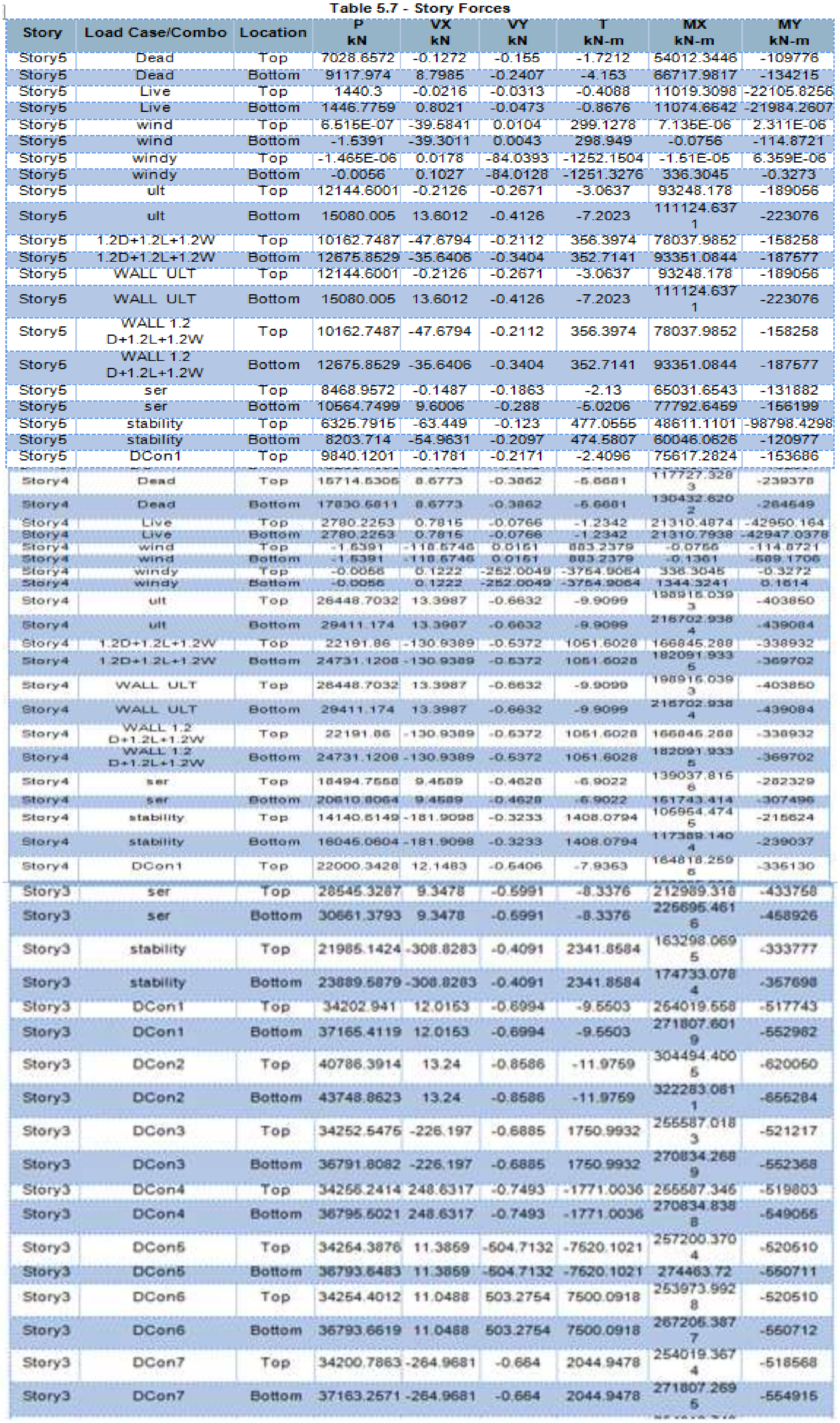
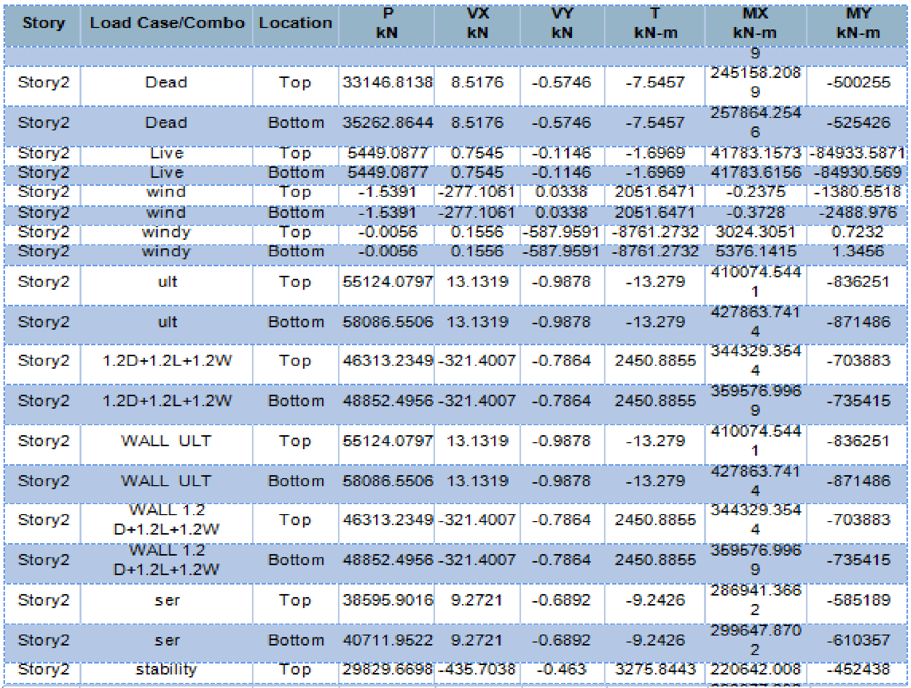


Table 5.7 - Story Forces

Story	Load Case/Combo	Location	P kN	VX kN	VY kN	T kN-m	MX kN-m	MY kN-m
Story5	Dead	Top	7028.6572	-0.1272	-0.155	-1.7212	54012.3446	-109776
Story5	Dead	Bottom	9117.974	8.7985	-0.2407	-4.153	66717.9817	-134215
Story5	Live	Top	1440.3	-0.0216	-0.0313	-0.4088	11019.3098	-22105.8256
Story5	Live	Bottom	1446.7759	0.8021	-0.0473	-0.8676	11074.6642	-21984.2607
Story5	wind	Top	6.515E-07	-39.5841	0.0104	299.1278	7.135E-06	2.311E-06
Story5	wind	Bottom	-1.5391	-39.3011	0.0043	298.949	-0.0756	-114.8721
Story5	windy	Top	-1.465E-06	0.0178	-84.0393	-1252.1504	-1.51E-05	6.359E-06
Story5	windy	Bottom	-0.0056	0.1027	-84.0128	-1251.3276	336.3045	-0.3273
Story5	ult	Top	12144.6001	-0.2126	-0.2671	-3.0637	93248.178	-189056
Story5	ult	Bottom	15080.005	13.6012	-0.4126	-7.2023	111124.6371	-223076
Story5	1.2D+1.2L+1.2W	Top	10162.7487	-47.6794	-0.2112	356.3974	78037.9852	-158258
Story5	1.2D+1.2L+1.2W	Bottom	12675.8529	-35.6406	-0.3404	352.7141	93351.0844	-187577
Story5	WALL ULT	Top	12144.6001	-0.2126	-0.2671	-3.0637	93248.178	-189056
Story5	WALL ULT	Bottom	15080.005	13.6012	-0.4126	-7.2023	111124.6371	-223076
Story5	WALL 1.2 D+1.2L+1.2W	Top	10162.7487	-47.6794	-0.2112	356.3974	78037.9852	-158258
Story5	WALL 1.2 D+1.2L+1.2W	Bottom	12675.8529	-35.6406	-0.3404	352.7141	93351.0844	-187577
Story5	ser	Top	8468.9572	-0.1487	-0.1863	-2.13	65031.6543	-131882
Story5	ser	Bottom	10564.7499	9.6006	-0.288	-5.0206	77792.6459	-156199
