Chapter One

Introduction

1.1- General Introduction:

The need for large unobstructed space has led to the increase of the use of space structures. Building domes using space frames is actually quite simple. The struts are made from solid bars and they are connected together with solid balls that have fixing points machined into them. The space frame can be formed on either a flat or a curved surface assembled of linear elements so arranged that forces are transferred in a three-dimensional manner.The type of covering is an important component of each roof system and must conform to a strict set of requirements. Roof coverings must be lightweight, tough, water-tight, and incombustible.The stadia dome roof requires care in construction and design. Before the design the structure's analysis must be done. The most suitable method of analysis of these structures is the finite element method, which is a numerical technique used to obtain approximate solutions of linear and non-linear differential equations in engineering [1] .

The stability of space structures largely depends on the joints where the structural members are interconnected [2]. Joints in space structures can be broadly classified as rigid, semi-rigid or pinned. According to Chilton [3], the stability of rigid jointed space frames depends on the bending resistance of the joints for its structural integrity, while space truss structures depend on their geometrical configuration to ensure stability.A semi-rigid joint is generally subjected to three different forces; tensile force, compression and bending moment [4].Therefore in designing the joint, all this forces have to be considered. As stated by M. Hansson and P.Ellegaard pin-connected joint has a higher probability of failure as compared to the semi-rigid and rigid connections [5]. As stated and recommended by some researchers [Omer Alsied Ali Alnigey],the study of the effect of the joints type on the strenght and stability of roof domes is necessary.

1.2- Research Problem Statement:

This research is directed towards the study of the effect of the type of joints on the performance of space frames and specifically stadia dome roofs.The joints are considered to be pinned, rigid and semi-rigid. The effect of this on different types of stadia dome roofs that can adequately and safety transfer loads to the foundations is studied.

1.3- Objectives of study:

This study aims at achieving the following objectives:

1. To study the different types of Stadia Dome Roofs and the methods of analysis, design.
2. To study the linear finite element formulation of space frames by adopting the 3D Frame Finite Element.
3. To study the effect of pinned, rigid, and semi-rigid joints in the behavior of Stadia Dome Roofs using SAP Structuer Analysis.
4. To verify the results obtained and draw conclusions and recommendations by comparison of the results for specific Stadia Dome Roofs as case studies.

1.4- The Methodology of study:

To achieve the above objectives the research uses the following methodology:

1. carrying out a comprehensive literature review of Stadia Dome Roofs including their types, analysis, design and construction. The information sources were Books, research, papers in Journals, Dissertations and Theses.

2. Studying the Formulation of the 2-node, 3D frame finite element and using this element to study the effect of the joint type on performance of dome roofs.

3. Using SAP2000 -16 program in the analysis and design of the case study Stadia Dome Roofs with pinned, semi-rigid, and rigid joints.
4. Analysis and discussion of results and drawing conclusions and recommendations.

1.5- Outlines of Thesis:

This study consists of six chapters; the contents of the chapters are as presented below:

Chapter one covers the general introduction, research problem, objectives, methodology of study, and outlines of thesis.

Chapter two contains the literature review, including types, design consideration for joints and joint categories, and analysis using finite elements.

Chapter three describes the linear formulation of space frame finite element and outlines how this element as implemented in SAP 2000-16 is used in the analysis and design of domes with different joint types.

Chapter four contains the results obtained using SAP2000-16 for five domes and the analysis and discussion of the results.

Chapter five contains study the effect of the type of connections on the behavior of stadia dome roofs taking into account practical design considerations.

Chapter six contains the conclusions and recommendations.

Chapter Two

Literature Review

2.1- Definition of Space Frame

In a very broad sense, space frame is literally a three-dimensional structure. However, in a more restricted sense, space frame means some type of special structural action in three dimensions. A definition of space frame given by a Working Group on Spatial Steel Structures of the International Association on Shell and Spatial Structures is [6]: "A space frame is a structure system assembled of linear elements so arranged that forces are transferred in a three-dimensional manner.In some cases, the constituent element may be two-dimensional. Macroscopically a space frame often takes the form of a flat or curved surface ".

It should be noted that virtually the same structure defined as space frame here is referred to as latticed structures in a state-of-the-art report prepared by the Task Committee on Latticed Structures [7], which states: "A latticed structure is a structure system in the form of a network of elements (as opposed to a continuous surface). Rolled, extruded or fabricated sections comprise the member elements ". The main characteristic of latticed structural systems is that their load-carrying mechanism is three-dimensional in nature.

The American Society of Civil Engineers (ASCE) report also specifies that the three-dimensional character includes flat surfaces with loading perpendicular to the plane as well as curved surfaces. The Report excludes structural systems such as common trusses on building frames, which can appropriately be divided into a series of planar frameworks with loading in the plane of the framework. Thus, usually the terms ‘‘ Space frames’’ and ‘‘latticed structures ’’are considered synonymous [8].

A space frame is usually arranged in an array of single, double, or multiple layers of intersecting members. Some authors define space frames only as double-layer grids.A single-layer space frame that has the form of a curved surface is termed as braced vault braced dome, or latticed shell [8].

Occasionally, the term space truss appears in the technical literature. According to the structural analysis approach, a space frame is analyzed by assuming rigid joints that cause internal torsions and moments in the members, where as a space truss is assumed as hinged joints and therefore has no internal member moments. The choice between space frame and space truss action is mainly determined by the joint-connection detailing and the member geometry is no different for both. However, in engineering practice, there are no absolutely rigid or hinged joints. For example, a double-layer flat surface space frame is usually analyzed as hinged connections, while a single-layer curved surface space frame may be analyzed either as hinged or as rigid connections. The term ‘‘space structure’’ will be used to refer to both space frames and space trusses [8].

The space structure can be formed on either a flat or a curved surface. The earliest form of space structure is single-layer grid. By adding intermediate grids and including rigid connection to the joist and girder framing system, the single-layer grid is formed. The major characteristic of grid construction is the omnidirectional spread of the load as opposed to the linear transfer of the load in an ordinary framing system. Since such load transfer is mainly by bending, for larger spans the bending stiffness is increased most efficiently by changing to adouble-layer system. The load transfer mechanism of a curved surface space frame is essentially different from the grid system that is primarily membrane-like action [8].

As stated by Tien T. Lan [8],the concept of space frame can be best explained by the following example.It is necessary to design a roof structure for a square building. Figure (2.1a) and b shows two different ways of roof framing. The roof system shown in Figure (2.1a) is a complex roof composed of planar latticed trusses. Each truss resists the load acting on it independently and transfers the load to the columns on each end.

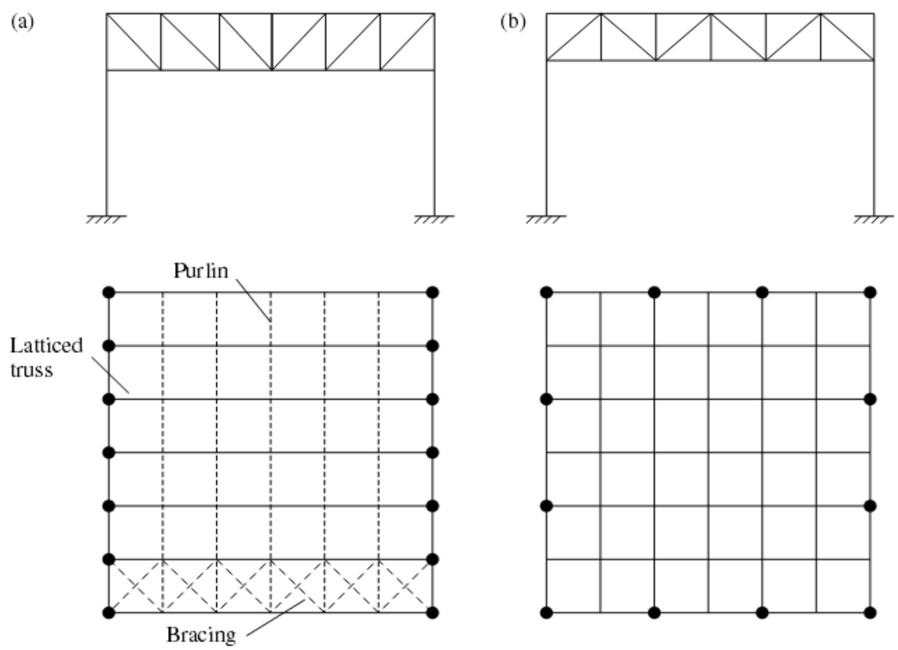


Figure (2.1): Roof framing for a square plan [8]

To ensure the integrity of the roof system, usually purlins and bracings are used between trusses. In Figure (2.1b) latticed trusses are laid orthogonally to form a system of space latticed grids that will resist the roof load through its integrated action as a whole and transfer the loads to the columns along the perimeters.

Since the loads can be taken by the members in three dimensions, the corresponding forces in space latticed grids are usually less than that in planar trusses and hence the depth can be decreased in a space frame.

The same concept can be observed in the design of a circular dome [8]. Again, there are two different ways of framing a dome. The dome shown in Figure (2.2a) is a complex of elements like arches, primary and secondary beams, and purlins, which all lie in a plane. Each of these elements constitutes a system that is stable by itself. In contrast, the dome shown in Figure (2.2b) is an assembly of a series of longitudinal, meridional, and diagonal members, a form of latticed shell. It is a system whose resisting capacity is ensured only through its integral action as a whole.

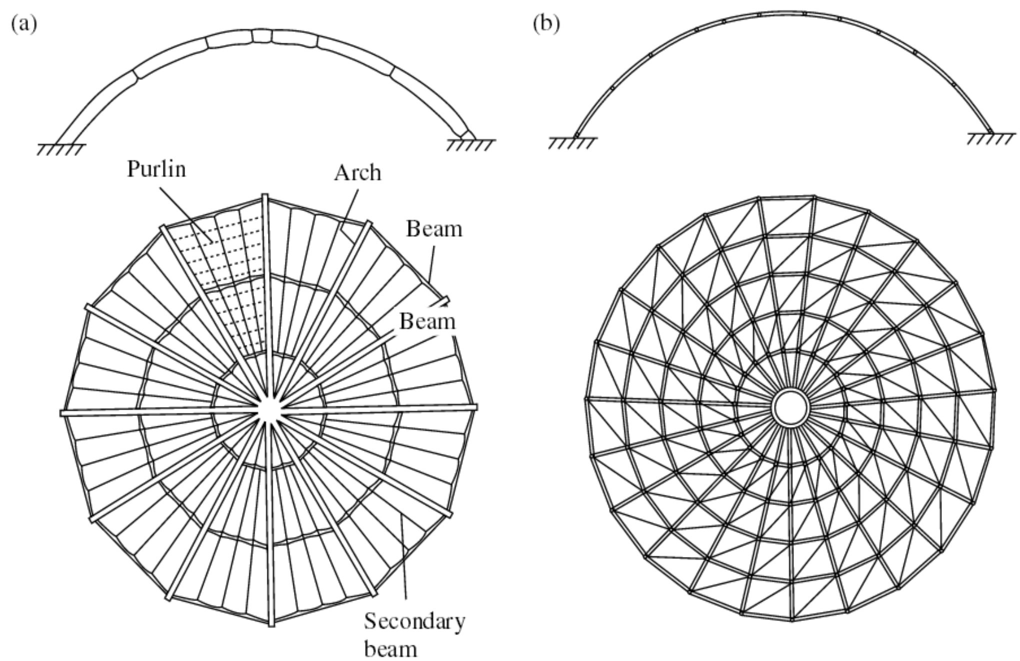


Figure (2.2): Roof framing for a Circular Dome [8]

As shown by Tien T. Lan [8], the difference between planar structures and space frames can be understood also by examining the sequence of flow of forces. In a planar system, the force due to the roof load is transferred successively through the secondary elements, the primary elements, and then finally to the foundation. In each case, loads are transferred from the elements of lighter class to the elements of heavier class. As the sequence proceeds, the magnitude of the load to be transferred increases, so does the span of the element. Thus, elements in a planar structure are characterized by their distinctive ranks, not only by the size of their cross-sections but also by the importance of the task assigned to them. In contrast, in a space system there is no sequence of load transfer, and all elements contribute to the task of resisting the roof load in accordance with the three-dimensional geometry of the structure. For this reason, the ranking of the constituent elements similar to planar structures is not observed in a space frame.

Braced domes are one of the oldest and well-established structural forms and have been used in architecture since the earliest times. They are of special interest to engineers as they enclose a maximum amount of space with a minimum surface and have proved to be very economical in terms of consumption of constructional materials. The stresses in a dome are generally membrane and compressive in the major part of the shell except circumferential tensile stresses near the edge and small bending moments at the junction of the shell and the ring beam. Most domes are surfaces of revolution. The curves used to form the synclastic shell are spherical, parabolic, or elliptical, covering circular or polygonal areas.

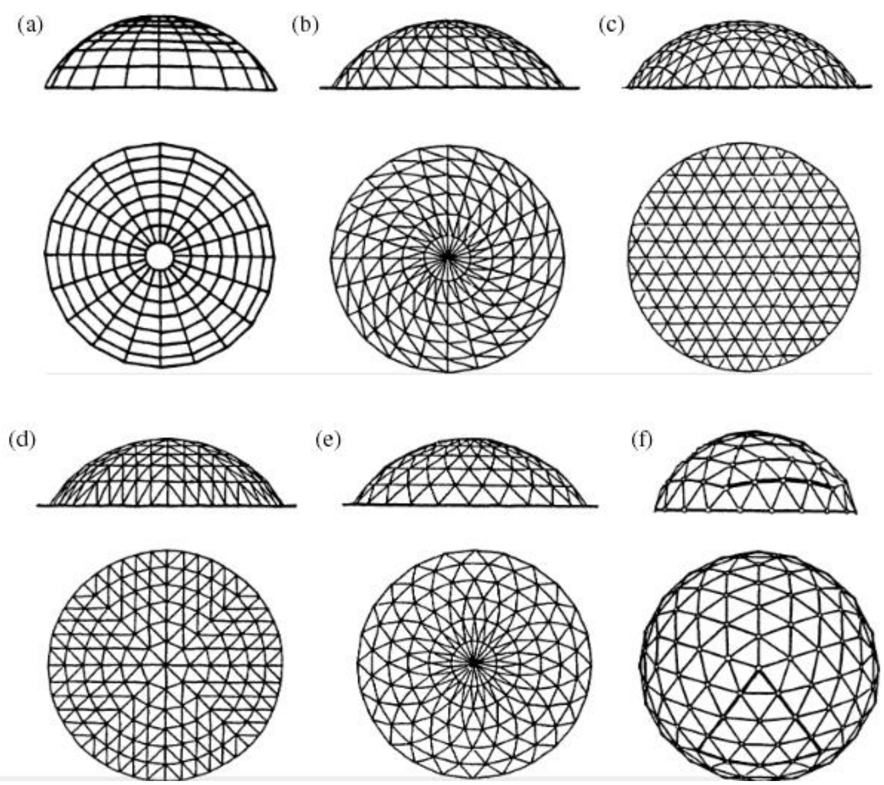


Figure (2.3): Braced domes [8]

Out of a large variety of possible types of braced domes, only four or five types proved to be frequently used in practice [8]. They are, as shown in Figure (2.3):

1. Ribbed domes (a).
2. Schwedler domes (b).
3. Three-way grid domes (c).
4. Lamella domes (d and e).
5. Geodesic domes (f).

