ROOF DESIGN OF AN INDUSTRIAL BUILDING USING SAP2000

Authors

Sajid Hussain	F2016132010
Umair Khan	F2016132035
Mohsin Zafar	F2016132006
Abdur Rahman Baig	F2016132091

Supervisor
Engr. Sardar Umer Sial

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MANAGEMENT AND TECHNOLOGY LAHORE, PAKISTAN

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Project Supervisor:

Engr.Sardar Umer Sial
Lecturer

Civil Engineering Department

External Examiner Signature: ____

Project Supervisor Signature: ____

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UNIVERSITY OF MANAGEMENT AND TECHNOLOGY
LAHORE

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ABSTRACT

A building structure utilized to store crude material or assembling products of an industry is known as an industrial building. The roofing system for such structures are trusses, purlins, columns and corrugated sheet. In this project the performance of industrial building according to various loads such as wind load, will be observed. Wind load is actually a major force act on roof of the industrial building. The basic wind speed applied on roof, calculation of wind speed, wind pressure, and wind forces will be explained and analyzed in software for design of members of the industrial building. Self-weight of the truss is also considered in designing of industrial building. An analysis will be done on software to check the performance of industrial building and the member forces in all directions including diagonal members. Keeping in view the different load cases will be taken to work on the severe or critical phase of the industrial building, also applying different load combinations for taken critical situation on which members of the industrial building will be designed

Keywords: Wind load, Load cases, Load Combinations and roof design of an industrial building.

UNDERTAKING

I certify that research work titled "*Roof Design of an industrial building*" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Sajid Hussain

F2016132010

Umair Khan

F2016132035

Mohsin Zafar

F2016132006

Abdur Rahman Baig

F2016132091

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CHAPTER I

Introduction

A building structure utilized to store crude material or assembling products of industry is known as an industrial building. These structures are low processing to medium-rise steel structures usually characterized by large spans and high clearance. The roofing system for such buildings is Truss, purlins, Columns, and Corrugated sheets. Purlins are beams provided over trusses to support corrugated sheets. Spans between top chords of two adjacent roof trusses.

A truss is a located plan of straight interconnected structural members. Trusses generally convey axial loads. The individual parts are related at center points; the connections are supposed to be pinned. The external forces applied to the system and the reactions at the supports are normally applied at the joints. Exactly when all the components and applied forces are in a proportional plane, the structure is a plane or 2D truss. The principal force in every component in a truss is axial tension or compression. [1]

The main Components of a Roof Truss are

- **Chord:** Fundamental members that structure the framework of the truss and subject to generally huge axial forces and bending moments.
- **Bottom Chords:** The most reduced longitudinal member of a truss.
- Top Chord or Rafter: horizontal part that builds up the upper edge of a truss.
- **Clear Span:** Horizontal distance between interior edges of supports.
- **Heel: The p**oint on which top and bottom chord intersect.
- **Joint:** Point of intersection of webs with a chord.
- **Node:** the point at which members and panels of truss intersect.

- **Nominal Span: the h**orizontal distance between outside edges of the supports usually the tie beam length.
- Panel: Support fragment characterized by two neighboring joints or nodes.
- Web: Members that join the top and base chords to shape a three-sided design.

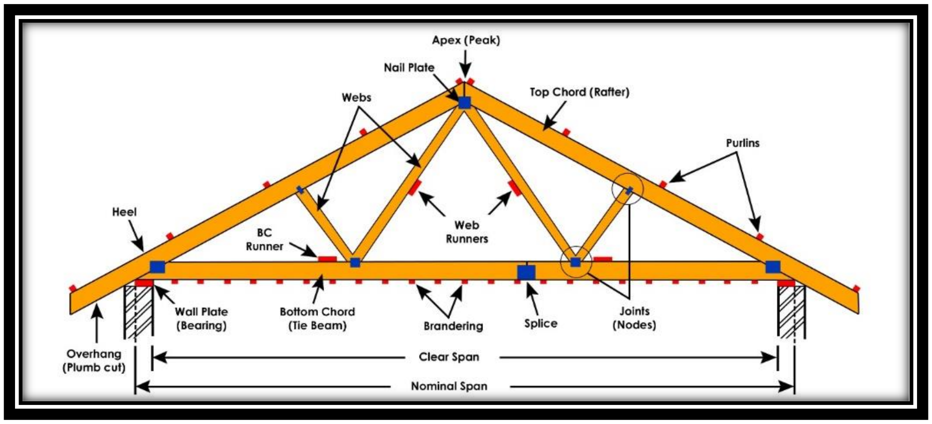

Figure 1.1 components of Truss [11]

1.1 Problem statement:

Design of roof structures for industrial buildings comprises of following steps.

- Calculate various loads (Dead loads, live loads and wind loads) which acts on roof.
- Type of suitable truss and truss spans/nodal distances.
- Analysis and Design roof truss and its component.

1.2 Aims and Objectives

The main aim and objective of the project are to design a safe and economical industrial building. Assuming you have a future construction project, one thing you should consider is the roof truss. That is because of roof truss type you select, will significantly affect the purpose of your roof truss. The significant choice you may need regards to the decision of the roof truss is the material. Normally, roof trusses are produced using two significant materials: steel or wood. Every one of these materials has its points of interest and defects. But, steel roof trusses achieved fame over the ongoing past even in residential structures due to their numerous advantages. There are some of the ways you stand to achieve by investing in steel roof trusses. Some of the significant focuses are as follow [2]

Durability: Development activities can be costly. Thus, it is basic to utilize materials that will endure forever. Steel roof trusses are extremely strong as compared to timber. Steel is commonly more durable than timber, which improves its capacity to withstand effect and components for a more extended period.

Lightweight: Something else that makes steel a favored material for roof truss is its lightweight property. Steel is more lightweight than timber, a component that proves to be useful during transportation and establishment. Taking care of lighter materials during transportation and establishment is typically simpler, and this can regularly mean decreased task costs.

Flexibility in Design: steel trusses are pre-assembled in processing plants, which makes it simpler to accomplish any shape or plan for your roof truss. That implies steel roofs can be utilized to suit any architectural appearance or concerns. With timber roof truss, though you have restricted options with regards to design.

No Span Restrictions: Range limitations are basic with wood trusses, which can just range to a restricted length. Steel truss, then again, have no restriction with regards to span. This makes them ideal for use in structures where large spans must be secured without the obstacle of structures, for example, segments.

Fire Resistance: Steel has a higher imperviousness to fire limit than wood. Suppose that you are developing your structure in a zone that is inclined to bushfires, steel trusses are the ideal alternative to go for.

Pest Resistance: A typical issue with timber materials is the pest's infestation, particularly termites. Termites and other wood-exhausting pests are exceptionally damaging and can influence the integrity of the structure. While you can generally treat your wood with bother safe items, this would mean greater expenses of preservation or maintenance. Steel roof trusses aren't helpless to such issues.

CHAPTER II

Literature Review

The analysis of structures comprises basically of mathematical modeling of the response of a structure to the applied loading. Such models depend on the idealization of the structural characteristics of the material. They are in this manner defective to a bigger or little degree, controlled by the degree of imprecision with the suppositions in modeling. This is not to refer that the calculations are useless, rather indicate the fact that the assessment of structural responses is the best estimate that can be attained in the light of the suppositions contain in the modeling of the system. Some of these suppositions are needed in the light of incomplete data; others are introduced to simplify the calculation step to financial levels.

Manual methods of analysis may be utilized to analyze the stresses, especially in simple trusses. For simple, statically determinate trusses, methods of analysis are

- Joints method,
- Graphical analysis
- Section method.

Computers are these days promptly accessible to designers and give valuable methods for analyzing the most complex trusses. Moreover, joint and member rigidities can undoubtedly be integrated into the modeling. So avoiding laborious hand calculations in determining moments caused by joint deformations. Local stresses produced by loads not applied at the panel points, joint eccentricities, and axial deformation should generally be calculated and superimposed on the direct stresses.

2.1 Structural Design

The principle aim of structural design is to design a safe structure that will assure its expected purpose. The structure should be able to withstand the forecast loading for its whole design life with enough margin of safety.

The other factors that should also be included in the design stage are

- Economy
- Safety
- Erection
- Transport

2.1.1 Computer Aided Analysis and Design

It is the wide use of computer programming to help in building analysis and design jobs. It contains finite element analysis (FEA), computational fluid dynamics (CFD), multibody dynamics (MBD), and optimization.

Software used for structural analysis and designs is ORION, STAAD Pro, ETABS and ABA, etc.

2.1.1.1 SAP2000

SAP2000 is general civil engineering software used for the analysis and design of any type of structure. i.e. steel structures. The fundamental and advanced system ranges from 2D-3D, of simple geometry to composite, may be modeled, analyzed and design. Made by engineers for successful building, SAP2000 is the ideal software for clients of any experience level, planning any basic framework. SAP2000 is additionally a great mechanism for education. From a little 2D static frame analysis to a huge complex 3D nonlinear unique analysis, SAP2000 is the most profitable software used for structural analysis and design.

2.2 Steel

The flexibility of steel for essential applications that it can be easily supplied at a relatively low cost in a broad range of different product forms, and with a beneficial range of material properties. Important to understanding the flexibility of steel lies in its fundamental metallurgical behavior. Steel is a productive material for main causes due to its great strength-to-weight proportion. Steel can be provided with quality levels from about 250N/mm2 up to about 2000N/mm2 for regular structural applications, although the quality necessities may restrict the item structure. Item frames go from slim sheet material, through enhanced structural segments and plates, to substantial forgings and castings of complicated shape. Although steel can be made to a wide scope of strength it generally acts as an elastic material with a high (and moderately steady) estimation of the versatile modulus up to the yield or proof quality. It also has a high limit for accepting plastic deformation after the yield quality, which is significant for drawing and framing of various items, just as for general ductility in structural applications. [8, 9]

Although steel is such an attractive material for a wide range of utilization, two specific issues which must be given cautious consideration are those of corrosion behavior and imperiousness to fire, Corrosion execution can be fundamentally changed by decision of a steel of appropriate chemical composition and warmth treatment, just as by corrosion protection measures. An ordinary structural steels hold their quality at temperatures up to about 300 °C, there is a reformist loss of strength over this temperature so that in an intense fire, exposed steel may lose the significant aspect of its basic quality. While the hot quality and creep quality of prepares at high temperature can be improved by extraordinary chemical formulation, it is typically less expensive to give fire security to ordinary structural steels by defensive cladding. [6]

2.2.1 Properties of steel: [7]

- Strength: Steel is solid, intense, and adaptable accordingly, and can withstand weighty burden. The quality of steel is a lot more prominent than that of wood.
- Durability: steel, keeps up toughness inconclusively; that is, it doesn't decay, gave its surface is shielded from rusts.
- Heat conductivity: steel is a decent conductor of warmth.