Story5	stability	Top	6325.7915	-63.449	-0.123	477.0555	48611.1101	-98798.4298
Story5	stability	Bottom	8203.714	-54.9631	-0.2097	474.5807	60046.0626	-120977
Story5	DCon1	Top	9840.1201	-0.1781	-0.2171	-2.4096	75617.2824	-153686
Story4	Dead	Top	15714.6305	8.6773	-0.3862	-5.6681	117727.3283	-239378
Story4	Dead	Bottom	17830.5811	8.6773	-0.3862	-5.6681	130432.6202	-264649
Story4	Live	Top	2780.2253	0.7815	-0.0766	-1.2342	21310.4874	-42950.164
Story4	Live	Bottom	2780.2253	0.7815	-0.0766	-1.2342	21310.7938	-42947.0378
Story4	wind	Top	-1.5391	-118.5746	0.0161	883.2379	-0.0756	-114.8721
Story4	wind	Bottom	-1.5391	-118.5746	0.0161	883.2379	-0.1361	-589.1706
Story4	windy	Top	-0.0056	0.1222	-252.0049	-3764.9064	336.3045	-0.3272
Story4	windy	Bottom	-0.0056	0.1222	-252.0049	-3764.9064	1344.3241	0.1614
Story4	ult	Top	26448.7032	13.3987	-0.6632	-9.9099	198916.0393	-403850
Story4	ult	Bottom	29411.174	13.3987	-0.6632	-9.9099	216702.9384	-439084
Story4	1.2D+1.2L+1.2W	Top	22191.86	-130.9389	-0.5372	1051.6028	166845.288	-338932
Story4	1.2D+1.2L+1.2W	Bottom	24731.1208	-130.9389	-0.5372	1051.6028	182091.9335	-369702
Story4	WALL ULT	Top	26448.7032	13.3987	-0.6632	-9.9099	198916.0393	-403850
Story4	WALL ULT	Bottom	29411.174	13.3987	-0.6632	-9.9099	216702.9384	-439084
Story4	WALL 1.2 D+1.2L+1.2W	Top	22191.86	-130.9389	-0.5372	1051.6028	166845.288	-338932
Story4	WALL 1.2 D+1.2L+1.2W	Bottom	24731.1208	-130.9389	-0.5372	1051.6028	182091.9335	-369702
Story4	ser	Top	18494.7558	9.4589	-0.4628	-6.9022	139037.8156	-282329
Story4	ser	Bottom	20610.8064	9.4589	-0.4628	-6.9022	161743.414	-307496