2.2- Design Consideration for Joints:

According to Holmes and Martin [9], a good structural connection should be:

- simple to manufacture and assemble,
- standardized for situations where the dimensions and dead loads are similar,
- manufactured from materials and components that are readily available,
- designed so that welding is generally confined to the workshop to ensure good quality and reduce costs,
- designed to avoid the use of temporary supports to the structure during its erection,
- detailed to resist corrosion and to be acceptable aesthetically, and
- low in cost and maintenance.

A cost-effective joint has to fulfill these requirements. Joints influence the economy of space frames because they may occupy up to 50% of the material required in the construction [10].

2.3- Categories of Joints in Space Structures:

There exist many different types of joints which have been classified into various categories. The joints are mainly manufactured by commercial companies. The joints are classified into three broad categories; type1(rigid), type 2 (semi-rigid), and type 3 (pinned) joints as outlined in the following sections.

1) Rigid Joints:

In this category, full continuity is assumed at the connection so that the original angles between intersecting members are held virtually constant; i.e, with rotational restraint on the order of 90% or more of that necessary to prevent any angle change. Such connections are used under both the working stress and plastic design metods [11].

The advantage of rigidity is that it increases the overall resistance to external loads but the joints have the disadvantages of requiring highly skilled labor to work on the construction site. Traditionally, most early space structures used this type of joints but the trend is changing to semi-rigid joints.

2) Semi-Rigid Joints:

In semi-rigid, rotational restraint is between 20 and 90% of that necessary to prevent any angle change. Alternatively, one may consider that with semi-rigid framing the moment transmitted across the joint is neither zero (a small amount) as in simple framing, nor is it the full continuity moment as assumed in elastic rigid frame analysis. AISC-1.2 states that design of constructions using this type may be used when‘‘the connections of beams and girders possess a dependable and known moment capacity intermediate in degree between the rigidity of type 1 and the flexibility of type 3.’’ [11].

These joints mainly consist of ball joints, members and connection mechanism using bolts alone or with nuts.According to Stephan [12] the classical node connector for double-layered structures is the ball node connector which can be complemented by the bowl node connector. For single-layer structures, the node connectors can be divided into two fundamental groups; splice connectors and end-face connectors. The advantages of semi-rigid joints include the following :

(a) It is possible to use tubular members which have a concentric profile and has the same second moment of area in all directions thus ensuring a constant buckling load in all directions.

(b) They can be used in a wider range of structures.

(c) They can be prefabricated in the industry and quickly assembled on site thus saving on time of construction and making use of Less-skilled labor.

(d) Many of the semi-rigid joints that have been developed have design rules that are mainly based on experimental results.

As stated by Satish Kumar and Prasada Rao D.V [13] advances in space structures joints are towards semi - rigid joints because:

1- Semi-rigid connections provide economical options for designing steel moment frames subjected to gravity loads, essentially due to the reduced moment transfer from the beams to the columns.

2- Semi-rigid connections could be used with great advantage to resist earthquake loads, provided they satisfy the seismic design requirements.

3- Due to their inherent flexibility, semi-rigid connections would take less moment and also accommodate large rotations without severe stress concentration effects.

4- Structures with semi-rigid connections will be more flexible compared to those employing rigid connections, there by leading to a reduction in the seismic loads.

5- In regions of low to moderate seismicity, semi-rigid connections may provide a more economical and aesthetic alternative to braced frames or frames with other lateral load resisting systems such as shear walls.

6- Semi-rigid frames can also be used in conjunction with such systems where they will serve as a second line of defense against severe earthquakes.

The disadvantage of such joints is that if not well designed, they may turn out to be very complex and expensive as compared to other categories of joints. An example of such is the universal connector suitable for all types of structures by Konrad Wachsmann [14].

3) Pinned Joints:

Simple framing, where rotational restraint at the ends of members is as little as practicable. For beams, simple framing provides only shear transfer at the ends. One may consider the framing simple if the original angle between intersecting pieces may change up to 80% percent of the amount it would theoretically change if frictionless hinged connections could be used. Design of simply supported beams under working stress method uses type 3 [11].

The members are connected to the joint so as to eliminate bending moments in some or all directions. The pinning concept is to design the splice plate by taking the center lines of the members either welded or bolted into it and aligning it to the joint, thus making it pinned.

2.4- Summary:

The space framed structure can be formed of either a flat or a curved surface. It will be composed of single, double, or multiple layers of intersecting members. The single and double layers are used in this study.The joints are classified into three broad categories; rigid, semi-rigid and pinned joints. The joint type has a major influence on the performance of the space framed structure. The finite element method represents an efficient tool for the analysis and design of these structures.

Chapter Three

Formulation of the Space Frame Finite Eelement for Linear Analysis

3.1- Introduction:

A frame element is formulated to model a straight bar of an arbitrary cross-section, which can deform not only in the axial direction but also in the directions perpendicular to the axis of the bar. The bar is capable of carrying both axial and transverse forces, as well as moments. Therefore, a frame element is seen to possess the properties of both truss and beam elements.

The simplest way to approximate the curvature of the axis of a bar is to split it into a number of straight bars attached sequentially. In this case the element that must be formulated is the 3D straight frame element.The element has two nodes at ends.Each node has six degrees of freedom in local direction, and six degrees of freedom in the global direction.

3.2- Discretization of structures using Finite elements method:

In a typical structural analysis, the cross-sectional behavior of each member of a framed structure under certain loading conditions can be described by the so-called governing differential equations or differential equations of equilibrium. A framed structure, as well as structures of other types, is said to possess an infinite number of degrees of freedom, because the behavior of the structure is known only when the behavior at every point of the structure is known. The finite element method approximates the original structural system that has an infinite number of degrees of freedom by a simplified mathematical model that has only a finite number of degrees of freedom.

The finite element procedure for analyzing structures of the framed type based on the linear theory can be summarized as follows:

First, the entire framed structure is broken down into a number of line elements which are connected to each other at the nodal points or nodes. Each element is given an element number and each node a node number. Next, the stiffness equations are derived for each element in terms of the nodal degrees of freedom. This step ensures the equilibrium of individual elements to be satisfied in a weak or average sense. By transforming the element stiffness equations from local coordinates for each element to a common global coordinate system. All the element equations are then assembled to yield the structure stiffness equations This step, in contrast, ensures the satisfaction of compatibility and equilibrium conditions for the entire structure at each nodal point. Further, by imposing appropriate geometric boundary conditions, the structure will achieve its kinematic stability.For a given set of applied loadings, the nodal displacements can then be solved from the structure stiffness equations. The final step in finite element analysis is the processing of elements to obtain quantities such as forces and stresses, for the purpose of designing member cross sections.

3.3- Geometric definition of the element:

a- In local coordinates:

The geometric definition of the element (e) is shown in figure (3-1) which shows the straight element with six degrees of freedom per node (node 1 and 2), three translational displacements in the x, y, and z axes and three rotations with respect to the x, y, and z axes.The effective length of the element is Le. The element has six corresponding stress.resultants figure (3.1b).

b- In global coordinates:

In the global coordinates there are six degrees of freedom per node, three translational displacements in the X, Y, and Z axes and three rotations with respect to the X, Y, and Z axes, with six generalized corresponding forces at each node.

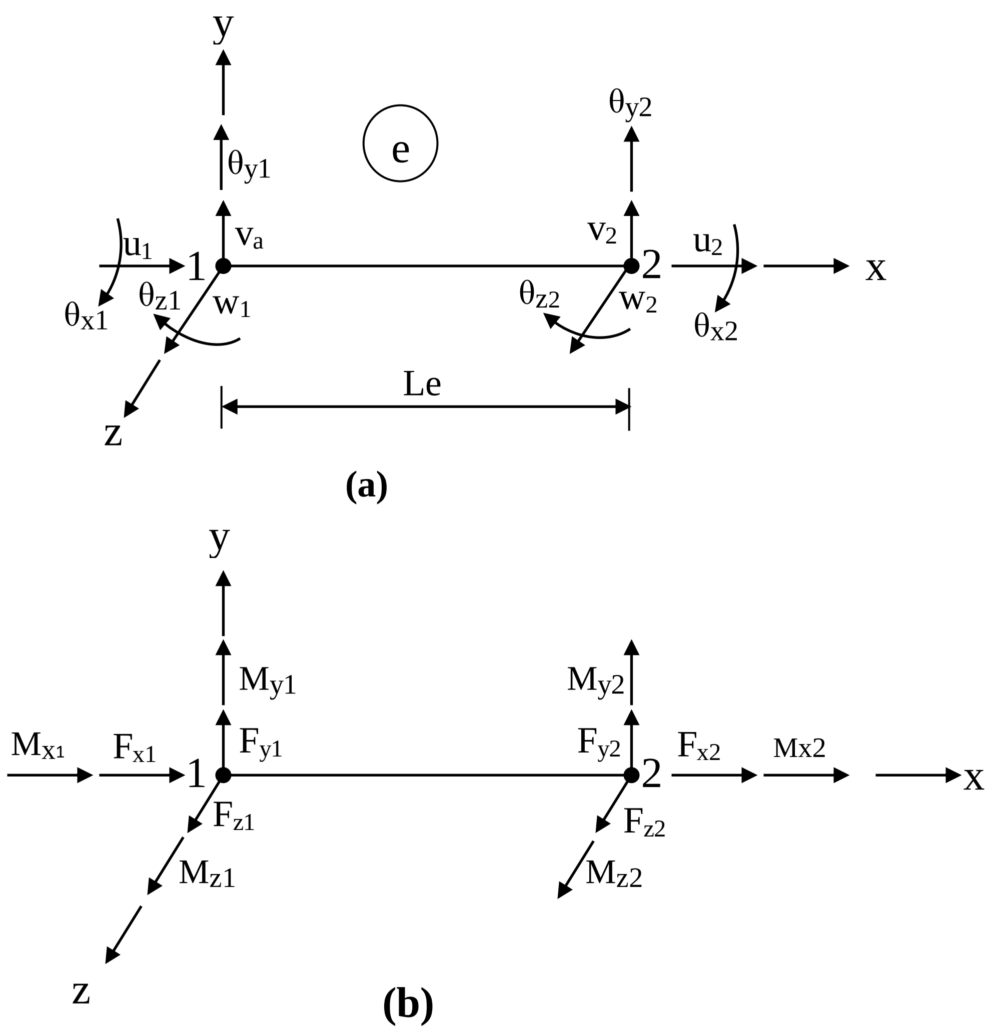


Figure (3.1): Space Frame Element: (a) Nodal degrees of freedom; (b) Nodal forces and moments.

3.4- The displacement function:

a- In local coordinates:

The local displacement function of element can be written as follows:

$$u = [\bar{N}_1 \quad \bar{N}_2] \begin{Bmatrix} u_1^e \\ u_2^e \end{Bmatrix} = [\bar{N}]\{u^e\} \tag{3.1}$$

$$v = [\bar{\bar{N}}_1 \quad \bar{\bar{N}}_2 \quad \bar{\bar{N}}_3 \quad \bar{\bar{N}}_4] \begin{Bmatrix} v_1^e \\ \theta_{z1}^e \\ v_2^e \\ \theta_{z2}^e \end{Bmatrix} = [\bar{\bar{N}}] \{v^e\} \tag{3.2}$$

$$w = [\bar{\bar{N}}_1 \quad \bar{\bar{N}}_2 \quad \bar{\bar{N}}_3 \quad \bar{\bar{N}}_4] \begin{Bmatrix} w_1^e \\ \theta_{y1}^e \\ w_2^e \\ \theta_{y2}^e \end{Bmatrix} = [\bar{\bar{N}}] \{w^e\} \tag{3.3}$$

$$\theta_x = [\bar{N}_1 \quad \bar{N}_2] \begin{Bmatrix} \theta_{x1}^e \\ \theta_{x2}^e \end{Bmatrix} = [\bar{N}] \{ \theta_x^e\} \tag{3.4}$$

The shape functions to describe the element in terms of local coordinates are:

$$\bar{N}_1 = 1 - \frac{x}{L_e} \quad \text{and} \quad \bar{N}_2 = \frac{x}{L_e} \tag{3.5}$$

$$\bar{\bar{N}}_1 = 1 - 3\left(\frac{x}{L_e}\right)^2 + 2\left(\frac{x}{L_e}\right)^3$$

$$\bar{\bar{N}}_2 = x\left(1 - \frac{x}{L_e}\right)^2 \tag{3.6}$$

$$\bar{\bar{N}}_3 = 3\left(\frac{x}{L_e}\right)^2 - 2\left(\frac{x}{L_e}\right)^3$$

$$\bar{\bar{N}}_4 = x\left[\left(\frac{x}{L_e}\right)^2 - \frac{x}{L_e}\right]$$

The element displacement vector for a frame element in space can be written as

$$\{d_e\} = \{d_1 \quad d_2 \quad d_3 \quad d_4 \quad d_5 \quad d_6 \quad d_7 \quad d_8 \quad d_9 \quad d_{10} \quad d_{11} \quad d_{12}\}^T$$

$$= \{u_1 \quad v_1 \quad w_1 \quad \theta_{x1} \quad \theta_{y1} \quad \theta_{z1} \quad u_2 \quad v_2 \quad w_2 \quad \theta_{x2} \quad \theta_{y2} \quad \theta_{z2}\}^T \tag{3.7}$$

$$\{d\} = \begin{pmatrix} \bar{N}_1 & 0 & 0 & 0 & 0 & 0 & \bar{N}_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & \bar{\bar{N}}_1 & 0 & 0 & 0 & \bar{\bar{N}}_2 & 0 & \bar{\bar{N}}_3 & 0 & 0 & 0 & \bar{\bar{N}}_4 \\ 0 & 0 & \bar{\bar{N}}_1 & 0 & \bar{\bar{N}}_2 & 0 & 0 & 0 & \bar{\bar{N}}_3 & 0 & \bar{\bar{N}}_4 & 0 \\ 0 & 0 & 0 & \bar{N}_1 & 0 & 0 & 0 & 0 & 0 & \bar{N}_2 & 0 & 0 \end{pmatrix} \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ \theta_{x1} \\ \theta_{y1} \\ \theta_{z1} \\ u_2 \\ v_2 \\ w_2 \\ \theta_{x2} \\ \theta_{y2} \\ \theta_{z2} \end{Bmatrix} = [N]\{d_e\} \qquad (3.8)$$

b- In global coordinates:

$$\{d\} = [N][T]\{D_e\} \qquad (3.9)$$

Where: $D_e \equiv$ the nodal displacements in global coordinates.

$$\{D_e\} = \{U_1 \quad V_1 \quad W_1 \quad \Theta_{x1} \quad \Theta_{y1} \quad \Theta_{z1} \quad U_2 \quad V_2 \quad W_2 \quad \Theta_{x2} \quad \Theta_{y2} \quad \Theta_{z2}\}^T \qquad (3.10)$$

And, $T \equiv$ the transformation matrix.

$$T = \begin{pmatrix} T_3 & 0 & 0 & 0 \\ 0 & T_3 & 0 & 0 \\ 0 & 0 & T_3 & 0 \\ 0 & 0 & 0 & T_3 \end{pmatrix} \qquad (3.11)$$

$$T_3 = \begin{pmatrix} l_x & m_x & n_x \\ l_y & m_y & n_y \\ l_z & m_z & n_z \end{pmatrix} \qquad (3.12)$$

Where l_k, m_k, n_k ($k = x, y, z$) are direction cosines defined by :

$$l_x = \cos(x,X) = \frac{X_{21}}{L_e}, \quad m_x = \cos(x,Y) = \frac{Y_{21}}{L_e}, \quad n_x = \cos(x,Z) = \frac{Z_{21}}{L_e} \qquad (3.13)$$