2.2.2 Rolled Steel Sections

Rolled sections are accessible in different structures for use in steel development. The shape, size, and properties of these sections are examined. It is one of the significant materials in the development industry. It may be utilized from numerous points of view for some reason.

Different steel sections are fabricated in the processing plants depending on their utilization. They are cast in persistent projecting molds with no joints. Various shapes or types of rolled steel sections are clarified beneath. [10]

i. T sections

ii. I sections

iii. Angle Sections

iv. Channel sections

v. Round bars

vi. Tube sections

vii. Corrugated sheets

viii. Flat bars

ix. Plates

x. Expended metals

xi. Ribbed bars (mild steel)

xii. Ribbed bars

xiii. Welded wire fabrics

xiv. Thermo-mechanically treated bars

I-Sections: I-section which are also known as steel beams or rolled steel joists are broadly utilized as pillars, lintels, segments and so on it comprises two ribs and web associated. These are accessible in different ranges sizes from 75.00 mm x 50.00 mm at 61.00 N for every meter length to 600.00 mm x 210.00 mm at 995.00 N for each meter length.

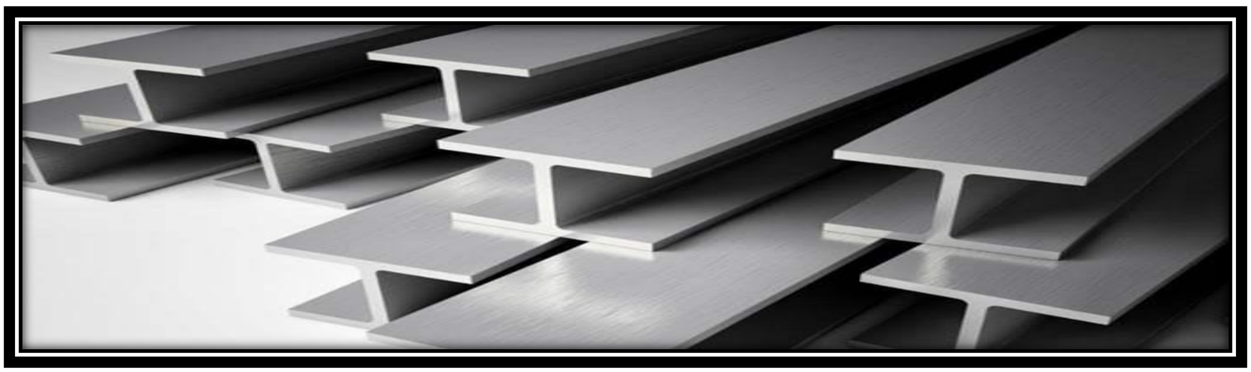

Figure 2.1 I-Sections

I - section is either used for universal beams or columns.

Corrugated sheets Plain steel sheets are gone through machines that produce twists by squeezing them known as corrugation. These sheets are utilized in rooftop covers.

Figure 2.2 Corrugated

2.2.3 Advantages of Steel as roofing material:

Following are sure points of interest of steel which add to appeal in the utilization of steel as roofing material; [4]

- Steel can be reused; that is steel segments can be utilized over and over without influencing the earth.
- It has a low support cost when contrasted with Timber.
- Steel has life span and strength over both a short and significant stretch of time.
- It has a high caliber and stylish.
- Steel has dimensional points of interest thus it is famously utilized in the development of long range rooftops.
- Steel is solid and adaptable thus can withstand weighty burden.

2.2.4 Disadvantages of Steel:

Disadvantages of using steel as industrial building material are [4]

- Availability: Steel isn't promptly accessible and must be imported which makes it to be more costly to procure.
- Labor: Steel rooftop required particular gifted work to deal with and these are not effectively gotten.
- Time consuming: The utilization of steel as a roofing material is tedious because of the utilization of screw, fasteners, and nuts.
- Corrosion: steel is helpless to consumption consequently steel structures presented legitimately to air must be painted constantly.
- Mobility: Steel is weighty and hence costly to ship.

CHAPTER III

Methodology

The analysis and design the roof of an industrial building using SAP2000.while designing the roof truss following points are under consideration.

Spacing of truss**: (**distance between two consecutive trusses)

- If truss span is less than 15meter then spacing is 3m-5m.
- If truss span is 15m-30m then spacing is 4.5m-6m.
- If span is greater than 30m then spacing is 12m-15m.\

Purlin: it is supported on the panel point of two consecutive roof trusses. Its function is to support roofing sheets as well as to stiff the entire roof structure.

Spacing of roof truss	**Type of steel section**
Small(3m-4m)	Angles
Medium(4m-5m)	Channels
Large(>5m)	I-section

Table 3.1 Table of roof truss spacing

There are four methods of solving truss (analysis-design)

- Joint's Method
- Section's Method
- Maxwell Diagram
- Computer Modelling, Analysis & Design

3.1 Analysis and Design

The step by step procedure for analysis and design an industrial building using SAP2000 is as follows

All the dimensions of the industrial building are shown below

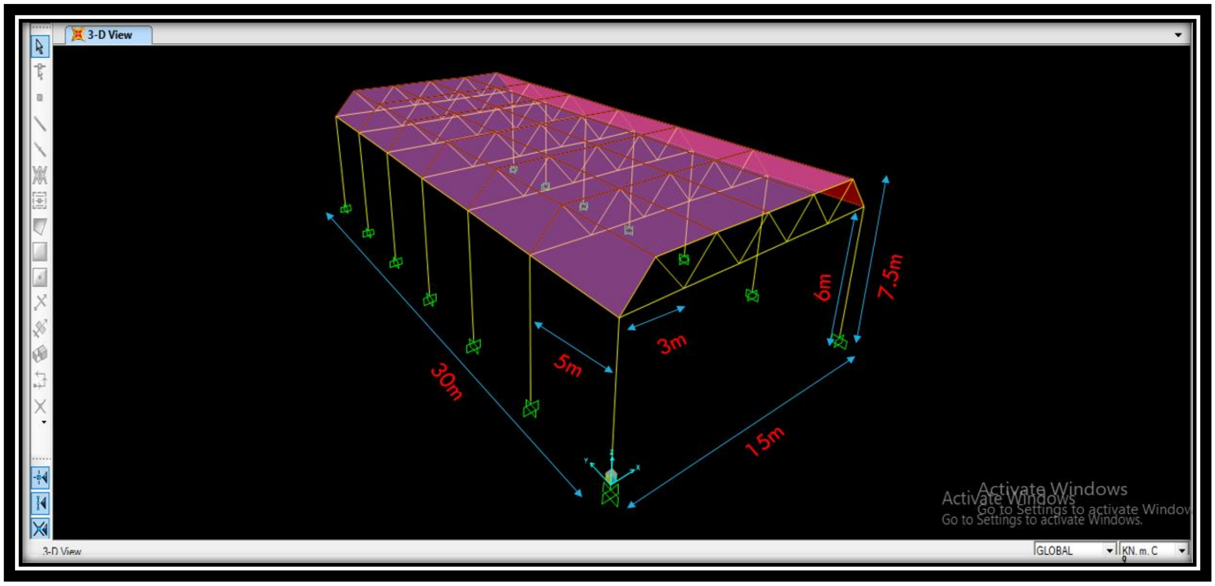

Figure 3.1 Dimensions

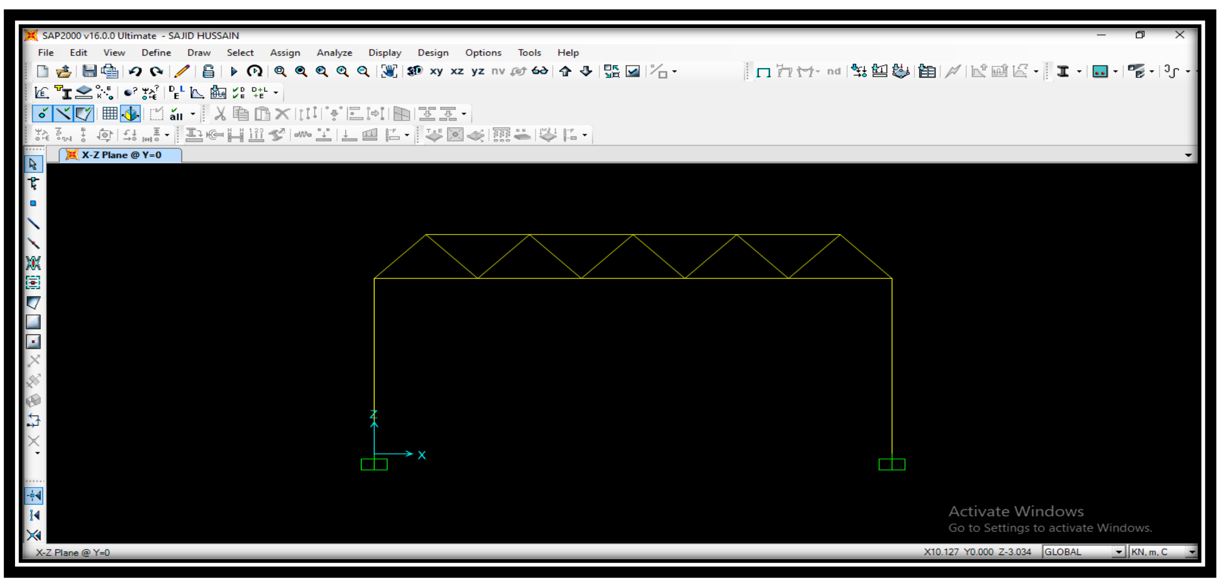

Figure 3.2 warren truss

When SAP2000 is open it displays the following interface window:

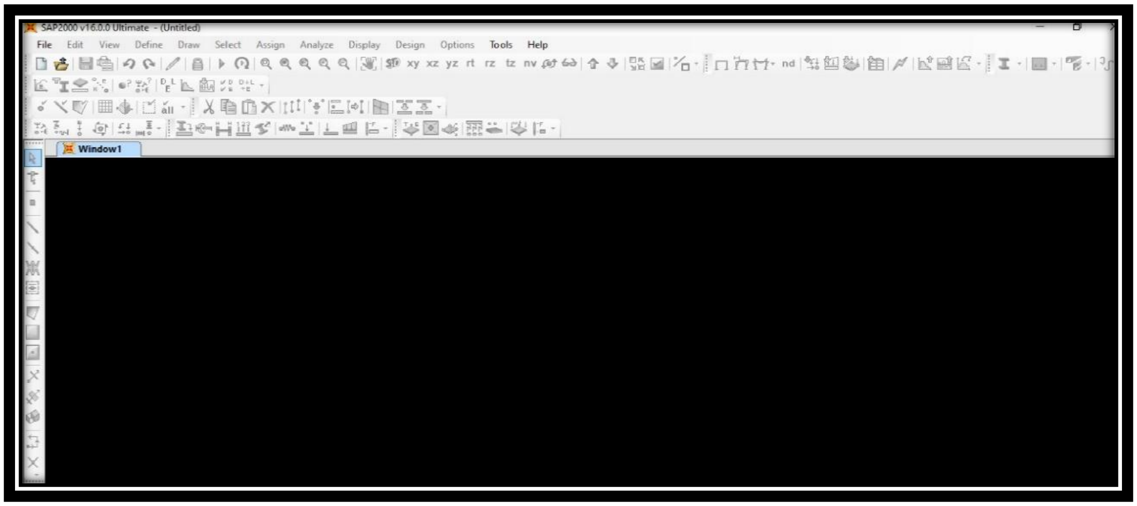

Figure 3.3 SAP2000 interface window

3.1.1 Step 1: Set Units

Set the ideal units for the design. In this design, units are meters (m) and kilo Newton (KN).