Story4	stability	Top	14140.6149	-181.9098	-0.3233	1408.0794	106954.4745	-215624
Story4	stability	Bottom	16045.0604	-181.9098	-0.3233	1408.0794	117389.1404	-239037
Story4	DCon1	Top	22000.3428	12.1483	-0.5406	-7.9363	164818.2598	-336130
Story3	ser	Top	28545.3287	9.3478	-0.5991	-8.3376	212989.318	-433758
Story3	ser	Bottom	30661.3793	9.3478	-0.5991	-8.3376	225695.4616	-458926
Story3	stability	Top	21985.1424	-308.8283	-0.4091	2341.8584	163298.0695	-333777
Story3	stability	Bottom	23889.5879	-308.8283	-0.4091	2341.8584	174733.0784	-357698
Story3	DCon1	Top	34202.941	12.0153	-0.6994	-9.5503	264019.558	-517743
Story3	DCon1	Bottom	37165.4119	12.0153	-0.6994	-9.5503	271807.6019	-552982
Story3	DCon2	Top	40786.3914	13.24	-0.8586	-11.9769	304494.4005	-620060
Story3	DCon2	Bottom	43748.8623	13.24	-0.8586	-11.9769	322283.0811	-656284
Story3	DCon3	Top	34252.5475	-226.197	-0.6885	1750.9932	255587.0183	-521217
Story3	DCon3	Bottom	36791.8082	-226.197	-0.6885	1750.9932	270834.2689	-552368
Story3	DCon4	Top	34256.2414	248.6317	-0.7493	-1771.0036	255587.346	-519803
Story3	DCon4	Bottom	36795.6021	248.6317	-0.7493	-1771.0036	270834.8388	-549056
Story3	DCon5	Top	34254.3876	11.3859	-504.7132	-7520.1021	257200.3704	-520610
Story3	DCon5	Bottom	36793.6483	11.3859	-504.7132	-7520.1021	274463.72	-560711
Story3	DCon6	Top	34254.4012	11.0488	503.2754	7500.0918	253973.9928	-520510
Story3	DCon6	Bottom	36793.6619	11.0488	503.2754	7500.0918	267206.3877	-560712
Story3	DCon7	Top	34200.7863	-264.9681	-0.664	2044.9478	254019.3674	-518568