To define these direction cosines, the position and the three-dimensional orientation of the frame element have to be defined first. With nodes 1 and 2, the location of the element is fixed on the local coordinate frame, and the orientation of the element has also been fixed in the x direction. However, the local coordinate frame can still rotate about the axis of the beam. One more additional point in the local coordinate has to be defined.This point can be chosen any where in the local x–y plane, but not on the x-axis. Therefore, node 3 is chosen,as shown in Figure (3.2). The position vectors $\vec{V_1}$,$\vec{V_2}$ and $\vec{V_3}$ can be expressed as:

$$\vec{V_1} = X_1\vec{X} + Y_1\vec{Y} + Z_1\vec{Z}$$
$$\vec{V_2} = X_2\vec{X} + Y_2\vec{Y} + Z_2\vec{Z} \qquad (3.14)$$
$$\vec{V_3} = X_3\vec{X} + Y_3\vec{Y} + Z_3\vec{Z}$$

The length of the frame element can be obtained by:

$$L_e = \left|\vec{V_2} - \vec{V_1}\right| = \sqrt{X^2_{21} + Y^2_{21} + Z^2_{21}} \qquad (3.15)$$

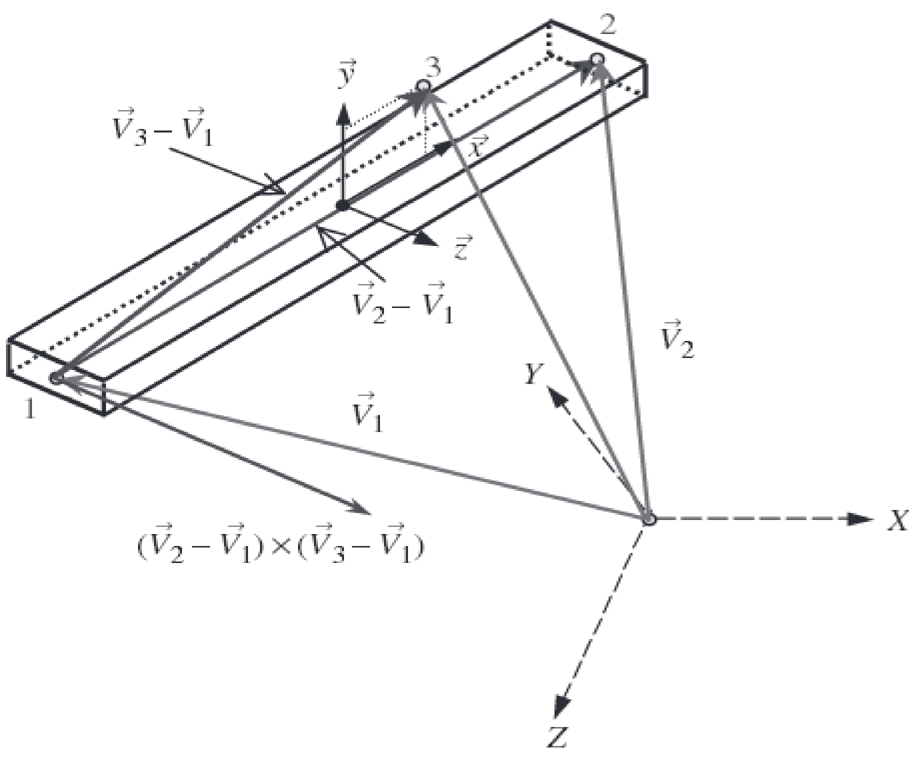


Figure (3.2): Vectors for defining the location and three-dimensional orientation of the frame element in space.

$$l_z = \cos(y,X) = \frac{1}{2A_{123}}\left(Y_{21} Z_{31} - Y_{31} Z_{21}\right)$$

$$m_z = \cos(y,Y) = \frac{1}{2A_{123}}(Z_{21}X_{31} - Z_{31}X_{21}) \tag{3.16}$$

$$n_z = \cos(y,Z) = \frac{1}{2A_{123}} + (X_{21}Y_{31} - X_{31}Y_{21})$$

Where:

$$A_{123} = \sqrt{(Y_{21}Z_{31}-Y_{31}Z_{21})^2 + (Z_{21}X_{31}-Z_{31}X_{21})^2 + (X_{21}Y_{31}-X_{31}Y_{21})^2} \tag{3.17}$$

$$l_y = \cos(z, X) = m_z n_x - n_z m_x$$

$$m_y = \cos(z, Y) = n_z l_x - l_z n_x \tag{3.18}$$

$$n_y = \cos(z, Z) = l_z m_x - m_z lx$$

3.5 - The strain:

a- In local coordinates:

$$\{\varepsilon_a\} = \frac{du}{dx} = \frac{1}{L_e}[-1 \quad 1]\begin{Bmatrix} u^e{}_1 \\ u^e{}_2 \end{Bmatrix} = [B_a]\{u^e\} \tag{3.19}$$

$$\{\varepsilon_{fv}\} = -\frac{d^2v}{dx^2}$$

$$= \left[\left(\frac{6}{L_e^2} - \frac{12x}{L_e^3}\right) \quad \left(\frac{4}{L_e} - \frac{6x}{L_e^2}\right) \quad \left(\frac{-6}{L_e^2} + \frac{12x}{L_e^3}\right) \quad \left(\frac{-6x}{L_e^2} + \frac{2}{L_e}\right)\right]\begin{Bmatrix} v_1^e \\ \theta_{z1}^e \\ v_2^e \\ \theta_{z2}^e \end{Bmatrix}$$

$$= [B_{fv}]\{v^e\} \tag{3.20}$$

$$\{\varepsilon_{fw}\} = -\frac{d^2w}{dx^2}$$

$$= \left[\left(\frac{6}{L_e^2} - \frac{12x}{L_e^3}\right) \quad \left(\frac{4}{L_e} - \frac{6x}{L_e^2}\right) \quad \left(\frac{-6}{L_e^2} + \frac{12x}{L_e^3}\right) \quad \left(\frac{-6x}{L_e^2} + \frac{2}{L_e}\right)\right]\begin{Bmatrix} w_1^e \\ \theta_{y1}^e \\ w_2^e \\ \theta_{y2}^e \end{Bmatrix}$$

$$= [B_{fw}]\{w^e\} \tag{3.21}$$

$$\{\varepsilon_T\} = \frac{du}{dx} = \frac{1}{L_e}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{Bmatrix} \theta_{x1}^{e} \\ \theta_{x2}^{e} \end{Bmatrix} = [B_T]\{\theta_x^e\} \qquad (3.22)$$

$$\{\varepsilon\} = \begin{Bmatrix} \{\varepsilon_a\} \\ \{\varepsilon_{fv}\} \\ \{\varepsilon_{fw}\} \\ \{\varepsilon_T\} \end{Bmatrix} = \begin{pmatrix} B_a & 0 & 0 & 0 \\ 0 & B_{fv} & 0 & 0 \\ 0 & 0 & B_{fw} & 0 \\ 0 & 0 & 0 & B_T \end{pmatrix}\begin{Bmatrix} u^e \\ v^e \\ w^e \\ \theta^e \end{Bmatrix} \qquad (3.23)$$

$$\{\varepsilon\} = \begin{pmatrix} \frac{-1}{L_e} & 0 & 0 & 0 & 0 & 0 & \frac{1}{L_e} & 0 & 0 & 0 & 0 & 0 \\ 0 & (\frac{6}{L_e^2} - \frac{12x}{L_e^3}) & 0 & 0 & 0 & (\frac{4}{L_e} - \frac{6x}{L_e^2}) & 0 & (\frac{-6}{L_e^2} + \frac{12x}{L_e^3}) & 0 & 0 & 0 & (\frac{-6x}{L_e^2} + \frac{2}{L_e}) \\ 0 & 0 & (\frac{6}{L_e^2} - \frac{12x}{L_e^3}) & 0 & (\frac{4}{L_e} - \frac{6x}{L_e^2}) & 0 & 0 & 0 & (\frac{-6}{L_e^2} + \frac{12x}{L_e^3}) & 0 & (\frac{6}{L_e^2} + \frac{12x}{L_e^3}) & 0 \\ 0 & 0 & 0 & \frac{-1}{L_e} & 0 & 0 & 0 & 0 & 0 & \frac{1}{L_e} & 0 & 0 \end{pmatrix}\begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ \theta_{x1} \\ \theta_{y1} \\ \theta_{z1} \\ u_2 \\ v_2 \\ w_2 \\ \theta_{x2} \\ \theta_{y2} \\ \theta_{z2} \end{Bmatrix}$$

$$\{\varepsilon\} = [B]\{\mathbf{d}\} \qquad (3.24)$$

Where: [B] is the strain matrix.

b- In global coordinates:

$$\{\varepsilon\} = [B]\,[T]\{D_e\} \qquad (3.25)$$

3.6 - The stress strain relation:

a- In local coordinates:

$$\{\sigma\} = [D]\{\varepsilon\} \qquad (3.26)$$

Where [D] = elasticity matrix.

$$[D] = \begin{pmatrix} EA & 0 & 0 \\ 0 & EI & 0 \\ 0 & 0 & GJ \end{pmatrix} \qquad (3.27)$$

$$\{\sigma\} = [D]\,[B]\,\{d_e\} \tag{3.28}$$

b- In global coordinates:

$$\{\sigma\} = [D]\,[B]\,[T]\{D_e\} \tag{3.29}$$

3.7 – Element stiffness matrix:

a- In local coordinates:

The stiffness matrix in local coordinates can be written as:

$$[k^e] = \int_{ve} [B]^T\,[D]\,[B].dv^e = \int_0^{L_e} [B]^T\,[D]\,[B].dx \tag{3.30}$$

The stiffness matrix [k] for the space frame element, which has adimension of 12*12, can be given as follows:

$$[k] = \begin{pmatrix} [k_1] & [k_2] \\ [k_2]^T & [k_3] \end{pmatrix} \tag{3.31}$$

Wher the submatrices are:

$$[k_1] = \begin{pmatrix} \frac{EA}{L_e} & 0 & 0 & 0 & 0 & 0 \\ & \frac{12EI_z}{L_e^{\,3}} & 0 & 0 & 0 & \frac{6EI_z}{L_e^{\,2}} \\ & & \frac{12EI_y}{L_e^{\,3}} & 0 & -\frac{6EI_y}{L_e^{\,2}} & 0 \\ & & & \frac{GJ}{L_e} & 0 & 0 \\ & & & & \frac{4EI_y}{L_e} & 0 \\ & \text{Symm} & & & & \frac{4EI_Z}{L_e} \end{pmatrix} \tag{3.32}$$

$$
[k_2] = \begin{pmatrix}
\frac{-EA}{L_e} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{-12EI_z}{L_e^{\,3}} & 0 & 0 & 0 & \frac{6EI_z}{L_e^{\,2}} \\
0 & 0 & \frac{-12EI_y}{L_e^{\,3}} & 0 & \frac{-6EI_y}{L_e^{\,2}} & 0 \\
0 & 0 & 0 & \frac{-2GJ}{L_e} & 0 & 0 \\
0 & 0 & \frac{6EI_y}{L_e^2} & 0 & \frac{2EI_y}{L_e} & 0 \\
0 & \frac{-6EI_z}{L_e^{\,2}} & 0 & 0 & 0 & \frac{2EI_Z}{L_e}
\end{pmatrix} \tag{3.33}
$$

$$
[k_3] = \begin{pmatrix}
\frac{EA}{L_e} & 0 & 0 & 0 & 0 & 0 \\
 & \frac{12EI_z}{L_e^{\,3}} & 0 & 0 & 0 & \frac{-6EI_z}{L^2} \\
 & & \frac{12EI_y}{L_e^{\,3}} & 0 & \frac{6EI_y}{L_e^{\,2}} & 0 \\
 & & & \frac{GJ}{L_e} & 0 & 0 \\
 & \text{Symm} & & & \frac{4EI_y}{L_e} & 0 \\
 & & & & & \frac{4EI_Z}{L_e}
\end{pmatrix} \tag{3.34}
$$

Where:

I_y and I_z are the second moment of area (or moment of inertia) of the cross-section of the beam with respect to the y and z axes, respectively. Note that the fourth DOF is related to the torsional deformation. The development of a torsional element of a bar is very much the same as that for a truss element. The only difference is that the axial deformation is replaced by the torsional angular deformation, and axial force is replaced by torque. Therefore, in the resultant stiffness matrix, the element tensile stiffness AE/l_e is replaced by the element torsional stiffness GJ/l_e, where G is the shear modules and J is the polar moment of inertia of the cross-section of the bar.

b- In global coordinates:

Using the transformation matrix, T, the matrices for space frame elements in the global coordinate system can be obtained as:

$$[K^e] = [T]^T [k] [T] \qquad (3.35)$$

3.8– Element nodal load vector:

a- In local coordinates:

The element nodal force vector in local coordinates can be written as:

$$\{R^e\} = \{R_b^e\} + \{R_s^e\} + \{R_{\varepsilon_\circ}^e\} - \{R_{\sigma_i}^e\} \qquad (3.36)$$

$$\{R_b^e\} = \int_0^{Le} [N]^T\{f_b\}.dx \qquad (3.37)$$

Where: $\{f_b\}$ is the body force vector, and $\{R_b^e\}$ can be written as:

$$\{R_b^e\}^T = \{f_{x1} \quad f_{y1} \quad f_{z1} \quad m_{x1} \quad m_{y1} \quad m_{z1} \quad f_{x2} \quad f_{y2} \quad f_{z2} \quad m_{x2} \quad m_{y2} \quad m_{z2}\} \qquad (3.38)$$

Similarry:

$$\{R_{\varepsilon_\circ}^e\} = \int_{ve} [B]^T [D]\{\varepsilon_\circ\}.dv^e = \int_0^{L_e} [B]^T [D]\{\varepsilon_\circ\}.dx \qquad (3.39)$$

$$\{R_{\sigma_i}^e\} = \int_0^{L_e} [B]^T\{\sigma_i\}.dx \qquad (3.40)$$

$$\{R_s^e\} = \int_S [N_s]^T\{f_s\}.ds \qquad (3.41)$$

Where :

$\{\varepsilon_\circ\}$ are initial strains, $\{\sigma_i\}$ are initial stresses, and $\{f_s\}$ are surface fractions.

b- In global coordinates:

$$\{F^e\} = \{F_b^e\} + \{F_s^e\} + \{F_{\varepsilon_\circ}^e\} - \{F_{\sigma_i}^e\} \qquad (3.42)$$

$$[F_b^e] = [T]^T\,[R_b^e] \qquad (3.43)$$

$$\{F_b^e\} = [T]^T\left(\int_0^{Le}[N]^T\{f_b\}.dx\right)$$

$$=\{F_{x1}\quad F_{y1}\quad F_{z1}\quad M_{x1}\quad M_{y1}\quad M_{z1}\quad F_{x2}\quad F_{y2}\quad F_{z2}\quad M_{x2}\quad M_{y2}\quad M_{z2}\}^T \qquad (3.44)$$

Similarry:

$$\{F_{\varepsilon_\circ}^e\} = [T]^T\{R_{\varepsilon_\circ}^e\} \qquad (3.45)$$

$$\{F_{\sigma_i}^e\} = [T]^T\{R_{\sigma_i}^e\} \qquad (3.46)$$

$$\{F_s^e\} = [T]^T\{R_s^e\}.ds \qquad (3.47)$$

Chapter Four

Finite Element Modeling And Results

4.1- Introduction

In this chapter,the SAP2000 -16 program was applied to obtain solutions for five stadia dome roofs.The displacement obtained from SAP2000 -16 program pin-jointed domes due to concentrated load without self weight are compared with the results from Linear Finite Element Analysis of Stadia Dome Roof program (LFEASDR) [1], to verify that these models give the correct results.