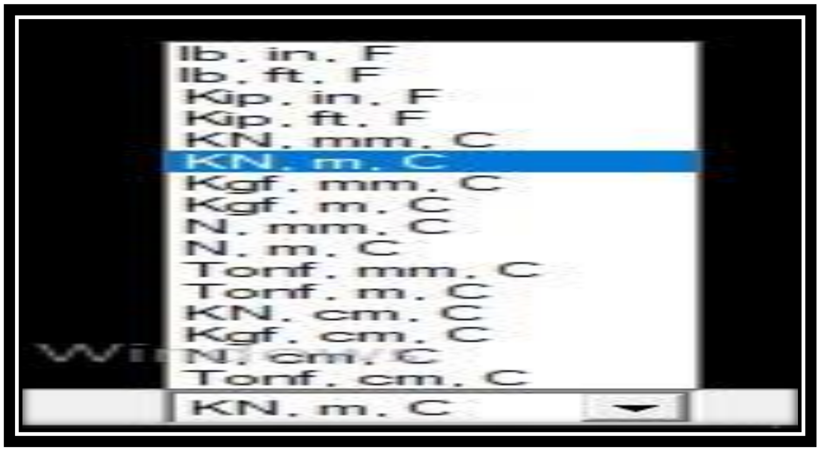

Figure 3.4 Units

3.1.2 Step 2: Grid Spacing

Decide the proper number of grid line and grid spacing. To make another model, select New Model under the File menu.

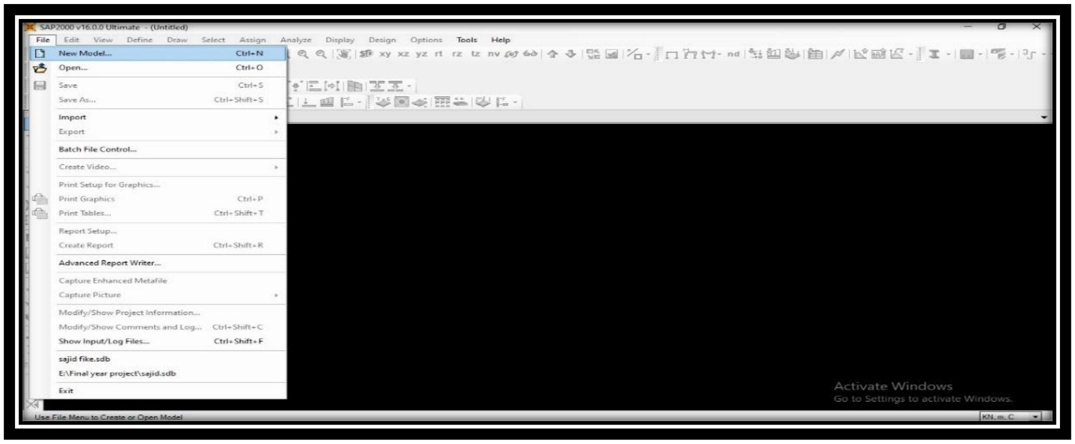

Figure 3.5 New Model

Pay attention to that SAP2000 expect the two-dimensional structure in the x-z plane.

Characterized the lattice framework by entering information on the Coordinate System Definition window. For the support appeared over, the framework separating in the x direction is 3m. The quantity of framework spaces in the y and z directions are 5m and 7.5m, respectively.

At the point click on OK, SAP2000 creates the lattices line that have quite recently characterized and shows the framework in the SAP2000 interface window.

Of course SAP2000 show two perspectives on concern, normally a 3-D view and x-y plane view.

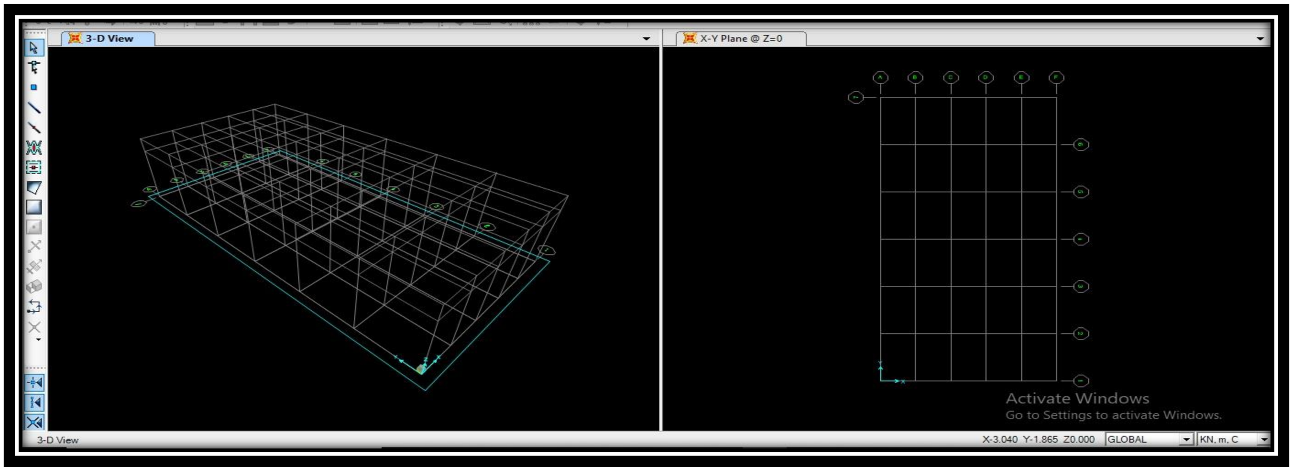

Figure 3.6 grids

3.1.3 Step 3: Define material properties

In this design, A36 steel is define for corrugated sheet and A992Fy50 is define for purlins, trusses and columns.

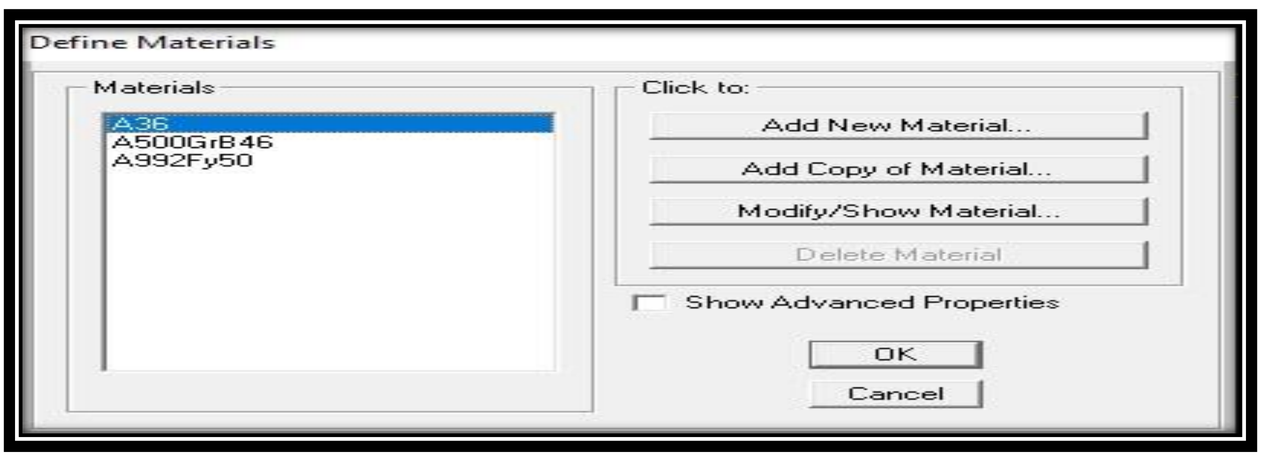

Figure 3.7 material properties

3.1.4 Step 4: Define Frame Sections

W8X67is defined for purlins and W12X14 to W12X336 is for TRUSS members and columns