Story3	DCon7	Bottom	37163.2571	-264.9681	-0.664	2044.9478	271807.2695	-554916



Story	Load Case/Combo	Location	P kN	VX kN	VY kN	T kN-m	MX kN-m	MY kN-m
							9	
Story2	Dead	Top	33146.8138	8.5176	-0.5746	-7.5457	245158.2089	-500255
Story2	Dead	Bottom	35262.8644	8.5176	-0.5746	-7.5457	257864.2546	-525426
Story2	Live	Top	5449.0877	0.7545	-0.1146	-1.6969	41783.1573	-84933.5871
Story2	Live	Bottom	5449.0877	0.7545	-0.1146	-1.6969	41783.6156	-84930.569
Story2	wind	Top	-1.5391	-277.1061	0.0338	2051.6471	-0.2375	-1380.5518
Story2	wind	Bottom	-1.5391	-277.1061	0.0338	2051.6471	-0.3728	-2488.976
Story2	windy	Top	-0.0056	0.1556	-587.9591	-8761.2732	3024.3051	0.7232
Story2	windy	Bottom	-0.0056	0.1556	-587.9591	-8761.2732	5376.1415	1.3456
Story2	ult	Top	55124.0797	13.1319	-0.9878	-13.279	410074.5441	-836251
Story2	ult	Bottom	58086.5506	13.1319	-0.9878	-13.279	427863.7414	-871486
Story2	1.2D+1.2L+1.2W	Top	46313.2349	-321.4007	-0.7864	2450.8855	344329.3544	-703883
Story2	1.2D+1.2L+1.2W	Bottom	48852.4956	-321.4007	-0.7864	2450.8855	359576.9969	-735415
Story2	WALL ULT	Top	55124.0797	13.1319	-0.9878	-13.279	410074.5441	-836251
Story2	WALL ULT	Bottom	58086.5506	13.1319	-0.9878	-13.279	427863.7414	-871486
Story2	WALL 1.2 D+1.2L+1.2W	Top	46313.2349	-321.4007	-0.7864	2450.8855	344329.3544	-703883
Story2	WALL 1.2 D+1.2L+1.2W	Bottom	48852.4956	-321.4007	-0.7864	2450.8855	359576.9969	-735415
Story2	ser	Top	38595.9016	9.2721	-0.6892	-9.2426	286941.3662	-585189
Story2	ser	Bottom	40711.9522	9.2721	-0.6892	-9.2426	299647.8702	-610357
Story2	stability	Top	29829.6698	-435.7038	-0.463	3275.8443	220642.008	-452438