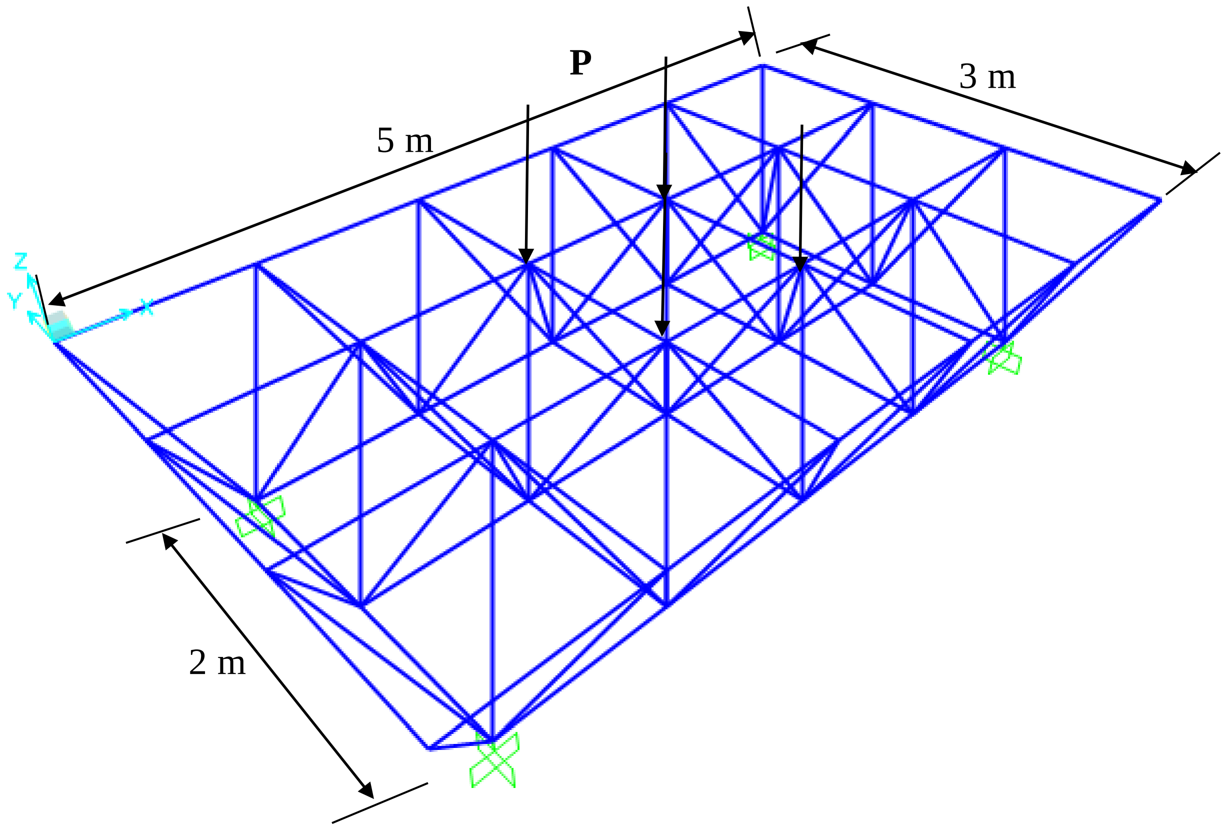
In addition the displacements for simi-rigid and rigid jointed domes are obtained and compared with the results of the pin-jointed domes all obtained using SAP2000 -16 program. The chapter, also, contains the analysis and discussion of these results.

4.2- Stadia dome case studies:

Five domes which cover the famous types of stadia roofs were selected here, these are:

1- Flat roof (which was modeled with finite elements as shown in Fig(4.1)).
2- Ascending roof towards the field (which was modeled with finite elements as shown in Fig(4.2)).
3- Curved roof (which was modeled with finite elements as shown in Fig(4.3)).
4- Circular arc roof (which was modeled with finite elements as shown in Fig(4.4)).
5- Circular dome roof (which was modeled with finite elements as shown in Fig(4.5)).

These were analysised using SAP2000-16 program as presented in the following sections. A sample of the Input data results is presented in Appendix A.



Cross section Area = 6.28318E^{-04} m^{2}

E = 205 kN/mm^{2}

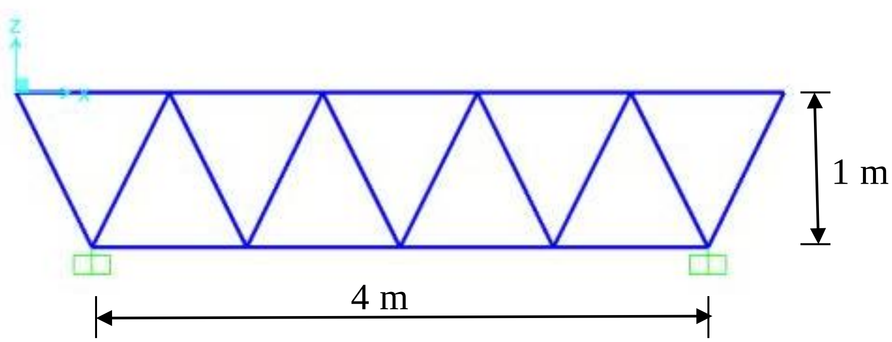
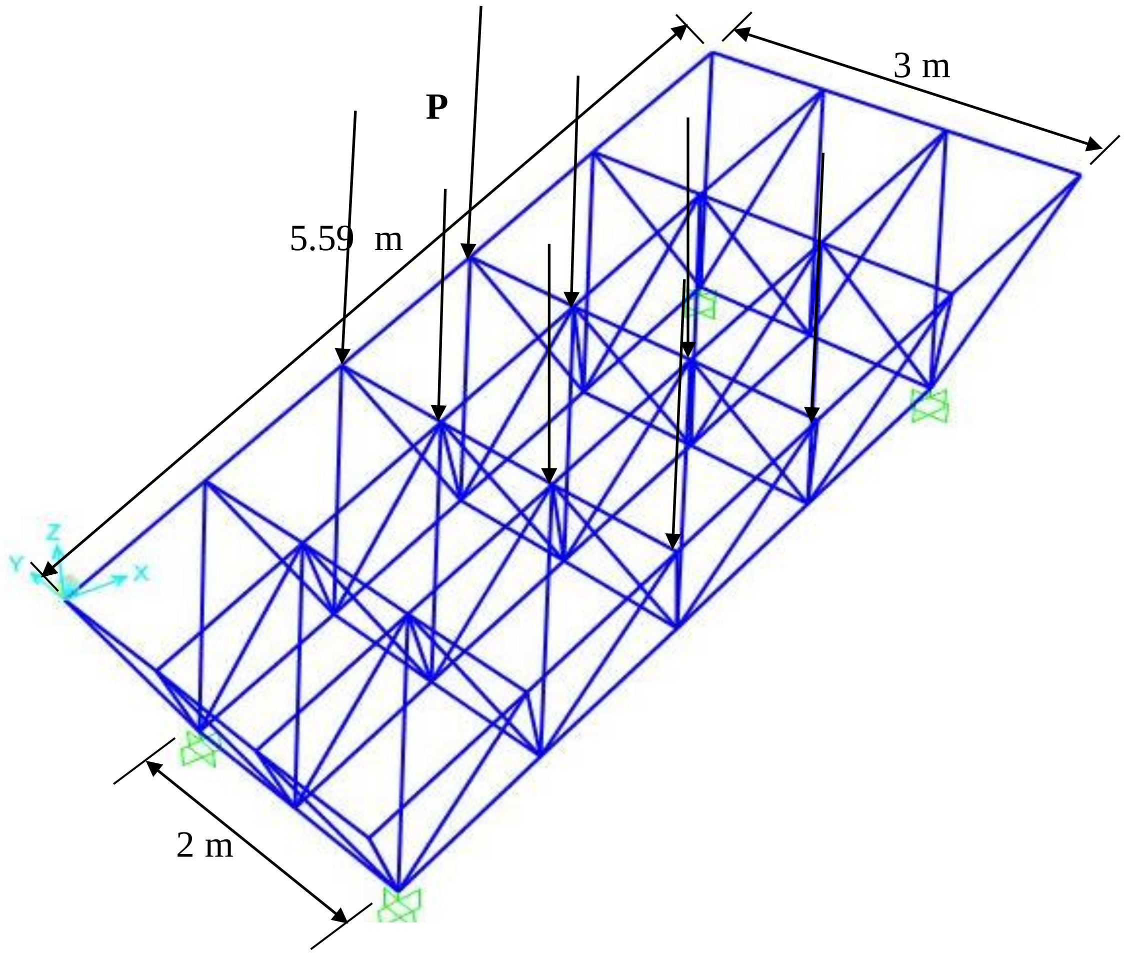


Figure (4.1): Flat roof.



Cross section Area = $6.28318E^{-04}$ m^2

E = 205 kN/mm^2

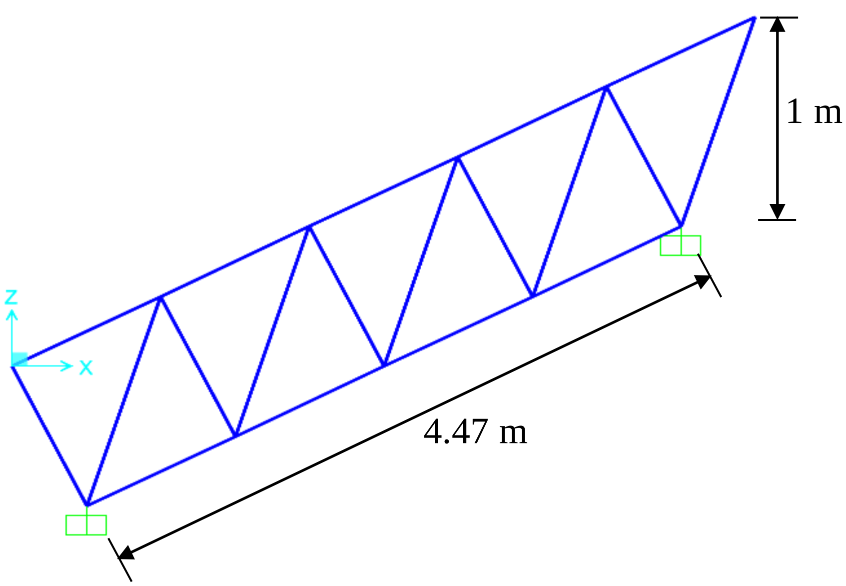
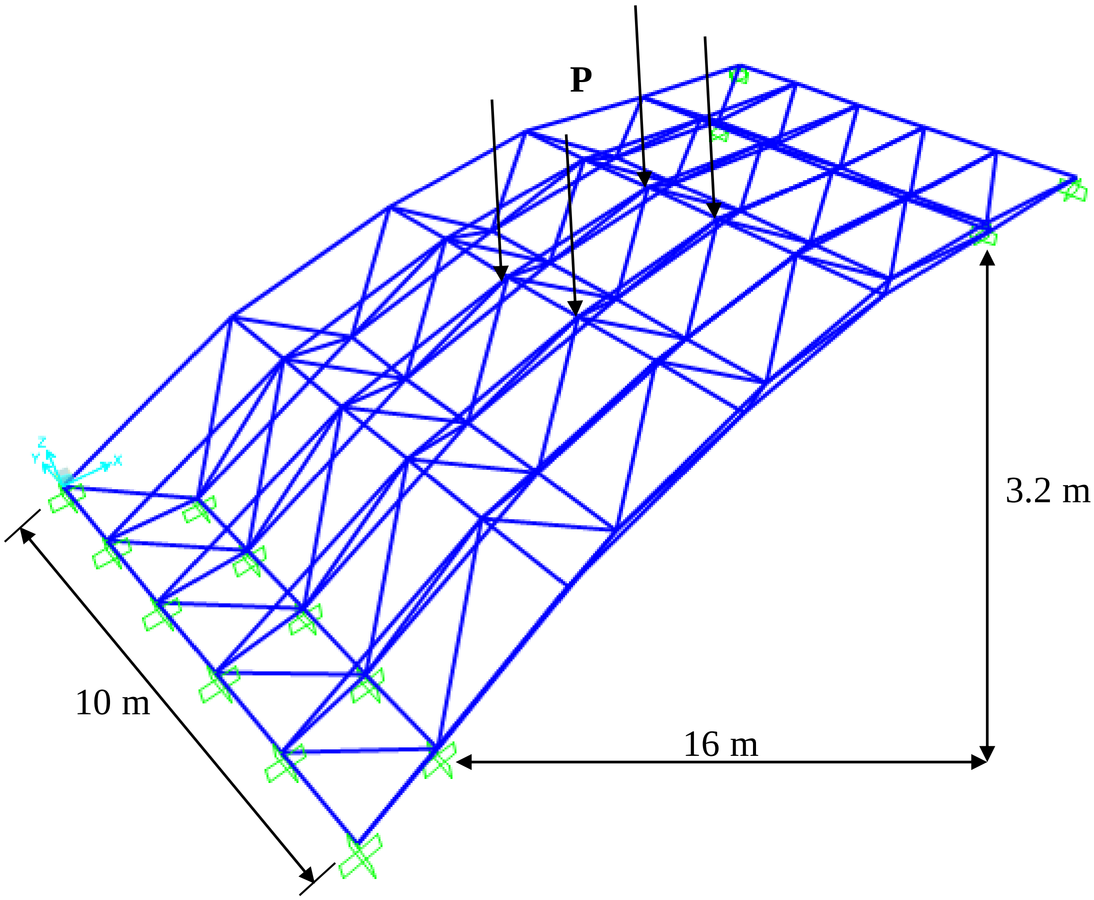


Figure (4.2): Ascending roof towards the field.