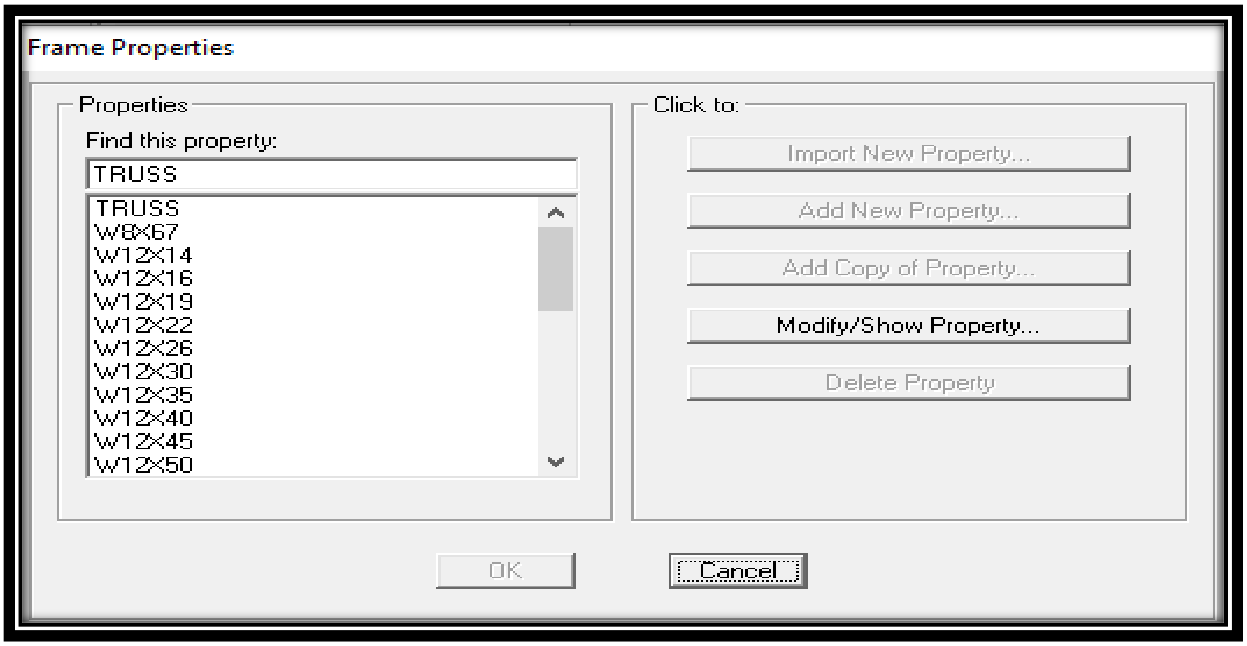

Figure 3.8 Frame properties

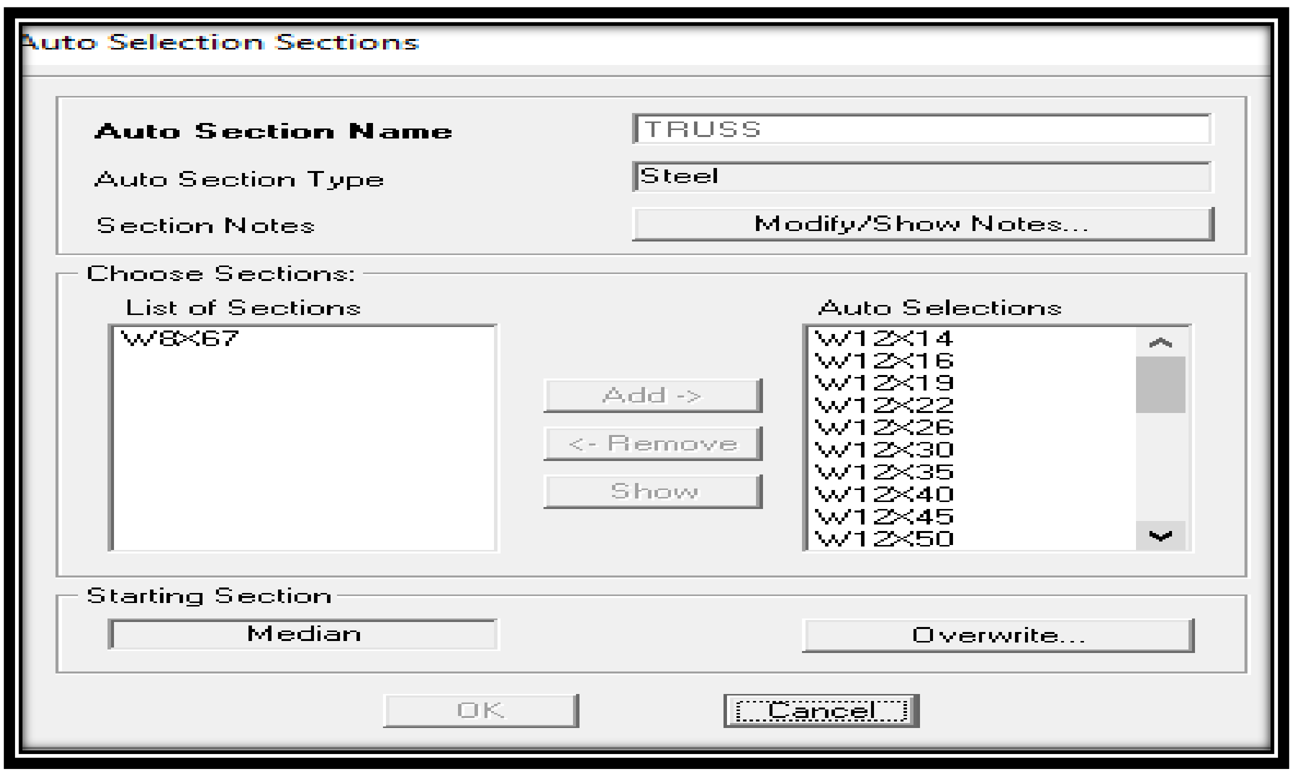

Figure 3.9 Auto Selection Sections

3.1.5 Step 5: Draw frame elements

Select the Draw Frame Element button on the left bar. To characterize a component, click on a joint toward the start of the component and afterward on the joint toward the finish of the component. To end a progression of components press Esc button. For this plan, the frame components are demonstrated as follows:

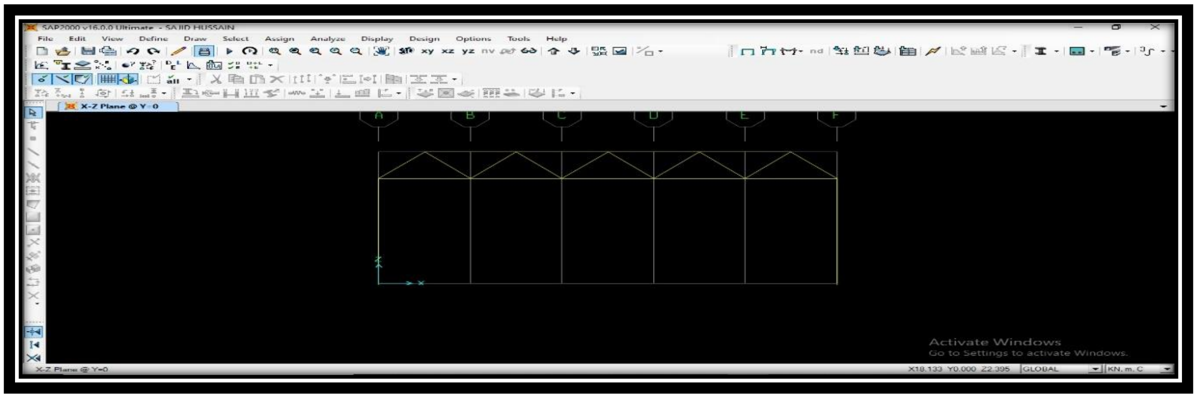

Figure 3.10 frame elements

3.1.6 Step 6: Define supports

To characterize the location and sort of basic support, select the support location by tapping on the joint with the pointer. A yellow "X" ought to show up at the joint to demonstrate that it is presently chosen. Next snap on the Joint Restraint button on the bar. The Joint Restraints menu will show up as appeared.

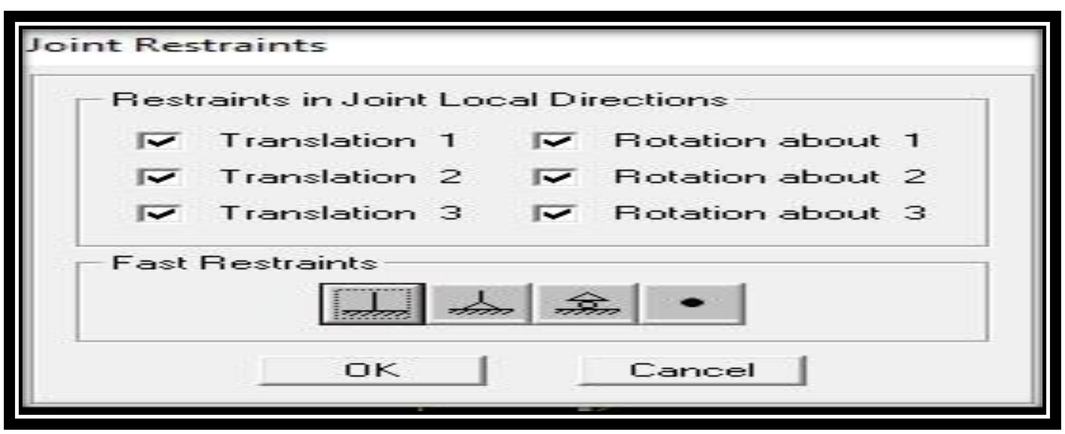

Figure 3.11 Joint Restraints

SAP2000 display the joints in interface window as follows:

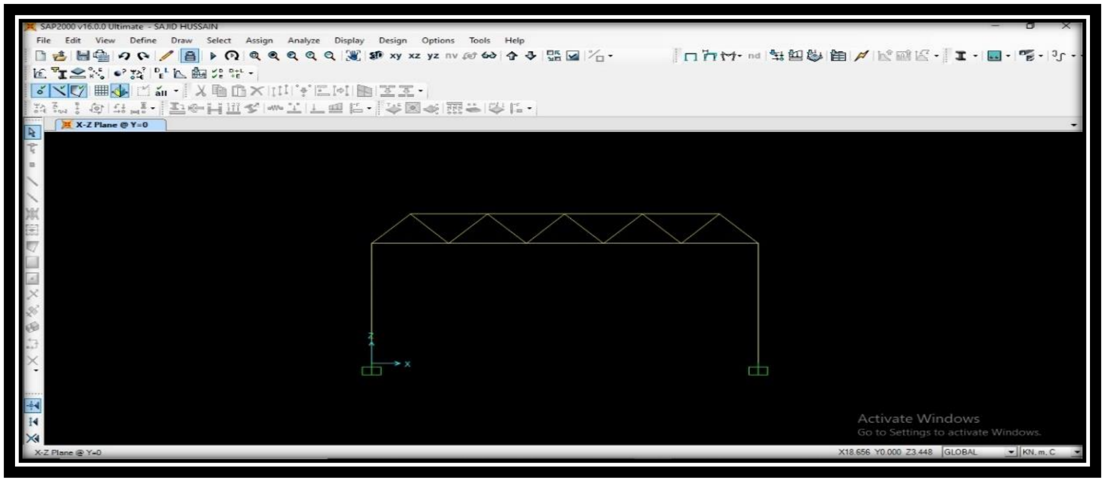

Figure 3.12 Display joints

3.1.7 Step 7: Internal moments releases at joints

SAP2000 expect that all structures are frame. Consequently, to analyze a truss the designer should change over each joint from a fixed association with a pin association. To guarantee that each joint in the structure is pin associated, select all the individuals by clicking all the support individuals. Next snap on Assign menu and select Frame at that point Releases and the Frame Releases window will show up.