Story	Load Case/Combo	Location	P kN	VX kN	VY kN	T kN-m	MX kN-m	MY kN-m
Story1	ser	Bottom	50818.9021	9.2334	-0.7129	-9.2567	374665.6625	-762773
Story1	stability	Top	37730.1207	-499.1687	-0.4719	3743.4426	278416.1704	-572562
Story1	stability	Bottom	39629.3822	-499.1687	-0.4719	3743.4426	290380.1823	-597175
Story1	DCon1	Top	58695.1295	11.8783	-0.8318	-10.5507	433092.7485	-884456
Story1	DCon1	Bottom	61649.5363	11.8783	-0.8318	-10.5507	451703.8243	-919591
Story1	DCon2	Top	69548.7598	13.0766	-1.0218	-13.3034	516324.1061	-1053937
Story1	DCon2	Bottom	72503.1667	13.0766	-1.0218	-13.3034	534935.9422	-1089066
Story1	DCon3	Top	58448.4868	-369.0234	-0.8084	2801.5609	433645.4267	-888203
Story1	DCon3	Bottom	60980.8355	-369.0234	-0.8084	2801.5609	449598.1592	-919835
Story1	DCon4	Top	58452.1807	391.1837	-0.9026	-2823.7769	433646.3214	-882229
Story1	DCon4	Bottom	60984.5294	391.1837	-0.9026	-2823.7769	449599.4307	-910820
Story1	DCon5	Top	58450.327	11.279	-807.2616	-12027.8656	440097.2438	-885214
Story1	DCon5	Bottom	60982.6757	11.279	-807.2616	-12027.8656	459275.7892	-915325
Story1	DCon6	Top	58450.3405	10.8813	805.5506	12005.6496	427194.5043	-885218
Story1	DCon6	Bottom	60982.6892	10.8813	805.5506	12005.6496	439921.8007	-915330

Table C4: joint reaction

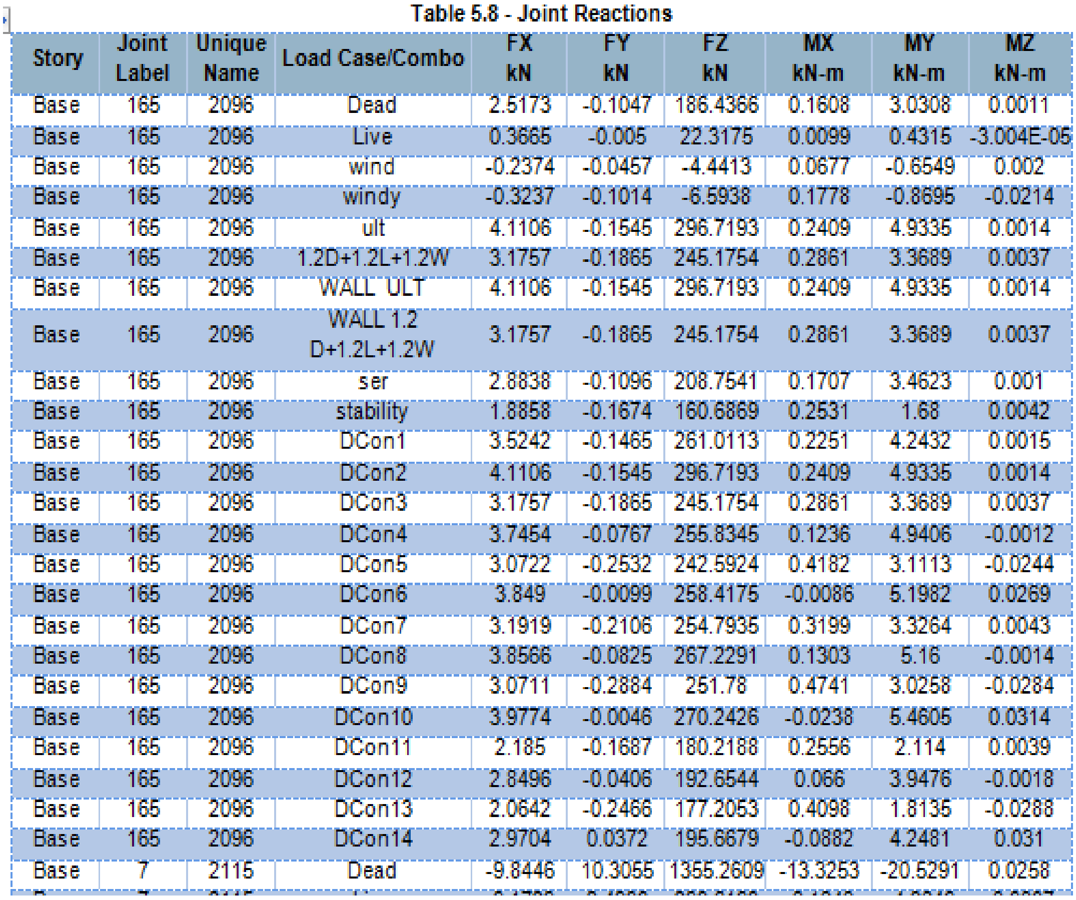


Table 5.8 - Joint Reactions

Story	Joint Label	Unique Name	Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Base	165	2096	Dead	2.5173	-0.1047	186.4366	0.1608	3.0308	0.0011
Base	165	2096	Live	0.3665	-0.005	22.3175	0.0099	0.4315	-3.004E-05