Cross section Area = $4.27257E^{-04}$ m^2

E = 205 kN/mm^2

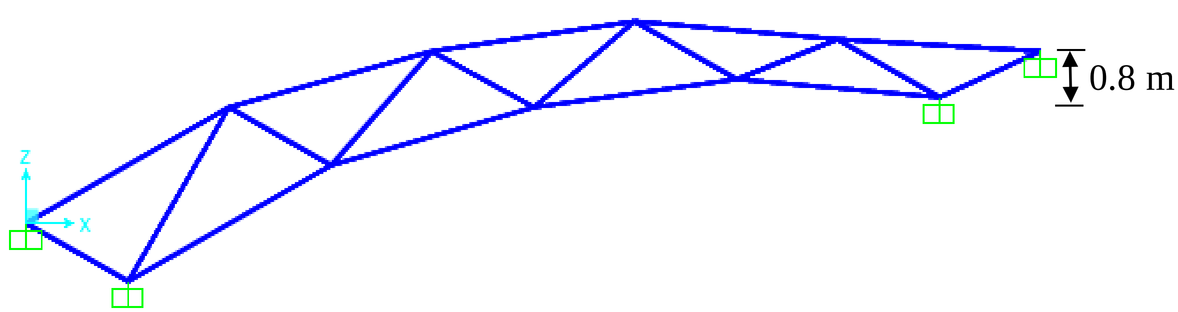
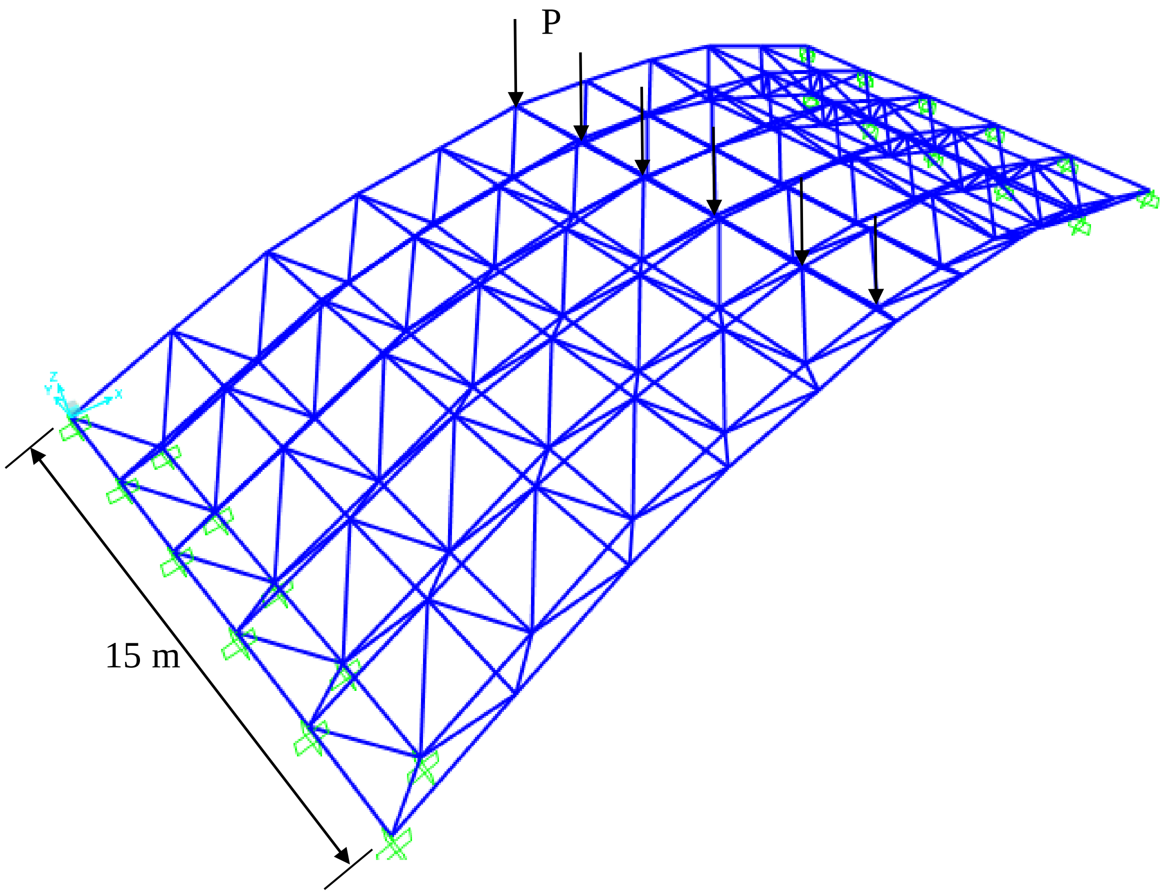


Figure (4.3): Curved roof.



Cross section Area = $4.27257E^{-04}$ m^2

E = 205 kN/mm^2

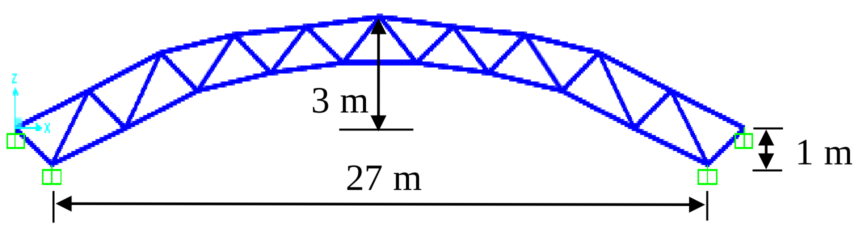
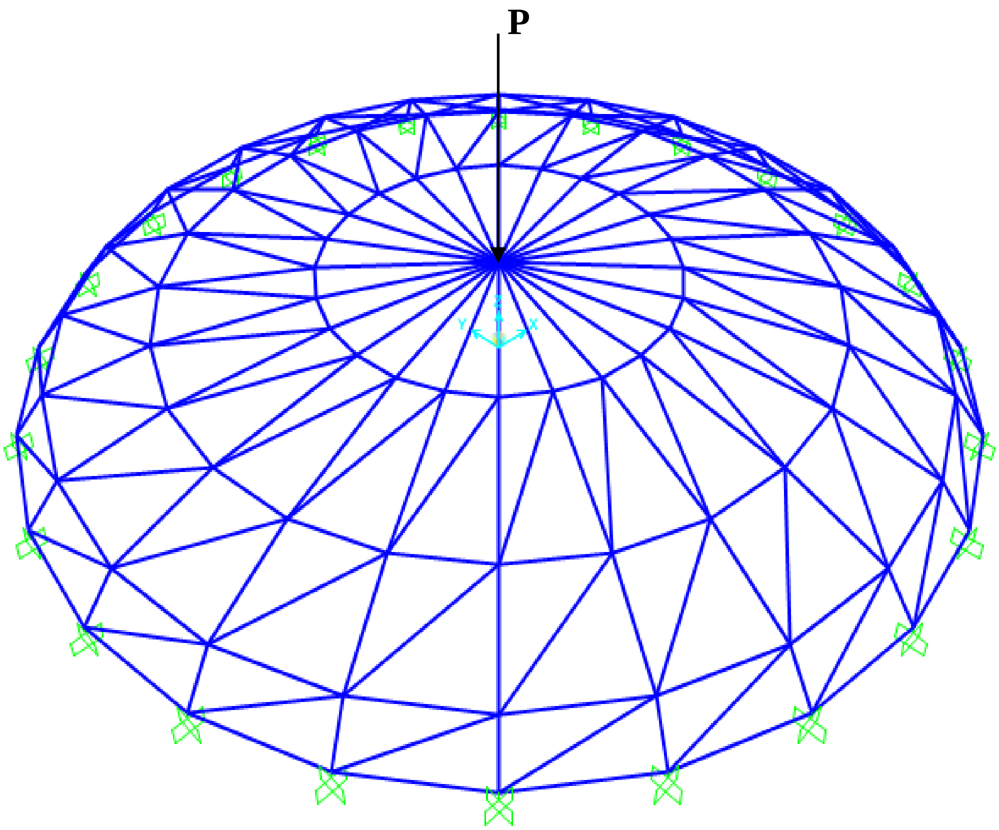


Figure (4.4): Circular arc roof.



Cross section Area = 0.0032 m^2

E = 205 kN/mm^2

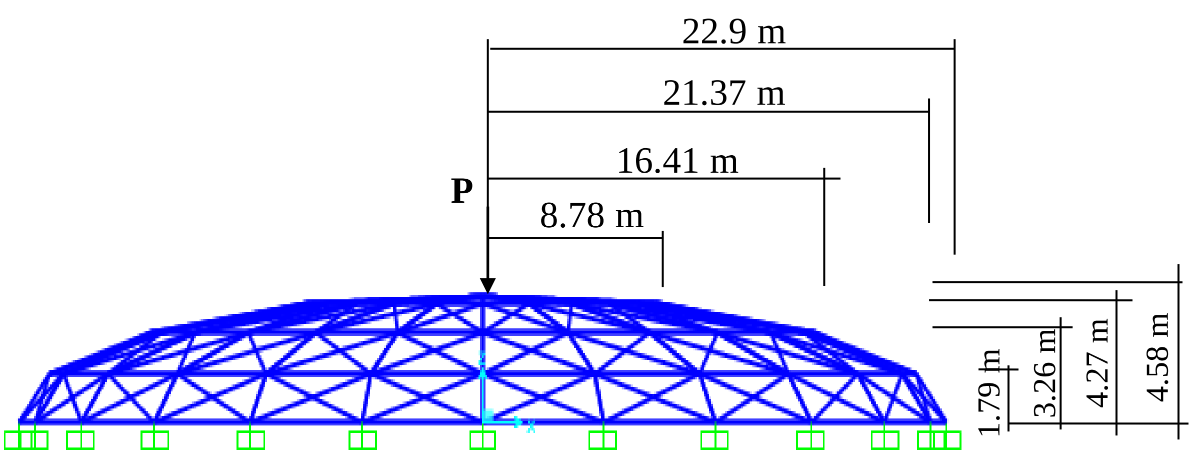


Figure (4.5): Circular dome roof.

4.2.1- Example one : Flat roof:

The flat roof was idealized with 39 nodes and 120 elements; the model is a two layer roof. The joints were considered to be pinned, rigid and semi-rigid.The roof geometry with materials properties, support conditions, and loading are shown in figures (4.1). The SAP2000 -16 program was used to analyze the roof.The results of the pin-joints obtained for vertical displacement due to increments of vertical load are compared with the same results from the Linear Finite Element Analysis of Stadia Dome Roof program (LFEASDR)[1] in table (4.1).The table also shows the percentage difference in results.

The results of the rigid and semi-rigid joints obtained for vertical displacement are compared with the same results of the pin-joints from the SAP2000 -16 in table (4.2). The maximum displacement at node 27 and 37.

Table (4.1): The vertical displacements for flat roof with pin-joints

Load (kN)	Prsent study Displacement (mm)	Displacement from reference [1] (mm)	% difference
1	0.034	0.034	0.00
2	0.068	0.068	0.00
3	0.102	0.102	0.00
4	0.136	0.136	0.00
5	0.170	0.170	0.00
6	0.204	0.204	0.00
7	0.238	0.238	0.00
8	0.271	0.271	0.00
9	0.305	0.305	0.00
10	0.339	0.339	0.00

Table (4.2): The vertical displacements (mm) for flat roof with pin, semi-rigid, and rigid joints

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
1	0.034	0.035	0.035
2	0.068	0.070	0.071
3	0.102	0.104	0.106
4	0.136	0.139	0.142
5	0.170	0.174	0.177
6	0.204	0.209	0.212
7	0.238	0.244	0.248
8	0.271	0.279	0.283
9	0.305	0.313	0.319
10	0.339	0.348	0.354

The solution of the pin-joint obtained by SAP2000-16 program gives typical results when compared with solution from reference [1]. The results are plotted in fig.(4.2a). The comparison of vertical displacement between rigid, semi-rigid joints with the same results of the pin-joints from the SAP2000 -16 are plotted in fig.(4.2b)

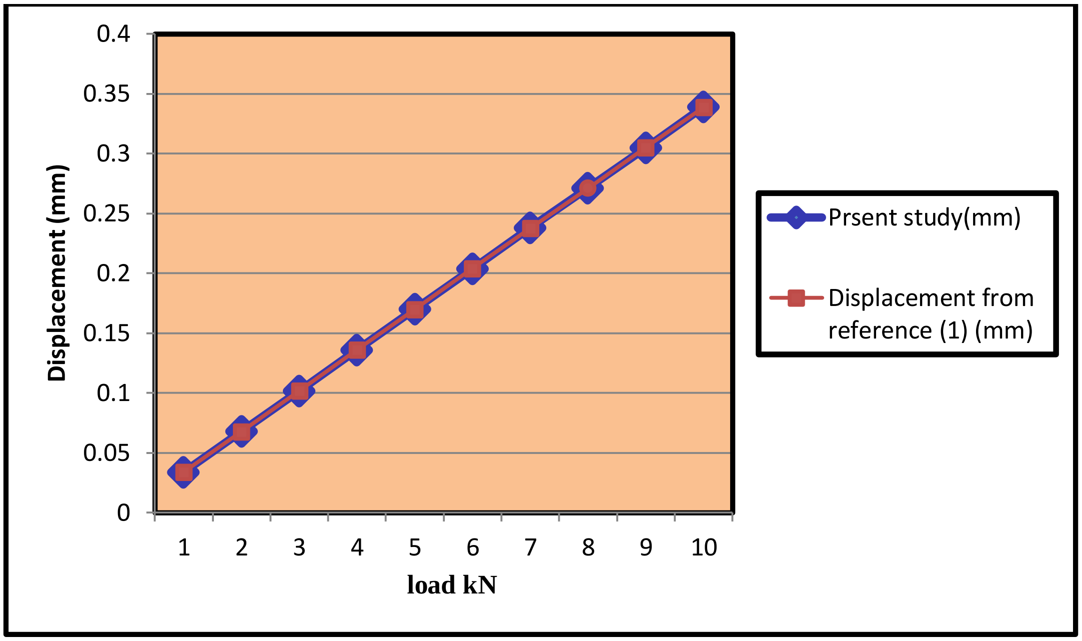


Figure (4.2a): Vertical Displacement for Flat roof

With pin-joint

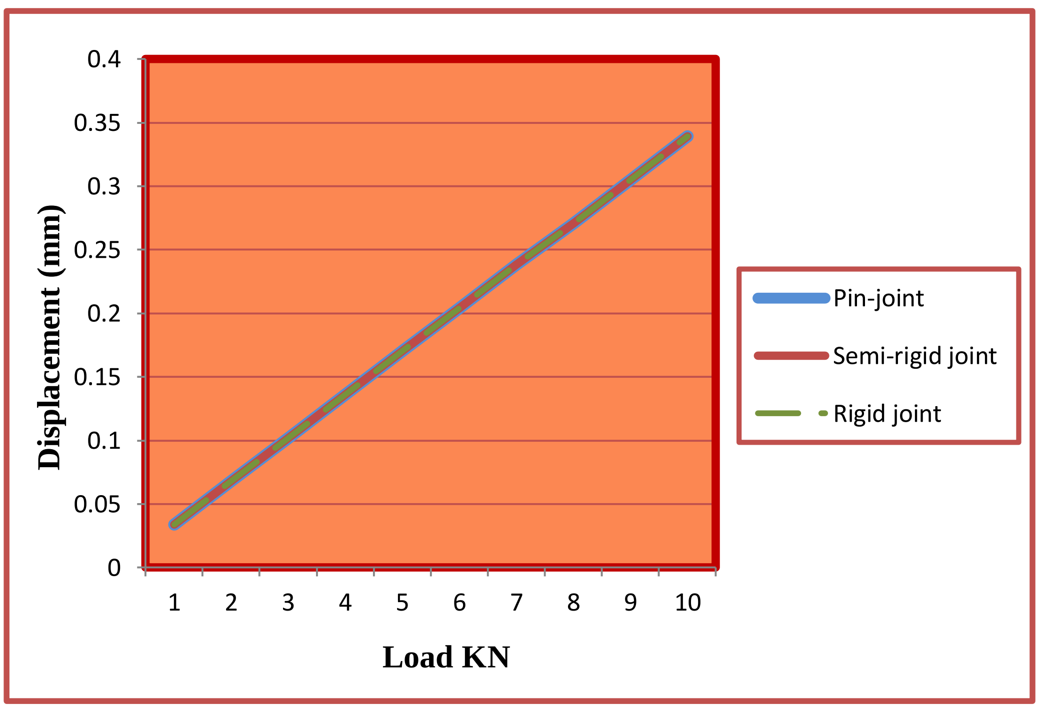


Figure (4.2b): Vertical Displacement for Flat roof

with pin, semi-rigid, and rigid joints

4.2.2- Example two :Ascending roof towards the field:

The ascending roof towards the field was represented by a finite element model with 39 nodes and 120 elements; the model is a two layer roof. The joints were considered to be pinned, rigid and semi-rigid.The roof geometry with materials properties, support conditions, and loading are shown in figures (4.3). The SAP2000 -16 program was used to analyze the roof.The results of the pin-joints obtained for vertical displacement due to increments of vertical load are compared with the same results from (LFEASDR) [1] in table (4.3).The table also shows the percentage difference in results.

The results of the rigid and semi-rigid joints obtained for vertical displacement are compared with the same results of the pin-joints from the SAP2000 -16 in table (4.4). The maximum displacement at node 27 and 37 .