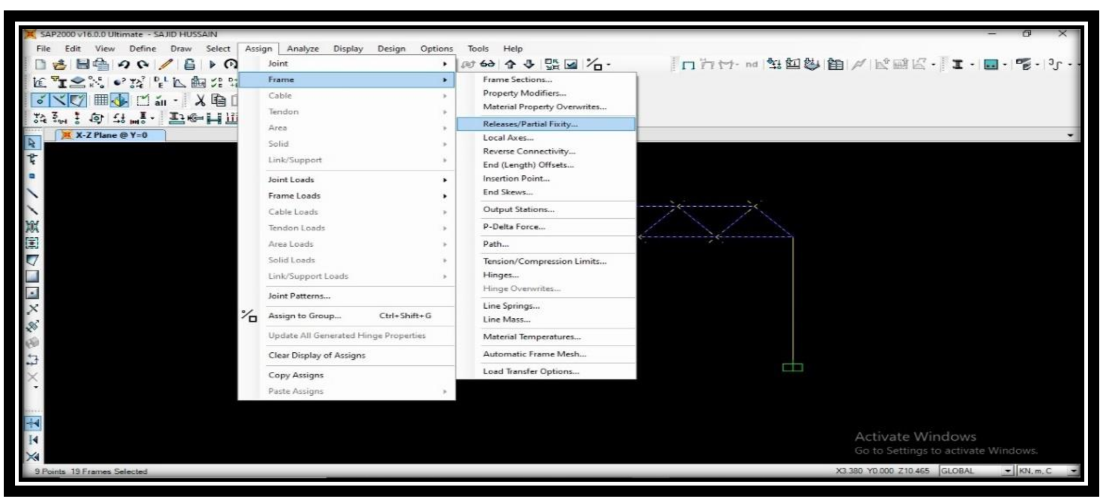

Figure 3.13 release partial fixity

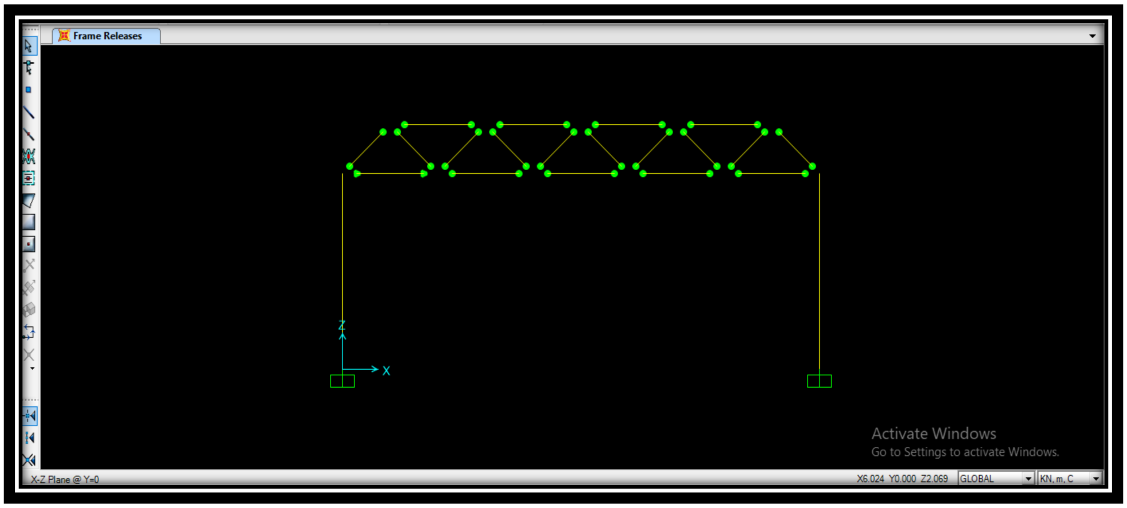

Figure 3.14 release moments at joints

3.1.8 Step 8: Assign Loads

- Live Load
- Windward Load
- Leeward Load

3.1.8.1 LIVE LOAD:

Live load is also known as applied or imposed load. It can be expressed as a uniformly distributed load (UDL). In this design live load is 0.98KN/m^2 taken from LRFD design aid. [5]

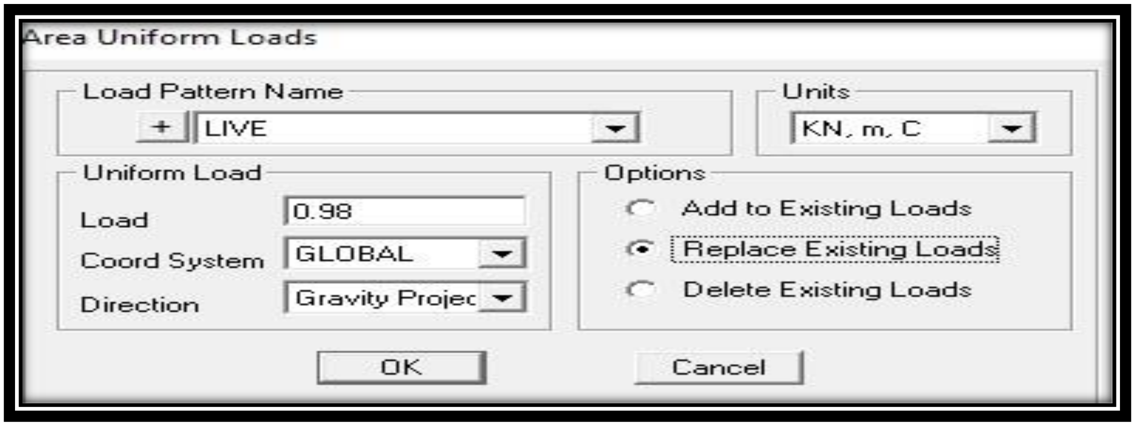

Figure 3.15 Live load

When live load applied, interface window of SAP2000 is shown as

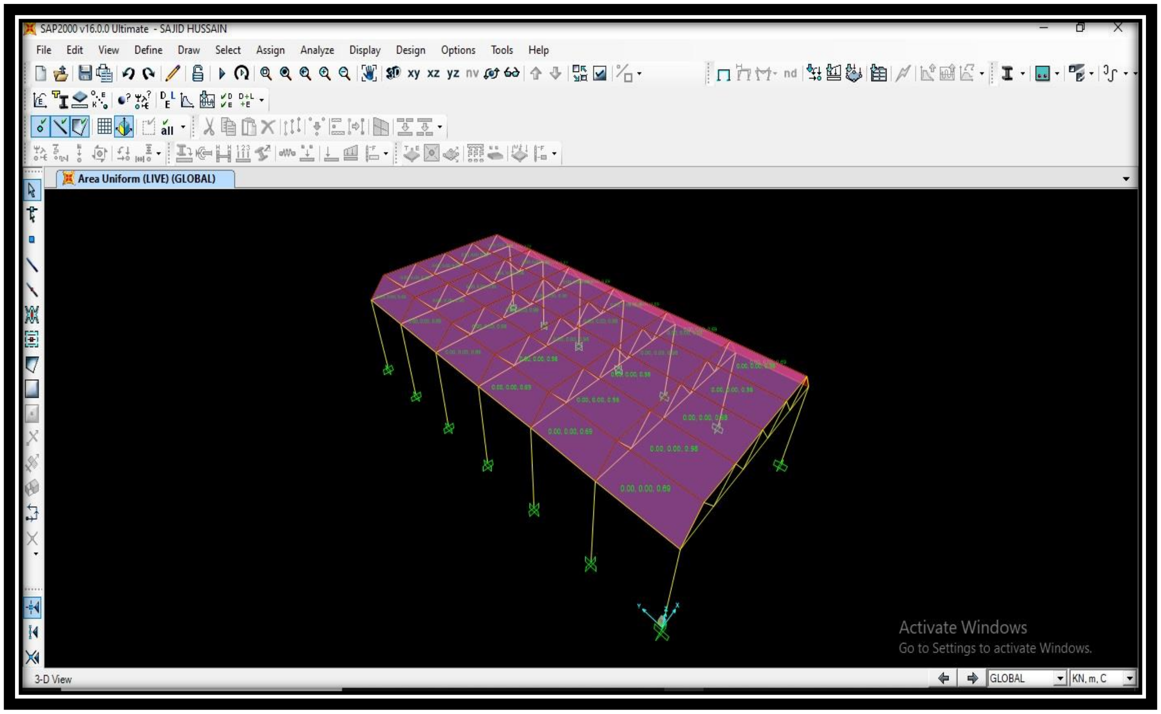

Figure 3.16 3D view Live load

3.1.8.2Wind Load:

In the design of an industrial building, calculation of wind load is important. [1]

P = 1250 C_q

Leeward wind pressure=1250(-0.7) =-875N/m^2 = -0.875KN/m^2

Windward wind pressure= 1250(-0.9) = -1.13KN/m^2

Panel wind load on leeward side = P_{wl} = (-0.875) (3/cos30) x 3 = -9.09KN/m^2

Panel wind load on windward side = P_{ww} = (-1.125) (3/cos30) x 3 = -12.21KN/m^2