Base	165	2096	wind	-0.2374	-0.0457	-4.4413	0.0677	-0.6549	0.002
Base	165	2096	windy	-0.3237	-0.1014	-6.5938	0.1778	-0.8695	-0.0214
Base	165	2096	ult	4.1106	-0.1545	296.7193	0.2409	4.9335	0.0014
Base	165	2096	1.2D+1.2L+1.2W	3.1757	-0.1865	245.1754	0.2861	3.3689	0.0037
Base	165	2096	WALL ULT	4.1106	-0.1545	296.7193	0.2409	4.9335	0.0014
Base	165	2096	WALL 1.2 D+1.2L+1.2W	3.1757	-0.1865	245.1754	0.2861	3.3689	0.0037
Base	165	2096	ser	2.8838	-0.1096	208.7541	0.1707	3.4623	0.001
Base	165	2096	stability	1.8858	-0.1674	160.6869	0.2531	1.68	0.0042
Base	165	2096	DCon1	3.5242	-0.1465	261.0113	0.2251	4.2432	0.0015
Base	165	2096	DCon2	4.1106	-0.1545	296.7193	0.2409	4.9335	0.0014
Base	165	2096	DCon3	3.1757	-0.1865	245.1754	0.2861	3.3689	0.0037
Base	165	2096	DCon4	3.7454	-0.0767	255.8345	0.1236	4.9406	-0.0012
Base	165	2096	DCon5	3.0722	-0.2532	242.5924	0.4182	3.1113	-0.0244
Base	165	2096	DCon6	3.849	-0.0099	258.4175	-0.0086	5.1982	0.0269
Base	165	2096	DCon7	3.1919	-0.2106	254.7935	0.3199	3.3264	0.0043
Base	165	2096	DCon8	3.8566	-0.0825	267.2291	0.1303	5.16	-0.0014
Base	165	2096	DCon9	3.0711	-0.2884	251.78	0.4741	3.0258	-0.0284
Base	165	2096	DCon10	3.9774	-0.0046	270.2426	-0.0238	5.4605	0.0314
Base	165	2096	DCon11	2.185	-0.1687	180.2188	0.2556	2.114	0.0039
Base	165	2096	DCon12	2.8496	-0.0406	192.6544	0.066	3.9476	-0.0018
Base	165	2096	DCon13	2.0642	-0.2466	177.2053	0.4098	1.8135	-0.0288
Base	165	2096	DCon14	2.9704	0.0372	195.6679	-0.0882	4.2481	0.031
Base	7	2115	Dead	-9.8446	10.3055	1355.2609	-13.3253	-20.5291	0.0258