Table (4.3): The vertical displacements for ascending roof with pin-joints

Load (kN)	Prsent study Displacement (mm)	Displacement from reference [1] (mm)	% difference
1	0.064	0.064	0.00
2	0.128	0.128	0.00
3	0.192	0.192	0.00
4	0.257	0.257	0.00
5	0.321	0.321	0.00
6	0.385	0.385	0.00
7	0.449	0.449	0.00
8	0.513	0.513	0.00

Cont.			
9	0.577	0.577	0.00
10	0.642	0.642	0.00

Table (4.4): The vertical displacements (mm) for ascending roof with pin, semi-rigid, and rigid joints

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
1	0.064	0.064	0.064
2	0.128	0.128	0.128
3	0.192	0.192	0.192
4	0.257	0.257	0.256
5	0.321	0.321	0.320
6	0.385	0.385	0.384
7	0.449	0.449	0.448
8	0.513	0.513	0.512
9	0.577	0.577	0.577
10	0.642	0.641	0.641

The model show typical results of the pin-joints when analysed by SAP2000-16 program and compared with solution from reference [1]. The solutions are plotted in fig. (4.4a). The comparison of vertical displacement between rigid, semi-rigid joints with the same results of the pin-joints from the SAP2000 -16 are plotted in fig.(4.4b)

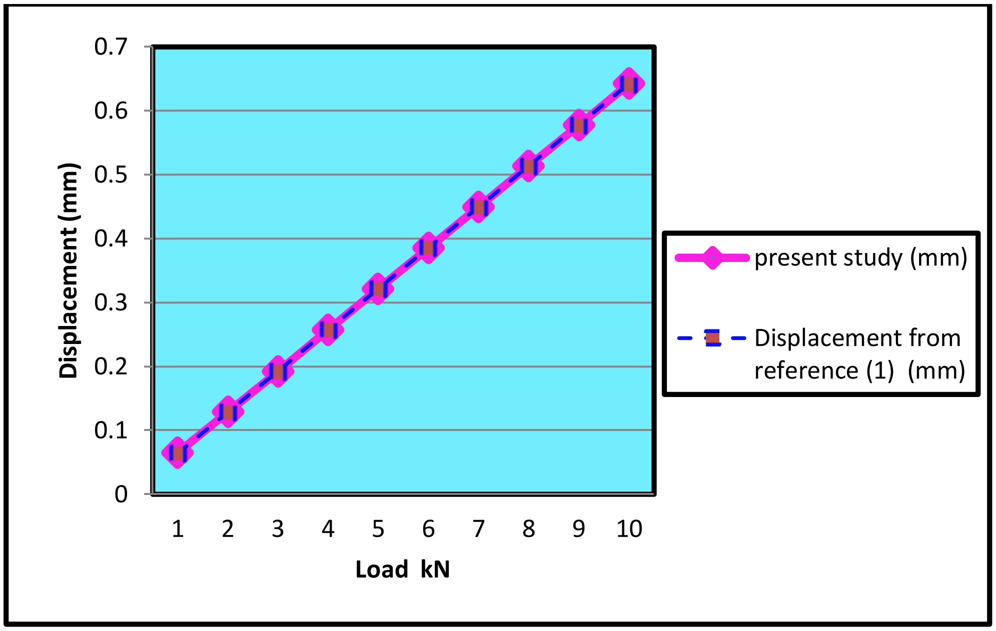


Figure (4.4a): Vertical Displacement for ascending roof

With pin-joints

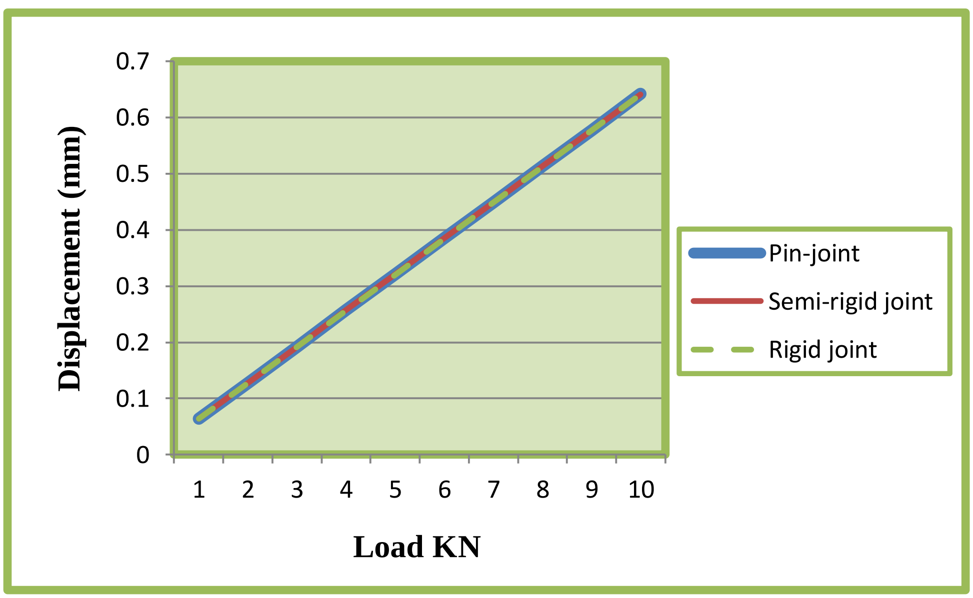


Figure (4.4b): Vertical Displacement for ascending roof

with pin, semi-rigid, and rigid joints

4.2.3- Example three : Curved roof:

The curved roof was modeled with 61 nodes and 200 elements, the model is a two layer roof.The joints are considered to be pinned, rigid and semi-rigid. The roof geometry with materials properties, support conditions, and loading are shown in figures (4.5). The SAP2000 -16 program was used to analyze the roof. The results of the pin-joints obtained for vertical displacement due to increments of vertical load are compared with the same results from (LFEASDR) [1] in table (4.5). The table also shows the percentage difference in results.

The results of the rigid and semi-rigid joints obtained for vertical displacement are compared with the same results of the pin-joints from the SAP2000 -16 in table (4.6). The maximum displacement at node 17 and 23.

Table (4.5): The vertical displacements for Curved roof with pin-joints

Load (kN)	Prsent study Displacement (mm)	Displacement from reference [1] (mm)	% difference
1	0.348	0.348	0.00
2	0.696	0.696	0.00
3	1.043	1.043	0.00
4	1.391	1.391	0.00
5	1.739	1.739	0.00
6	2.087	2.087	0.00
7	2.434	2.434	0.00
8	2.782	2.782	0.00

Con.			
9	3.130	3.130	0.00
10	3.478	3.478	0.00

Table (4.6): The vertical displacements (mm) for Curved roof with pin, semi-rigid, and rigid joints

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
1	0.348	0.348	0.348
2	0.696	0.695	0.695
3	1.043	1.043	1.043
4	1.391	1.391	1.391
5	1.739	1.739	1.738
6	2.087	2.086	2.086
7	2.434	2.434	2.434
8	2.782	2.782	2.781
9	3.130	3.130	3.129
10	3.478	3.477	3.477

The solution of the pin-joints obtained by SAP2000-16 program gives typical results when compared with solution from reference [1]. The results are plotted in fig. (4.6a). The comparison of vertical displacement between rigid, semi-rigid joints with the same results of the pin-joints from the SAP2000 -16 are plotted in fig.(4.6b).

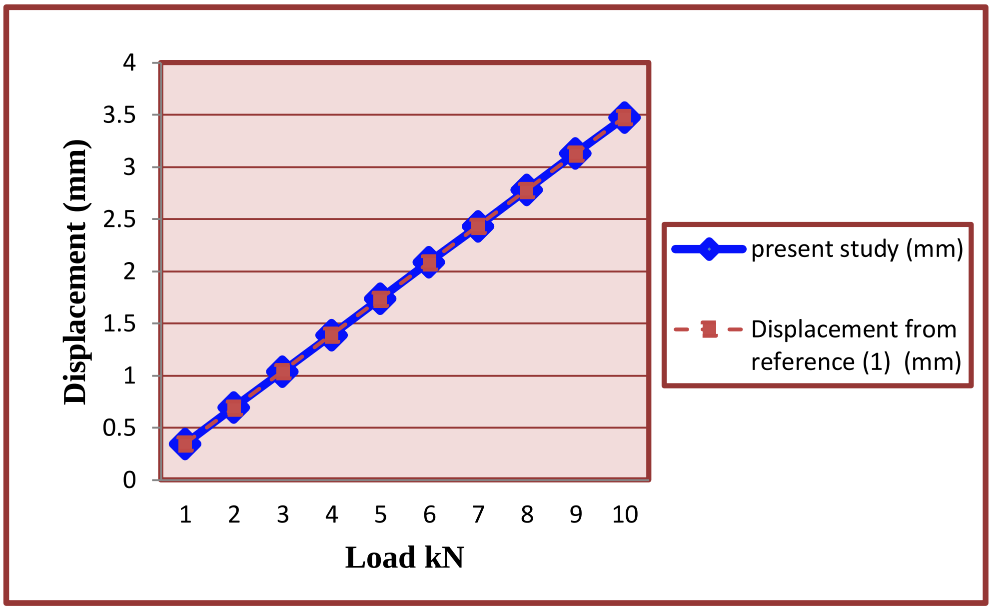


Figure (4.6a): Vertical Displacement for Curved roof

With pin-joints

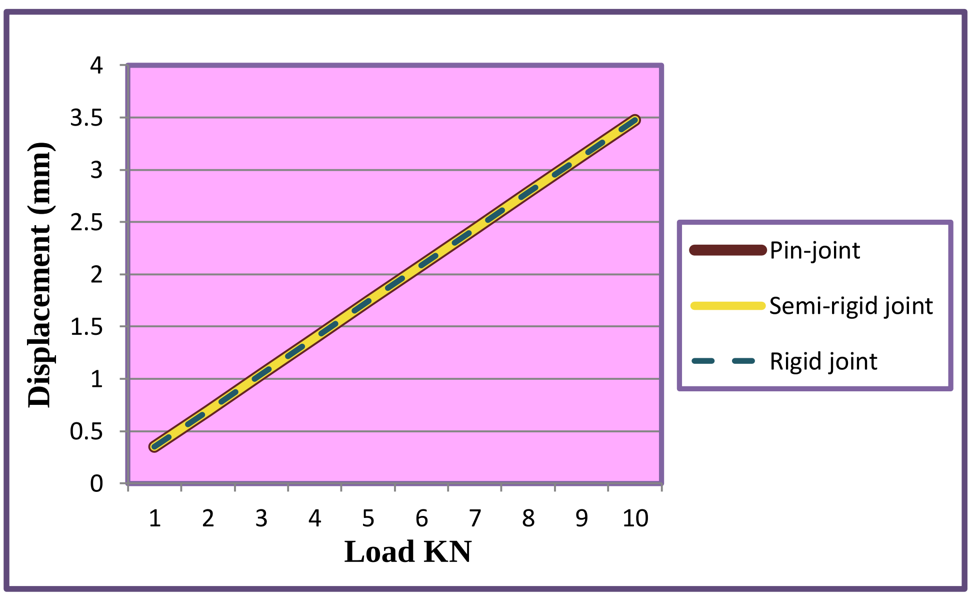


Figure (4.6b): Vertical Displacement for Curved roof

with pin, semi-rigid, and rigid joints

4.2.4- Example four: Circular arc roof:

The circular arc roof was modeled with 116 nodes and 400 elements. The joints are considered to be pinned, rigid and semi-rigid.The roof geometry with materials properties, support conditions, and loading are shown in figures (4.7). The SAP2000 -16 program was used to analyze the roof. The results of the pin-joints obtained for vertical displacement due to increments of vertical load are compared with the same results from (LFEASDR) [1] in table (4.7). The table also shows the percentage difference in results.

The results of the rigid and semi-rigid joints obtained for vertical displacement are compared with the same results of the pin-joints from the SAP2000 -16 in table (4.8). The maximum displacement at node 91 and 92.

Table (4.7) : The vertical displacements for Circular arc roof with pin-joints

Load (kN)	Prsent study Displacement (mm)	Displacement from reference [1] (mm)	% difference
1	0.985	0.985	0.00
2	1.971	1.971	0.00
3	2.956	2.956	0.00
4	3.941	3.941	0.00
5	4.927	4.927	0.00
6	5.912	5.912	0.00
7	6.897	6.897	0.00
8	7.883	7.883	0.00
9	8.868	8.868	0.00
10	9.853	9.853	0.00

Table (4.8): The vertical displacements (mm) for Circular arc roof with pin, semi-rigid, and rigid joints

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
1	0.985	0.985	0.985
2	1.971	1.971	1.970
3	2.956	2.956	2.956
4	3.941	3.941	3.941
5	4.927	4.926	4.926
6	5.912	5.912	5.911
7	6.897	6.897	6.896
8	7.883	7.882	7.881
9	8.868	8.867	8.866
10	9.853	9.853	9.852

The circular arc roof was analysed by SAP2000-16 program as two layer roof. The solution of the pin-joints gives typical results when compared with solution from reference [1]. The result of the pin-joints was plotted in fig. (4.8a) . The comparisons of vertical displacement between rigid, semi-rigid joints with the same results of the pin-joints from the SAP2000 -16 are plotted in fig. (4.8b).

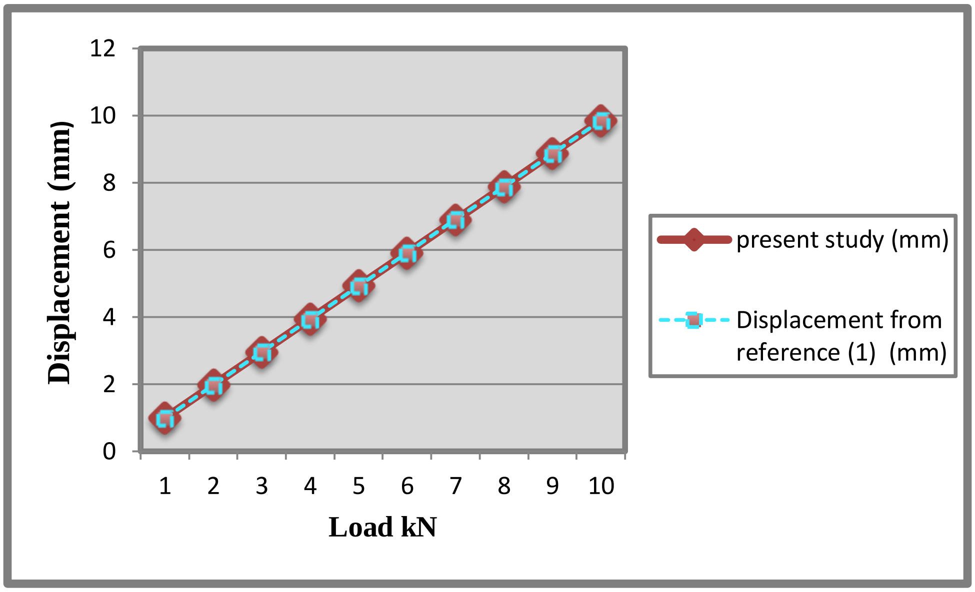


Figure (4.8a): Vertical Displacement for Circular arc roof With pin-joints

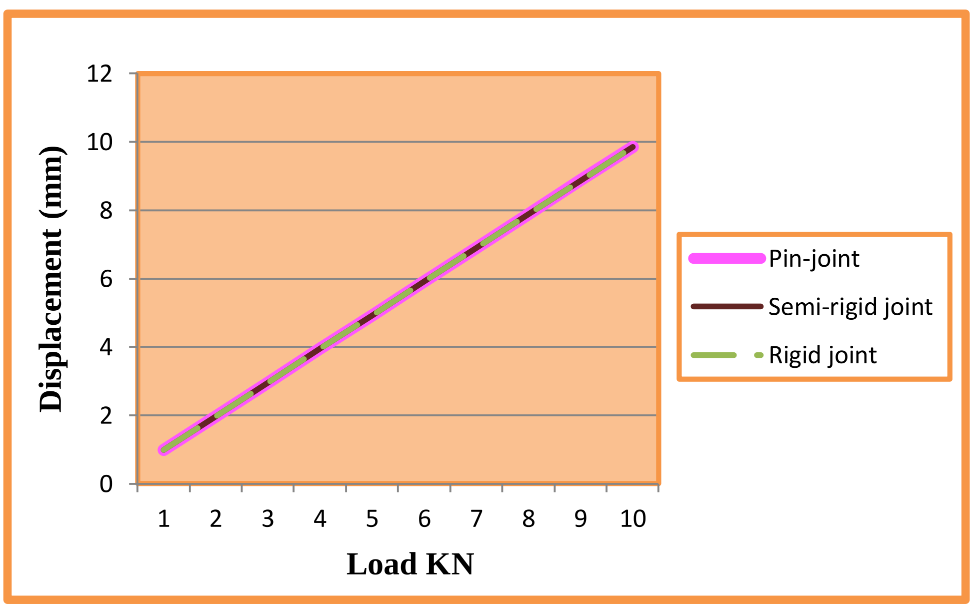


Figure (4.8b): Vertical Displacement for Circular arc roof with pin, semi-rigid, and rigid joints

4.2.5- Example five: Circular dome roof:

The circular dome roof was idealized with 97 nodes and 264 elements. The joints are considered to be pinned, rigid and semi-rigid. The roof geometry with materials properties, support conditions, and loading are shown in figures (4.9). The SAP2000 -16 program was used to analyze the roof. The results of the pin-joints obtained for vertical displacement due to increments of vertical load are compared with the same results from (LFEASDR) [1] in table (4.9). The table also shows the percentage difference in results.