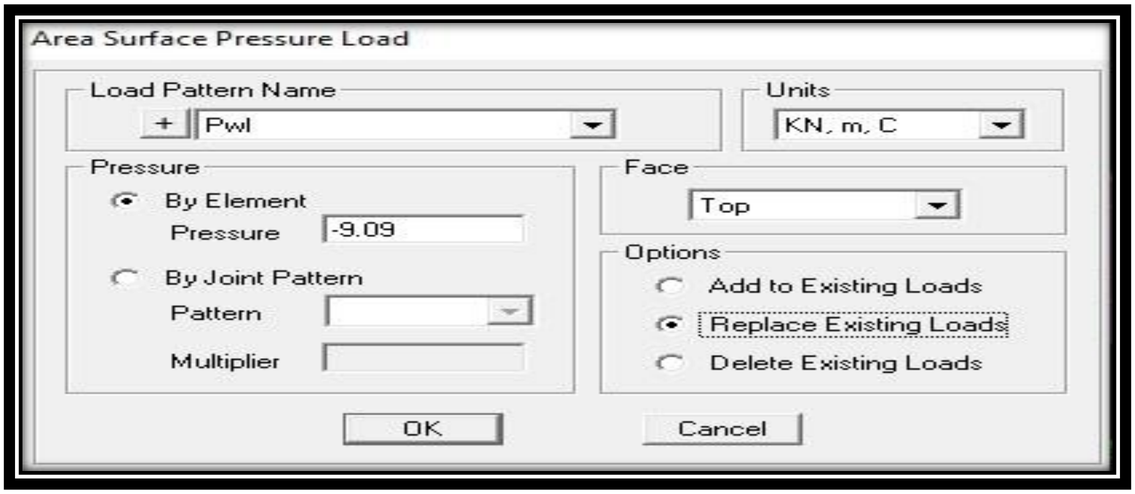

Figure 3.17 Leeward wind load

The figure below shows the applied loads on windward side and leeward side

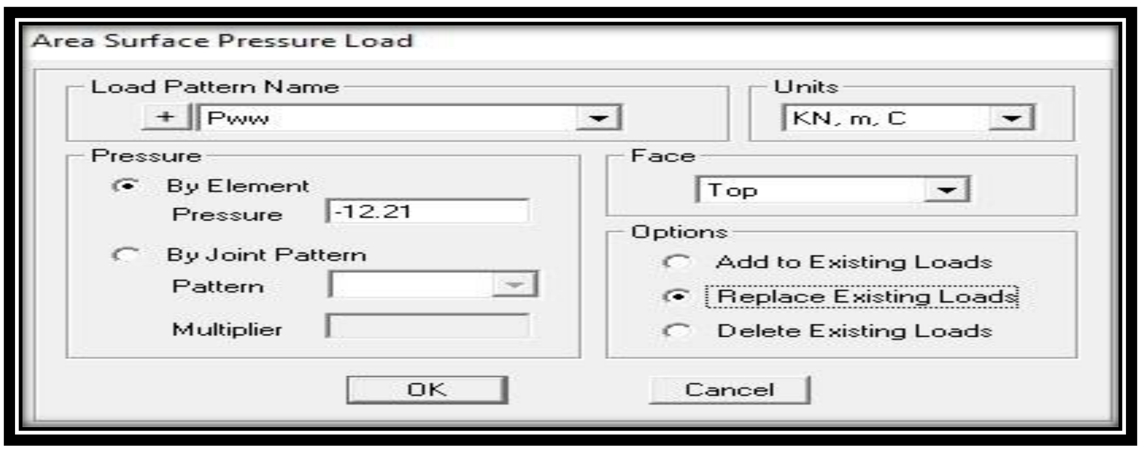

Figure 3.18 Windward wind load

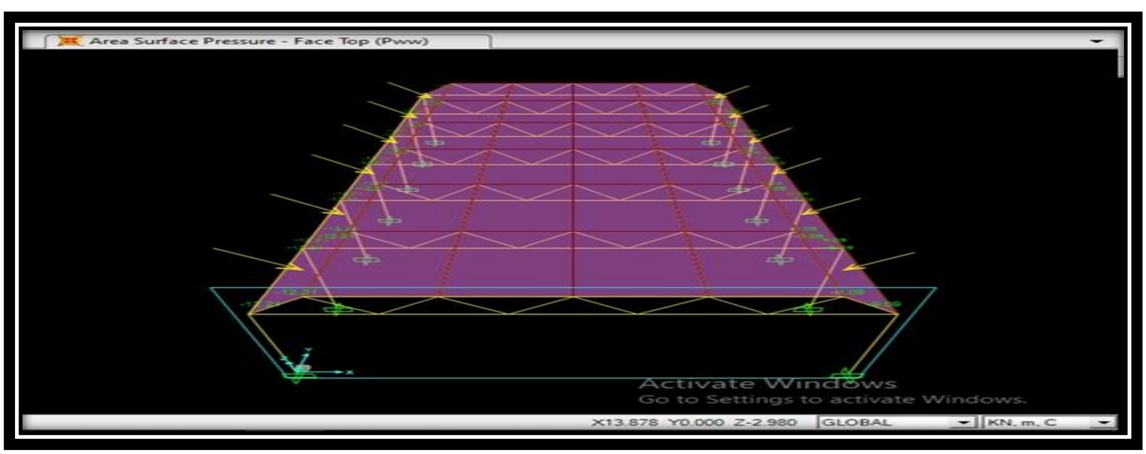

Figure 3.19 3D View of applied wind load

3.1.9 Step 9: Define load patterns:

The dead load (self-weight) of truss and live load was taken from LRFD design aid and wind load is calculated manually as discussed above.

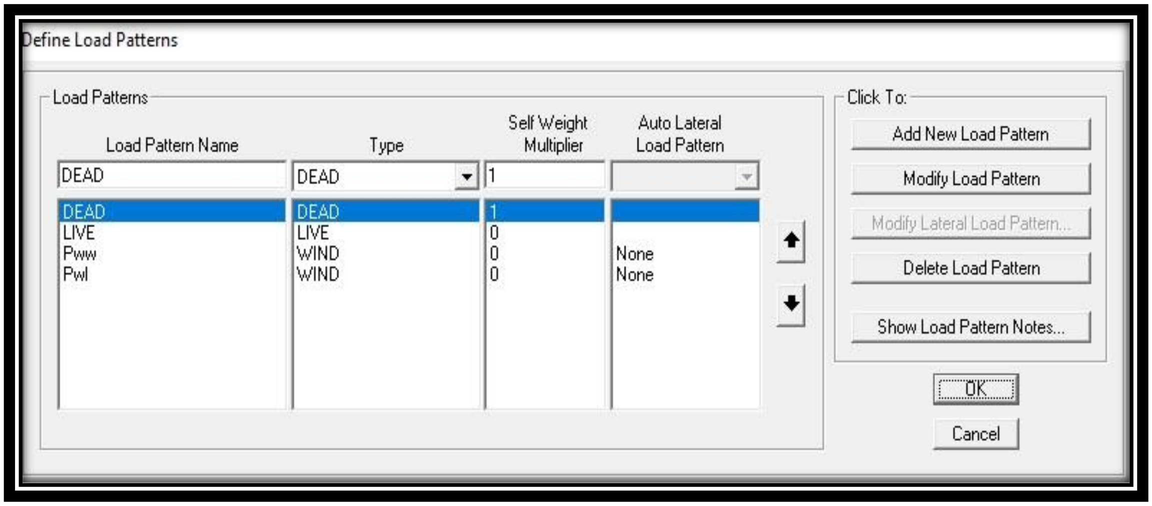

Figure 3.21 load patterns

3.1.10 Step 10: define load combinations

There are three load combinations as shown in figure below

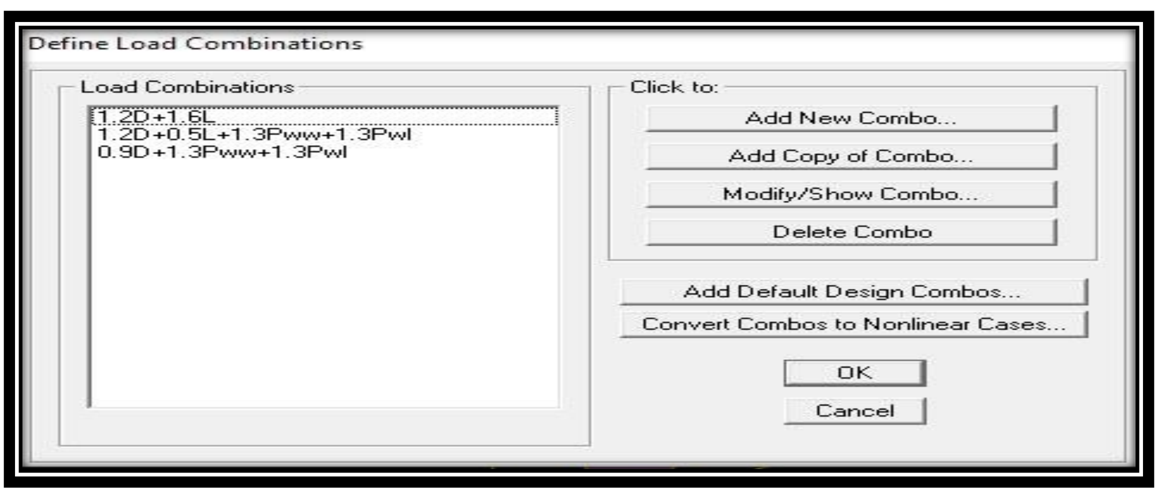

Figure 3.22 load combinations

3.1.11Step 11: Run Analysis

When all the components are defined, and loads are applied, the model has run for the analysis.

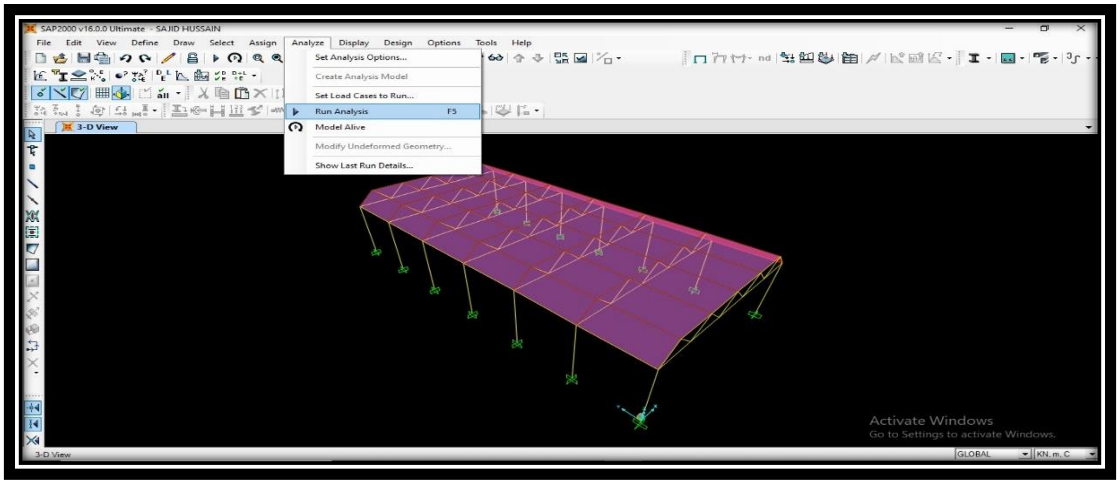

Figure 3.23 Run Analysis

When the analysis is completed, the deformed shapes of the structure displayed by the SAP2000 is shown below.

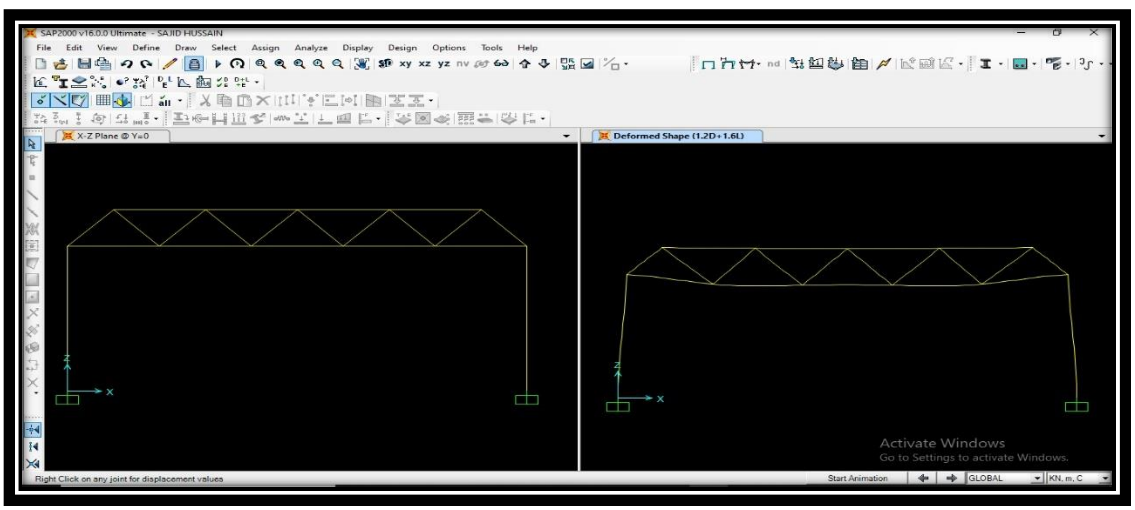

Figure 3.24 Deformed Shapes

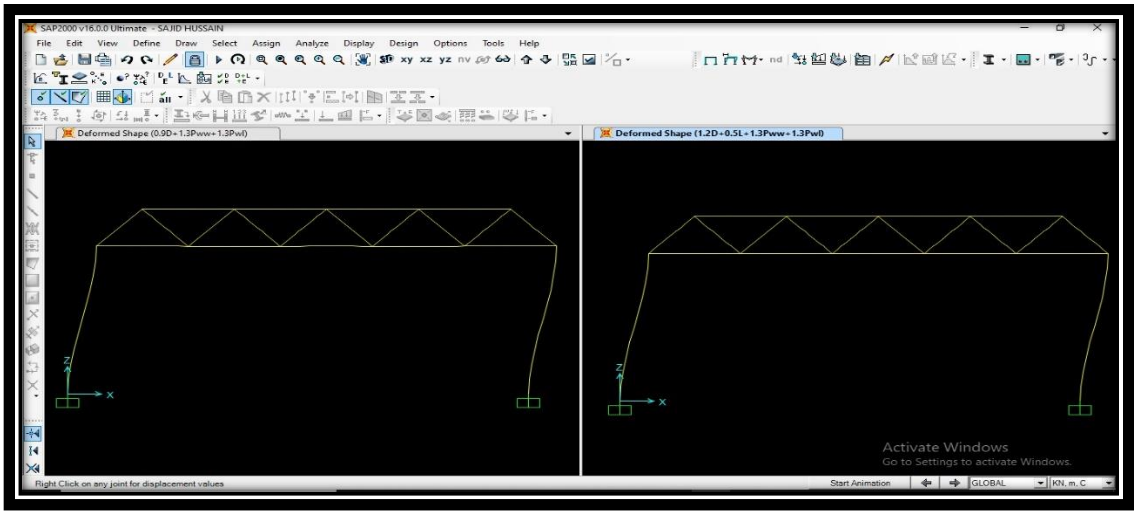

Figure 3.25 Deformed shapes

3.1.12 Step 12: Design

To design the structure, go to the design on the bar menu as shown in the figure below

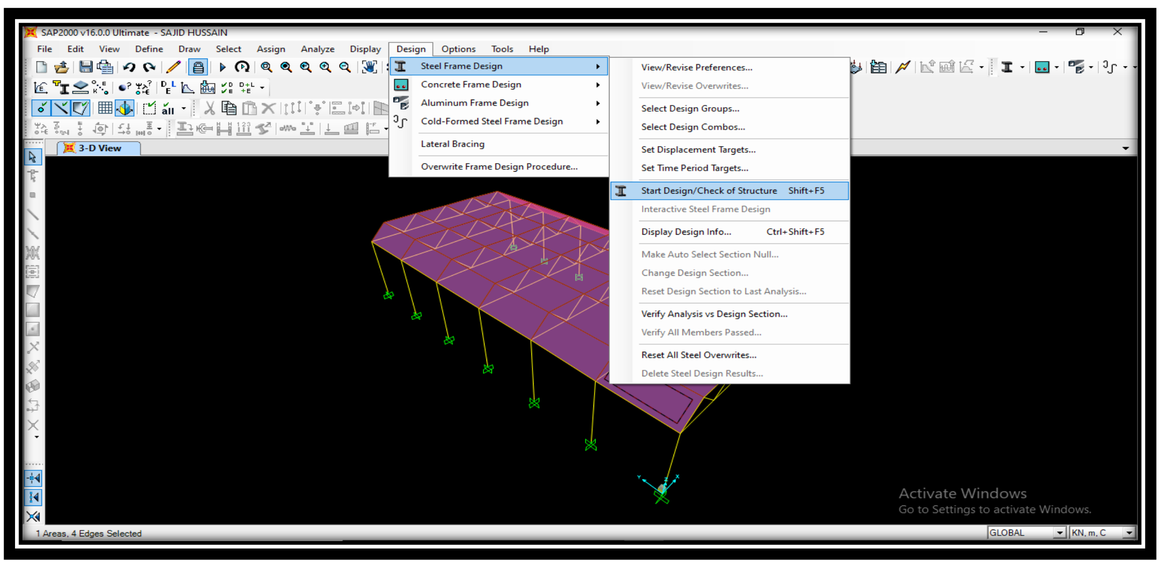

Figure 3.26 start design

Software automatically selected the suitable (economical) sections and all the sections are safe as shown below.

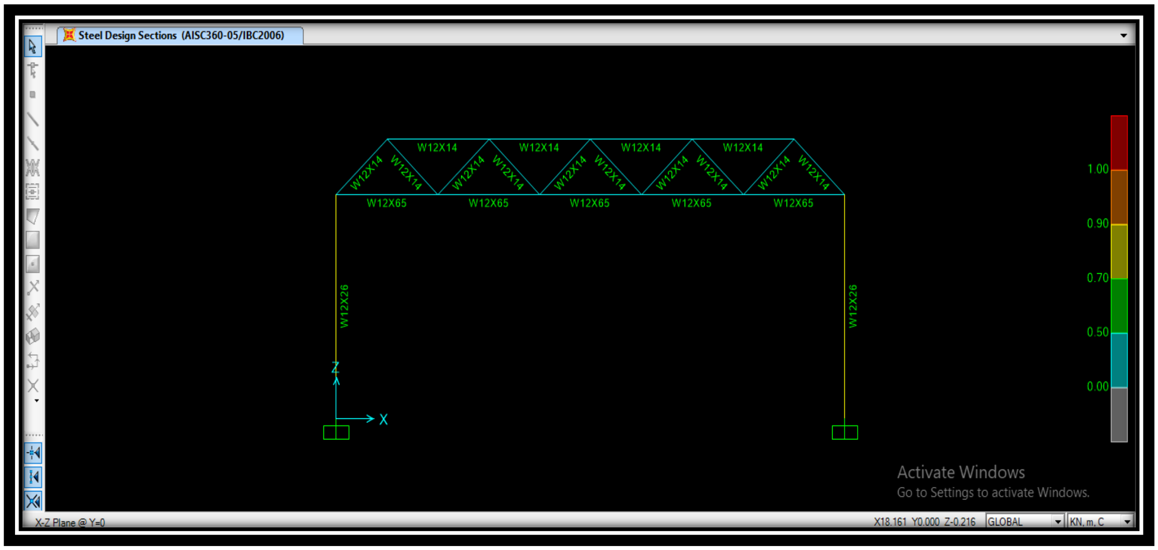

Figure 3.27 Design

CHAPTER IV

Results and Discussions

The safety of structure depends upon the loads acting on the structure because the acting loads produce axial forces, shear forces and bending moments in the structure which may cause failure of the structure. To verify the safety of structure see the stress/capacity check. SAP2000 display the result as all the members of the structure passed the check, then the structure is safe. The AFDs, SFDs, BMDs, Stress/capacity check and finalized sections are as follow

4.1 Axial Force Diagram for 1st load combination

The forces in blue color are positive axial forces and the members are in tension and the forces in red color are negative axial forces and the members are in compression as shown in figure 4.1

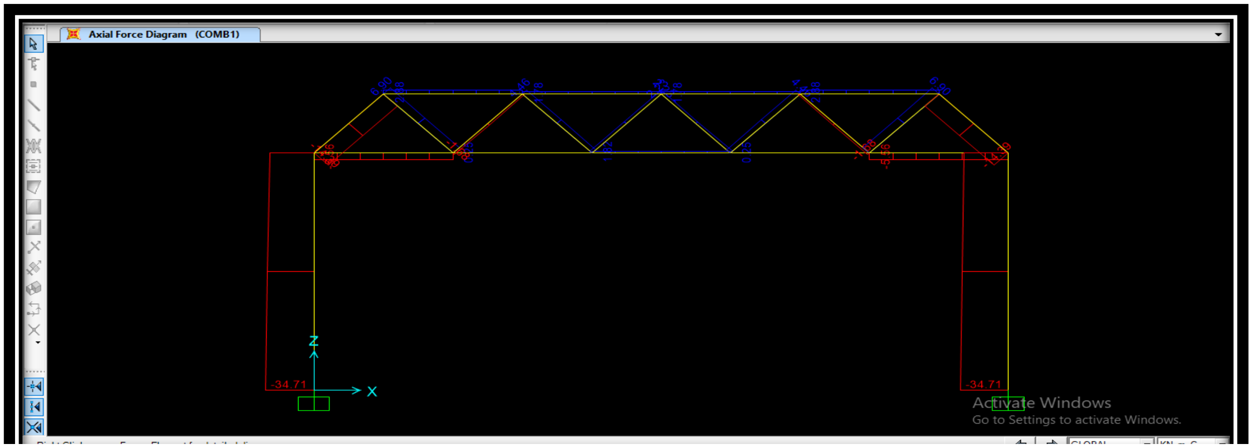

Figure 4.1 AFD for 1st load combination

4.2 Shear Force Diagram for 2nd load combination:

The forces in blue color are positive shear forces and the members are in tension and the forces in red color are negative shear forces and the members are in compression as shown in figure 4.2