The results of the rigid and semi-rigid joint supports obtained for vertical displacement are compared with the same results of the pin-joint supports from the SAP2000 -16 in table (4.10). The maximum displacement at node 96 .

Table (4.9): The vertical displacements for Circular dome With pin-joints

Load (kN)	Present study Displacement (mm)	Displacement from reference [1] (mm)	% difference
10	15.051	15	0.34
20	30.102	30	0.34
30	45.152	45	0.34
40	60.203	60	0.34
50	75.254	75	0.34
60	90.305	90	0.34

Table (4.10): The vertical displacements (mm) for Circular dome roof with pin, semi-rigid, and rigid joints

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
10	15.051	14.375	13.549
20	30.102	28.750	27.091
30	45.152	43.124	40.637
40	60.203	57.499	54.182
50	75.254	71.874	67.728
60	90.305	86.249	81.273
70	105.356	100.623	94.819
80	120.407	114.998	108.364
90	135.457	129.373	121.910
100	150.508	143.748	135.455

The circular dome roof model is a one layer dome roof. The model show agreement whith a very small difference (0.34%) when analysed by SAP2000-16 program and compared with solution obtained from reference [1]. The comparison between the results of the pin-joints are plotted in fig. (4.10a).

The comparisons of vertical displacement between rigid, semi-rigid joints with the same results of the pin-joints from the SAP2000 -16 are plotted in fig. (4.10b).

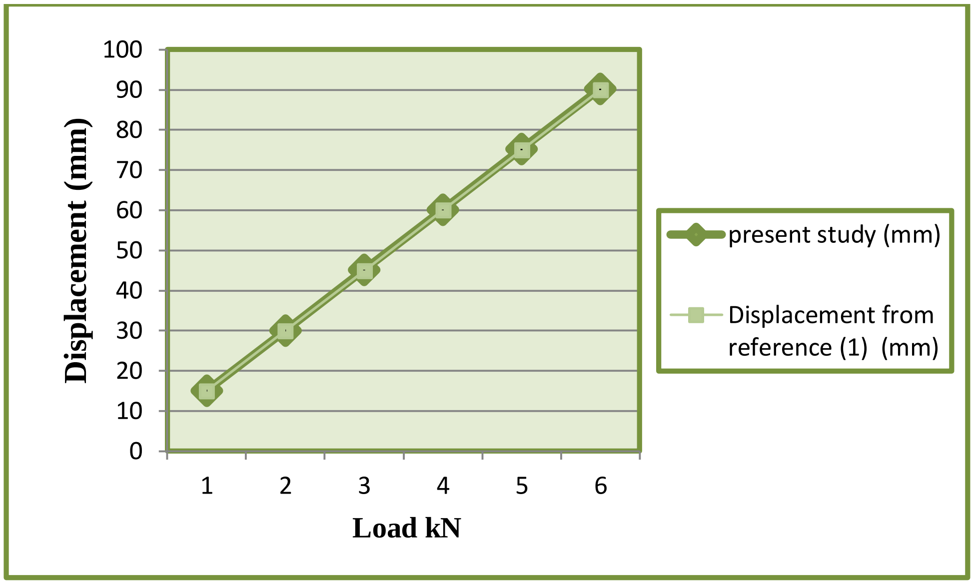


Figure (4.10a): Vertical Displacement for Circular dome roof

With pin-joints

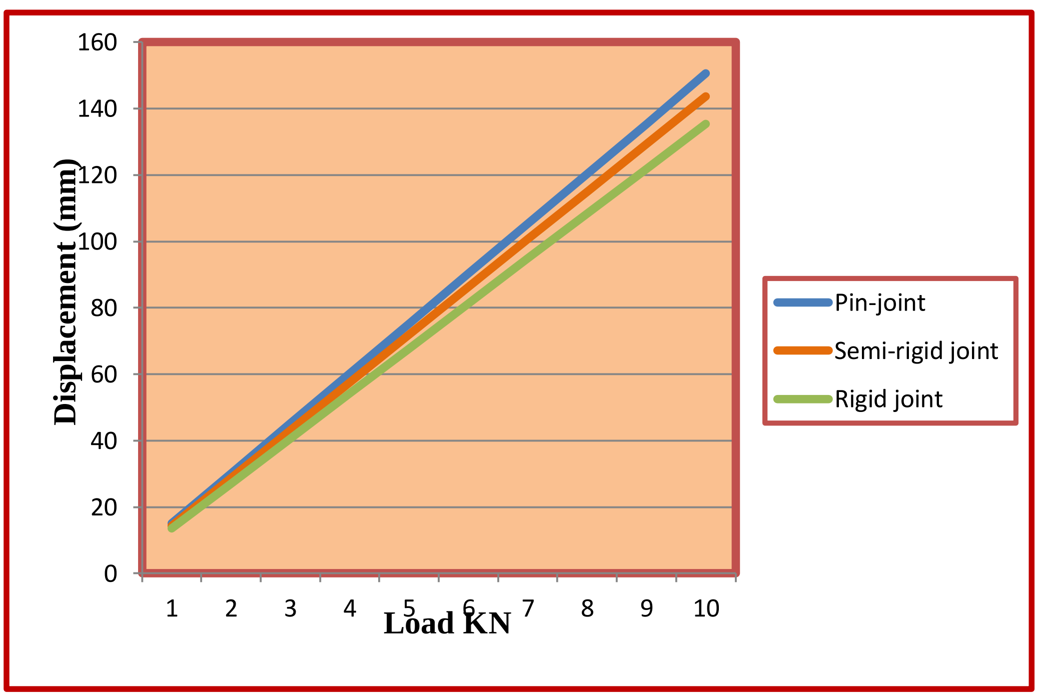


Figure (4.10b): Vertical Displacement for Circular dome roof

with pin, semi-rigid, and rigid joints

4.3- Summary of comparison of results:

The numerical examples show typical results for pinned joint when the displacements were compared with the results from reference [1], the accuracy of the results range from 99.66% to 100% . The results of the displacements for semi-rigid and rigid joints when compared with the displacement of pinned joint show that there are very small differences in the results, this for examples 1 to 4 , but for the circular dome roof the displacements of the semi-rigid are less than those of the pinned joints and greater than those the rigid joints.

Chapter Five

The Effect of the Type of Connections

5.1- Introduction:

The SAP2000 -16 program was applied to obtain solutions for the same stadia dome roofs presented in chapter four.The displacement obtained from SAP2000 -16 program due to increments of vertical load with the self weight of the dome compared with the result of the pin-jointed domes from the SAP2000-16. The self weight was added to have actual and exact analysis of stadia dome roofs.

Moreover, there is comparison of the displacements for the three types of the joints. Also the design of stadia dome roofs was carried out using SAP2000-16 program due to vertical load with the self weight of the dome based on AISC 360-10 code. The results are analysed and discussed with special emphasis on the study of the effect of the joint type.

Asample of the output data results is presented in Appendix A. Samples of deformed shapes and member forces are presented in Appendix B.

5.2- Example one: Flat roof:

In this example the joints considered to be pinned, semi-rigid, and rigid. The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load are compared with the same results of the pin-joint supports from the SAP2000 -16 program in tables (5.1a), (5.1b), and (5.1c) respectively. The cases are:

a- The vertical displacements (mm) due to self weight.

b- The vertical displacements (mm) due to uniform distributed load with self weight.

c- The vertical displacements (mm) due to concentrated load with self weight.

Table (5.1a) : The vertical displacements (mm) for flat roof due to self weight

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
self weight	0.026	0.026	0.027

Table (5.1b) : The vertical displacements (mm) for flat roof due to uniform distributed load with self weight

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
1	0.161	0.162	0.163
2	0.296	0.299	0.300
3	0.432	0.436	0.437
4	0.567	0.572	0.575
5	0.702	0.709	0.712
6	0.838	0.845	0.849
7	0.973	0.982	0.986
8	1.108	1.118	1.123
9	1.244	1.255	1.260
10	1.379	1.391	1.398

Table (5.1c) : The vertical displacements (mm) for flat roof due to concentrated load with self weight

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
1 - 1.5 - 2	0.161	0.161	0.161
2 - 3 - 4	0.296	0.296	0.296
3 - 4.5 - 6	0.432	0.432	0.431
4 - 6 - 8	0.567	0.567	0.566
5 - 7.5 - 10	0.702	0.702	0.702

The maximum displacement at node 27 and 37 for the three cases. The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load when compared with the same results of the pin-joints from the SAP2000 -16 are plotted in figures (5.1a) , (5.1b), and (5.1c) below **:**

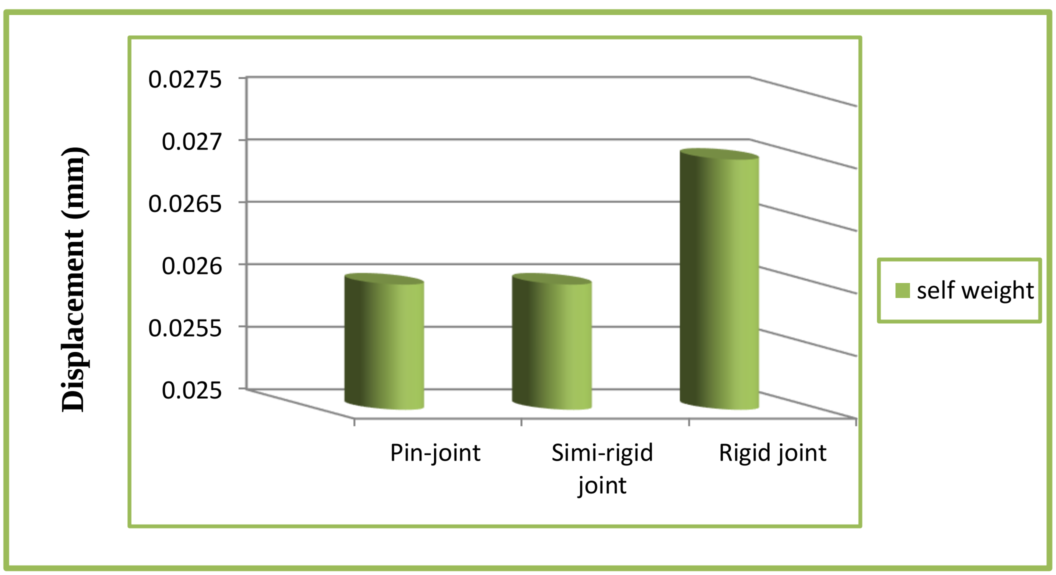


Figure (5.1a) : Vertical Displacement for Flat roof due to self weight

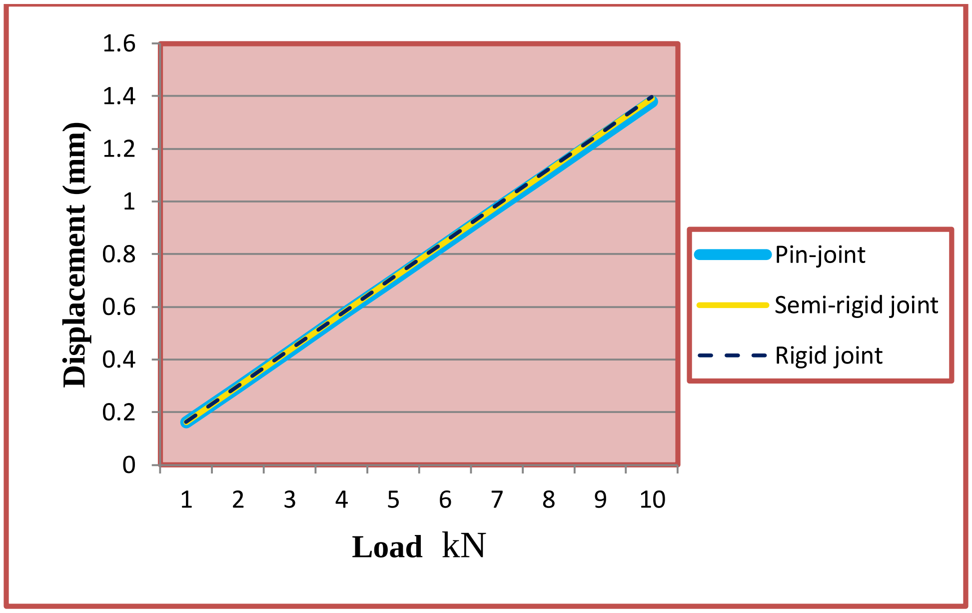


Figure (5.1b) : Vertical Displacement for Flat roof due to uniform distributed load with self weight

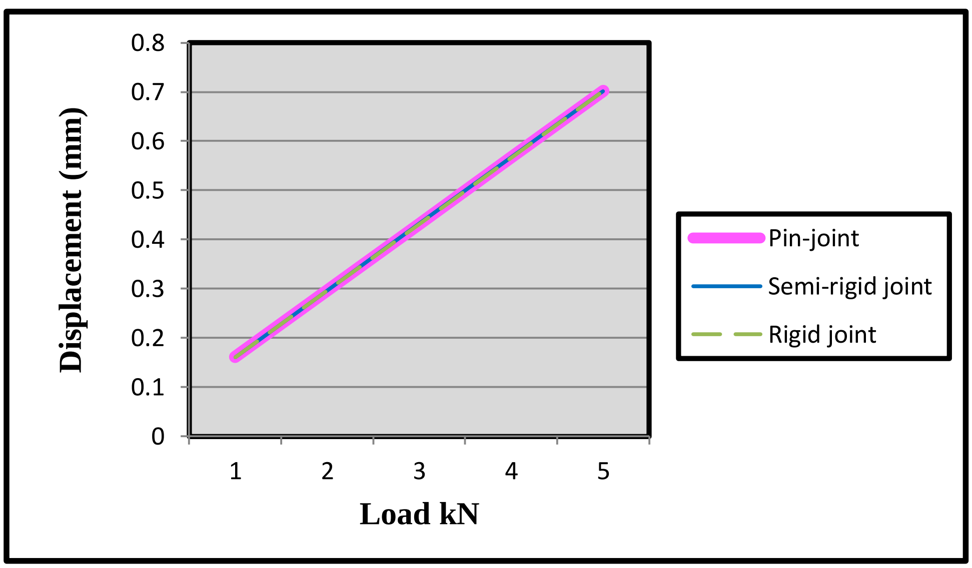


Figure (5.1c) : Vertical Displacement for Flat roof due to concentrated load with self weight

The steel P.M interaction ratios (AISC 360-10) due to case (a), all members are less than 0.5 percentages for pinned, semi-rigid, and rigid joints. The design for rigid and semi-rigid joints obtained due to case (b) and (c) of load compared with the same results of the pin-joints from the SAP2000-16 program in tables (5.2), (5.3), and (5.4) below.