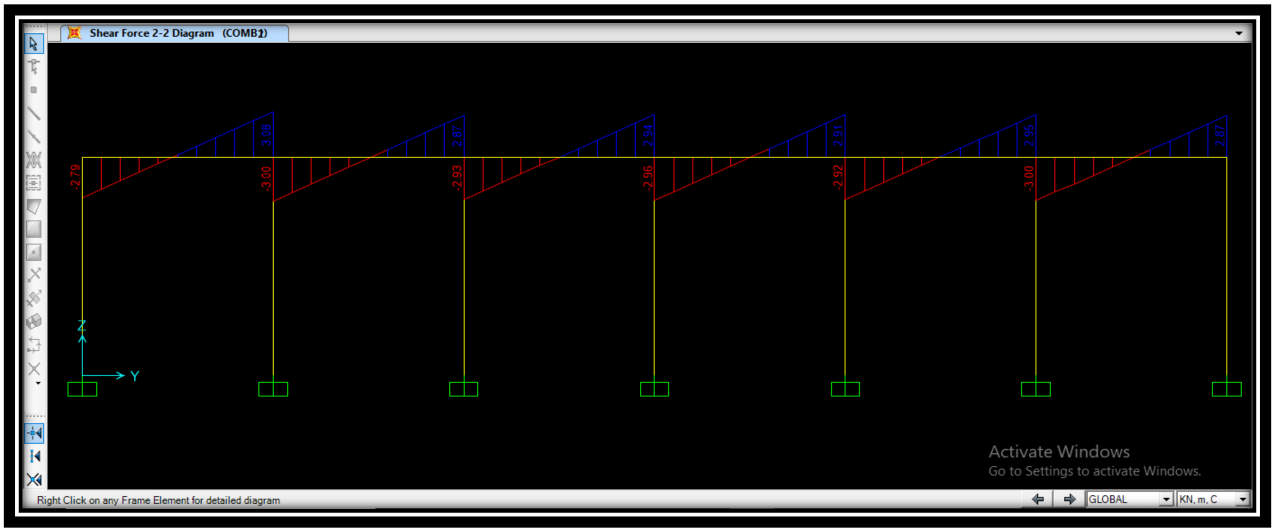

Figure 4.2 SFD for 2nd load combination

4.3 Bending Moment Diagram for 3rd load combination:

The moments in blue color are positive bending moment and the members are in tension and the moments in red color are negative bending moment and the members are in compression as shown in figure 4.3

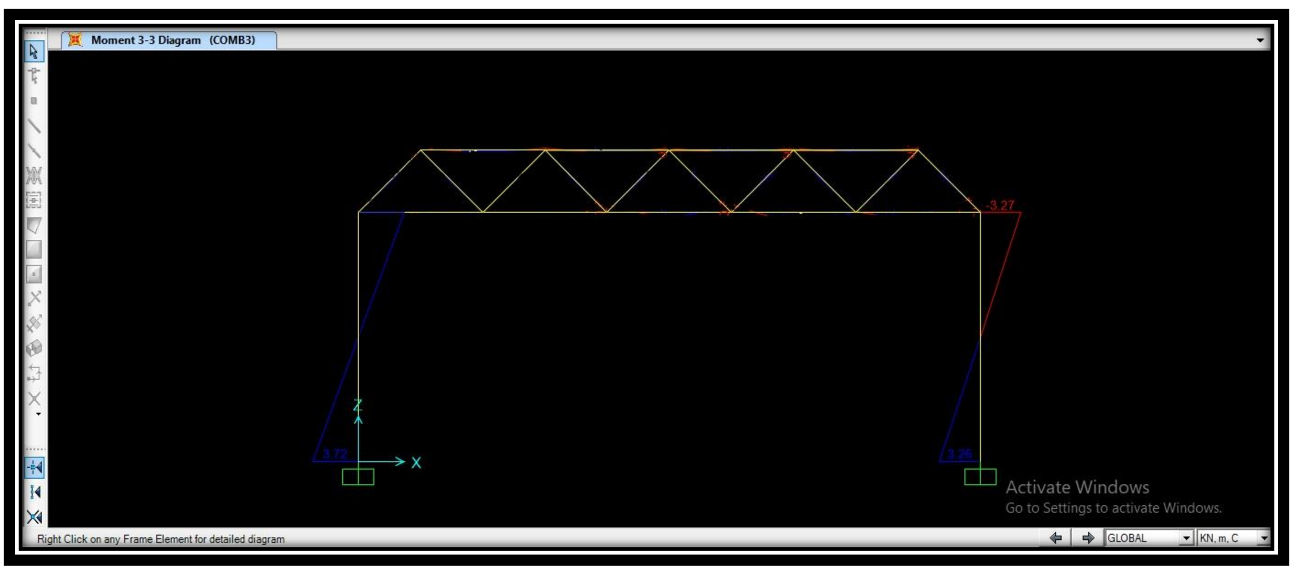

Figure 4.3 BMD for 3rd load combination

4.4 Stress/capacity check:

Go to design on command bar, steel frame design and click on verify all members passed as shown in the figure 4.4 below.

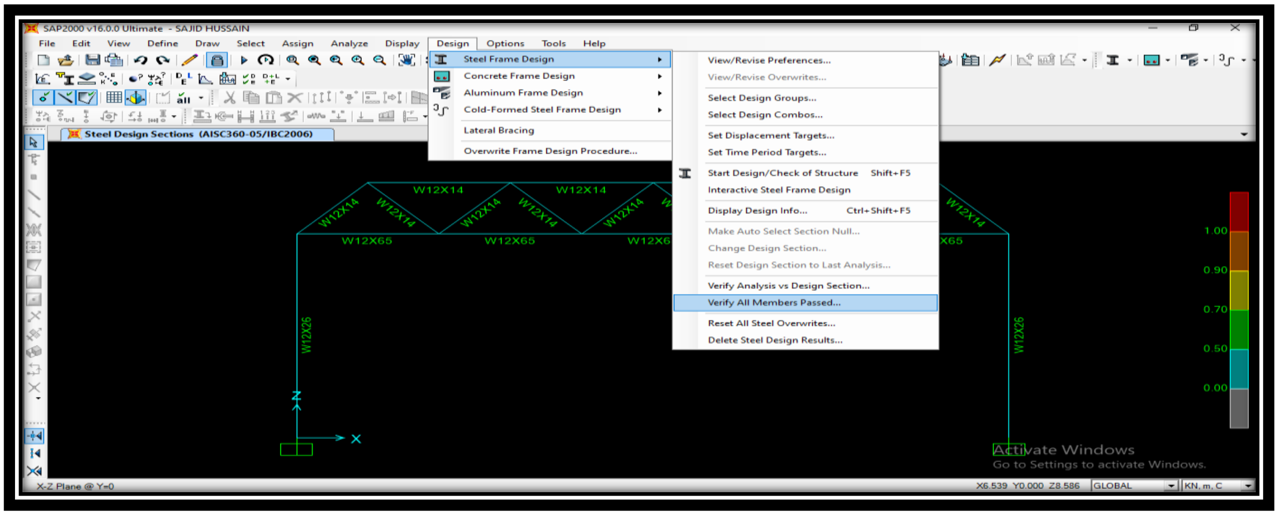

Figure 4.4 stress/capacity check

After clicking on verify all members passed then SAP2000 display the following window.

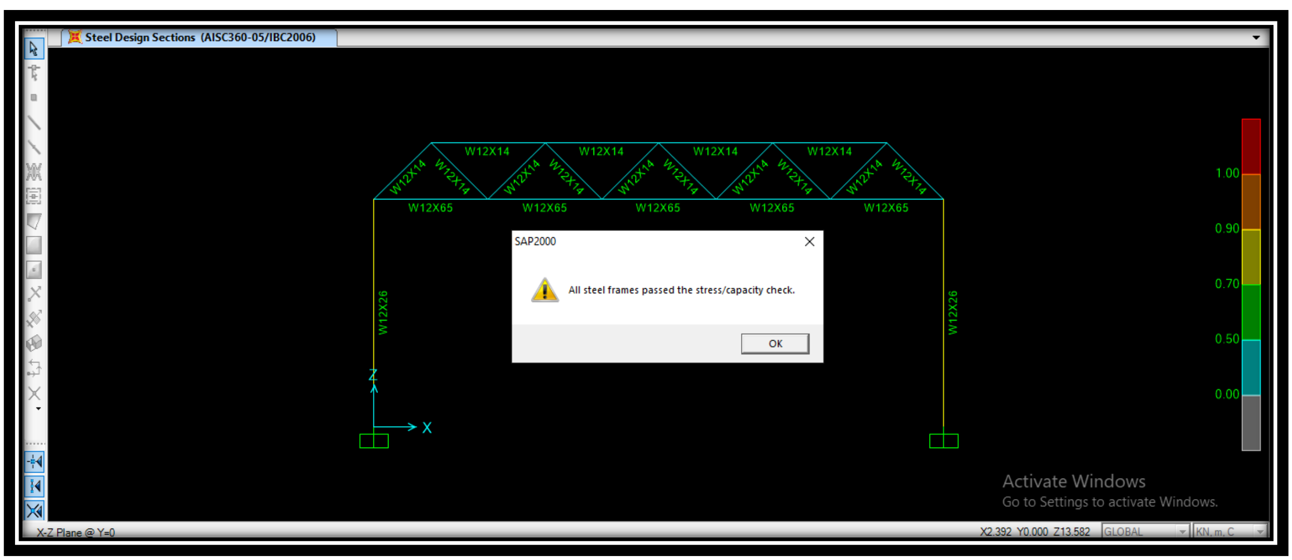

Figure 4.5 All members passed

All steel frames passed the stress/capacity check, so the industrial building is safe.

4.5 Finalized sections:

Truss(bottom chord)	W12 x 65
Truss(web and top chord)	W12 x 14
Purlins	W8 x 67
Columns	W12 x 26

Table 4.1 Finalized sections

CHAPTER V

Conclusion

A building structure utilized to store crude material or assembling products of industry is known as an industrial building. The roofing system for such structures are trusses, purlins, columns, and corrugated sheet. In this project, the performance of industrial buildings according to various loads such as wind load and live load has been observed. Wind load is a major force act on the roof of the industrial building. The basic wind speed applied on the roof, calculation of wind speed, wind pressure, and wind forces is explained and analyzed in software for the design of members of the industrial building. An analysis has been done on software to check the performance of the industrial building and the member forces in all directions including diagonal members. Keeping in view the different load cases is taken to work on the severe or critical phase of the industrial building, also applying different load combinations for taken critical situations on which members of the industrial building will be designed. The safety of structure depends upon the loads acting on the structure because the acting loads produce axial forces, shear forces, and bending moments in the members of the structure which may cause failure. To verify the safety of structure see the stress/capacity check. SAP2000 displays the result as all the members of the structure passed the check, then the structure is safe. The finalized section for top chord and web is W12 x 14, W12 x 65 for bottom chord, W8 x 67 for purlins, and W12 x 26 for columns, and all the members are safe. So the industrial building is economical and safe.

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