The summary of the design results presented in table (5.5). column A show the type of all failures , column B give the numbers of steel frames failed stress/capacity check, and column C explain the numbers of members over stressed.

Table (5.2) : Steel P.M interaction ratios (AISC 360-10) for flat roof due to Load = 6 kN/m + self weight

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
2, 4, 17, 19	4	1.134	0.787	0.929
3, 18	2	1.261	0.921	1.004
7, 9, 12, 14	4	1.168	0.824	0.941
8, 13	2	1.343	1.00	1.005
28, 31	2	0.973	0.573	0.691
62, 77, 104, 132	4	1.001	1.114	1.181
64, 79, 102, 117	4	1.143	1.161	1.188

Table (5.3): Steel P.M interaction ratios (AISC 360-10) for flat roof due to Load = 5 kN/m + self weight

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
2, 4, 17, 19	4	0.948	0.658	0.777
3, 18	2	1.054	0.770	0.840
7, 9, 12, 14	4	0.977	0.687	0.787
8, 13	2	1.123	0.837	0.908
28, 31	2	0.812	0.479	0.577
62, 77, 104, 132	4	0.839	0.932	0.988
64, 79, 102, 117	4	0.958	0.974	0.995

Table (5.4): Steel P.M interaction ratios (AISC 360-10) for flat roof due to Load = 5 - 7.5 - 10 kN + self weight

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
2, 4, 17, 19	4	0.283	0.281	0.285
3, 18	2	0.390	0.388	0.388
7, 9, 12, 14	4	0.312	0.310	0.313
8, 13	2	0.458	0.457	0.456
28, 31	2	0.064	0.062	0.061
62, 77, 104, 132	4	0.839	0.840	0.843
64, 79, 102, 117	4	0.958	0.959	0.962

Table (5.5): The summary of the design results for flat roof

The cases	Types of joint	A	B	C
Case (b) due to load 6KN/m with self weight	Pinned	Flexure	20	22
	Semi-rigid	Flexure	8	10
	Rigid	Flexure	12	12
Case (b) due to load 5KN/m with self weight	Pinned	Flexure	4	12
	Semi-rigid	Flexure	-	4
	Rigid	Flexure	-	8
Case (c) due to load 5KN/m with self weight	Pinned	Flexure	-	4
	Semi-rigid	Flexure	-	4
	Rigid	Flexure	-	4

Where : A show the type of all failures.

B give the numbers of steel frames failed stress/capacity check.

C explain the numbers of members over stressed.

5.3- Example two : Ascending roof towards the field :

In the ascending roof, the joints considered to be pinned, semi-rigid, and rigid. The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load are compared with the results of the pin-jointed dome from the SAP2000 -16 program in tables (5.6a), (5.6b), and (5.6c) respectively. The cases are:

a- The vertical displacements (mm) due to self weight.

b- The vertical displacements (mm) due to uniform distributed load with self weight.

c- The vertical displacements (mm) due to concentrated load with self weight.

Table (5.6a) : The vertical displacements (mm) for ascending roof due to self weight

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid join (mmt
self weight	0.029	0.029	0.029

Table (5.6b) : The vertical displacements (mm) for ascending roof due to uniform distributed load with self weight

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
1	0.179	0.180	0.180
2	0.329	0.331	0.331
3	0.480	0.482	0.483
4	0.631	0.634	0.634
5	0.781	0.785	0.785
6	0.932	0.936	0.937
7	1.082	1.087	1.088
8	1.233	1.238	1.240
9	1.384	1.390	1.391
10	1.534	1.541	1.543

Table (5.6c) : The vertical displacements (mm) for ascending roof due to concentrated load with self weight

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint(mm)
2.11803	0.179	0.179	0.179
4.23606	0.329	0.329	0.329
6.35409	0.480	0.480	0.479
8.47212	0.631	0.630	0.630
10.59015	0.781	0.781	0.780

The maximum displacement at node 27 and 37 for the three cases. The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load when compared with the results of the pin-jointed dome from the SAP2000 -16 are plotted in figures (5.2a) , (5.2b), and (5.2c) below **:**

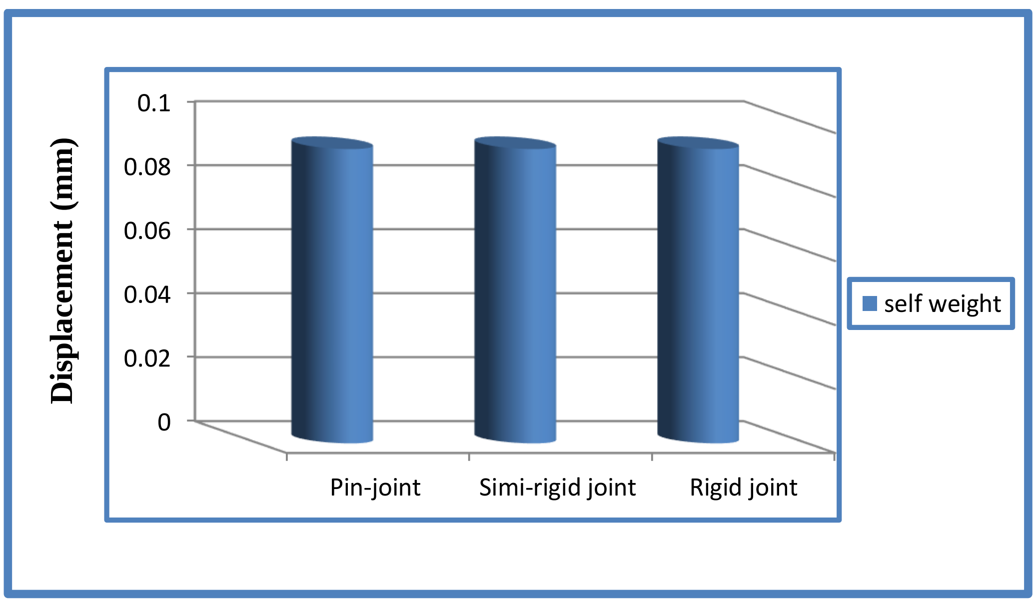


Figure (5.2a) : Vertical Displacement for ascending roof due to self weight

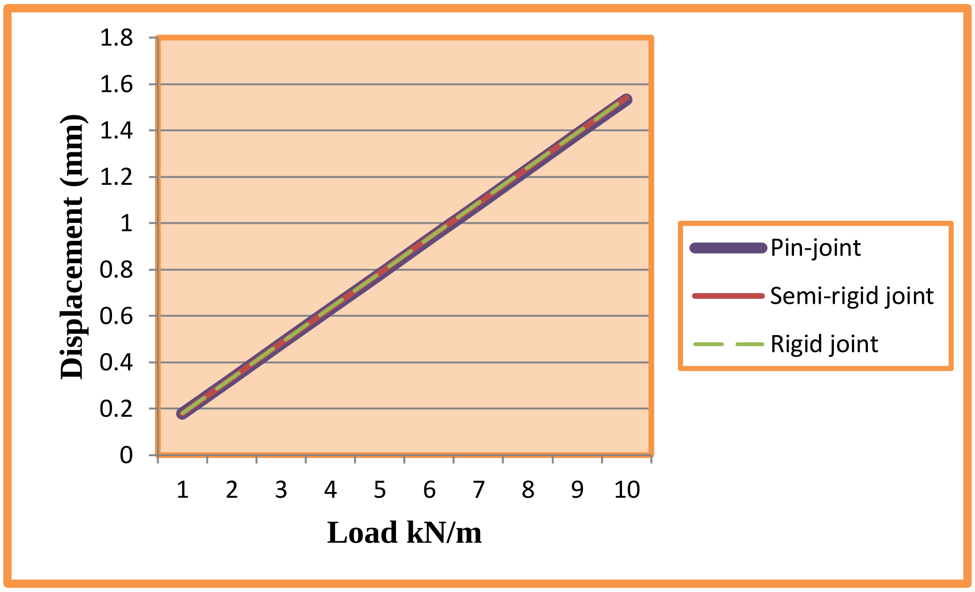


Figure (5.2b) : Vertical Displacement for ascending roof due to uniform distributed load with self weight

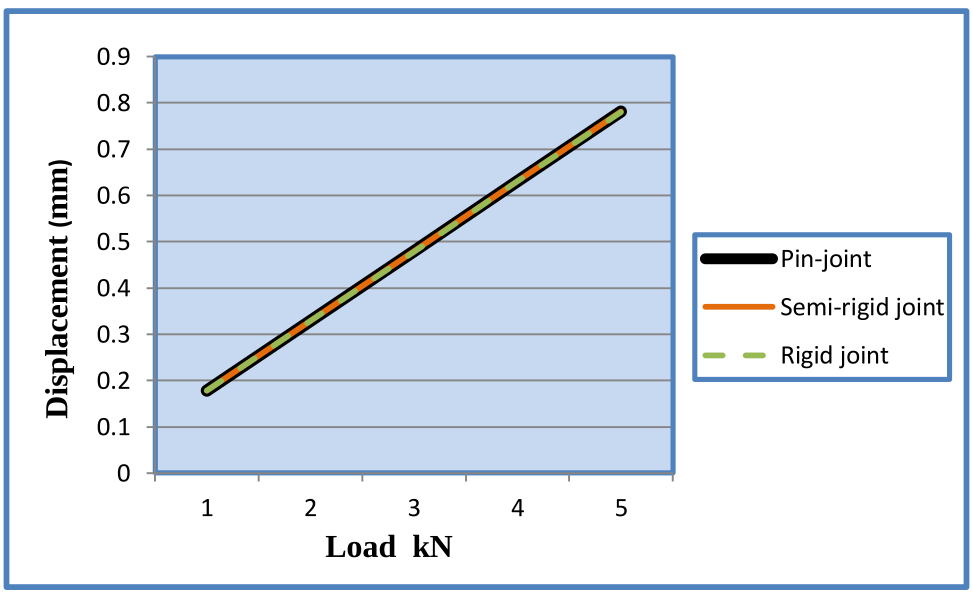


Figure (5.2c) : Vertical Displacement for ascending roof due to concentrated load with self weight

The steel P.M interaction ratios (AISC 360-10) for all members are less than 0.5 percentages for pinned, semi-rigid, and rigid joints thus for case (a). The results of case (b) and (c) presented in table (5.7), (5.8).

The summary of the design results presented in table (5.9).

Table (5.7) : Steel P.M interaction ratios (AISC 360-10) for ascending roof due to Load = 5 kN/m + self weight

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
2, 17	2	1.076	0.741	0.929
3, 18	2	1.198	0.869	1.007
4, 19	2	1.071	0.736	0.864
7, 12	2	1.125	0.791	0.958
8, 13	2	1.306	0.975	1.111
9, 14	2	1.130	0.794	0.919
62, 102	2	1.764	1.839	1.876
64, 104	2	1.875	1.896	1.915
66, 108	2	0.823	0.878	0.894
68, 106	2	0.783	0.790	0.800
77, 119	2	0.706	0.803	0.864
78, 120	2	0.556	0.680	0.715
79, 117	2	0.881	0.898	0.924
80, 118	2	0.850	0.945	0.990

Table (5.8) : Steel P.M interaction ratios (AISC 360-10) for ascending roof due to Load = 10.59015 kN + self weight

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
2, 17	2	0.333	0.331	0.334
3, 18	2	0.454	0.453	0.452
4, 19	2	0.328	0.326	0.331
7, 12	2	0.382	0.379	0.382
8, 13	2	0.563	0.561	0.560
9, 14	2	0.387	0.384	0.388
62, 102	2	1.764	1.765	1.767
64, 104	2	1.875	1.1.875	1.877
66, 108	2	0.823	0.822	0.823
68, 106	2	0.783	0.781	0.781
77, 119	2	0.706	0.706	0.709
78, 120	2	0.556	0.55	0.556
79, 117	2	0.881	0.555	0.884
80, 118	2	0.850	0.848	0.849

Table (5.9) : The summary of the design results for ascending roof

The cases	Types of joint	A	B	C	D
Case (a)	Pinned	-	-	-	20
	Semi-rigid	-	-	-	20
	Rigid	-	-	-	20
Case (b)	Pinned	Flexure	16	16	20
	Semi-rigid	Flexure	4	6	20
	Rigid	Flexure	8	12	20
Case (c)	Pinned	Flexure	4	4	20
	Semi-rigid	Flexure	4	4	20
	Rigid	Flexure	4	4	20

Where : A show the type of all failures.

B give the numbers of steel frames failed stress/capacity check.

C explain the numbers of members over stressed.

D give the numbers of warning.

5.4 - Example three : Curved roof:

The curved roof considered the joints to be as pinned, semi-rigid, and rigid. The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load are compared with the results of the pin-jointed dome from the SAP2000-16 program in tables (5.10a), (5.10b), and (5.10c) respectively. The cases are:

a- The vertical displacements (mm) due to self weight.

b- The vertical displacements (mm) due to uniform distributed load with self weight.

c- The vertical displacements (mm) due to concentrated load with self weight.

Table (5.10a) : The vertical displacements (mm) for Curved roof due to self weight

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
self $weight_1$	0.786	0.791	0.797
self $weight_2$	0.786	0.789	0.794

Wher : The self $weight_1$ obtained due to cross-section area $4.273*E^{-4}$ m^2 .
and self $weight_2$ obtained due to cross-section area $3.845*E^{-3}$ m^2.
The maximum displacement at node 28 and 39.

Table (5.10b) : The vertical displacements (mm) for Curved roof due to uniform distributed load (3*(0.75L)) with self weight $_2$

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
0.75L	1.470	1.474	1.486
2*(0.75L)	2.153	2.159	2.178
3*(0.75L)	2.836	2.844	2.870
4*(0.75L)	3.519	3.529	3.562
5*(0.75L)	4.202	4.214	4.255

Table (5.10 c) : The vertical displacements (mm) for Curved roof due to concentrated load with self weight $_2$

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
$0.75L^2$	1.470	1.471	1.473
$2*(0.75L^2)$	2.153	2.153	2.153
$3*(0.75L^2)$	2.836	2.836	2.833
$4*(0.75L^2)$	3.519	3.518	3.512
$5*(0.75L^2)$	4.202	4.200	4.192

The maximum displacement at node 17 and 23 for case (b) and (c). The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load when compared with the results of the pin-jointed dome from the SAP2000 -16 are plotted in figures (5.3a) , (5.3b), and (5.3c) below **:**

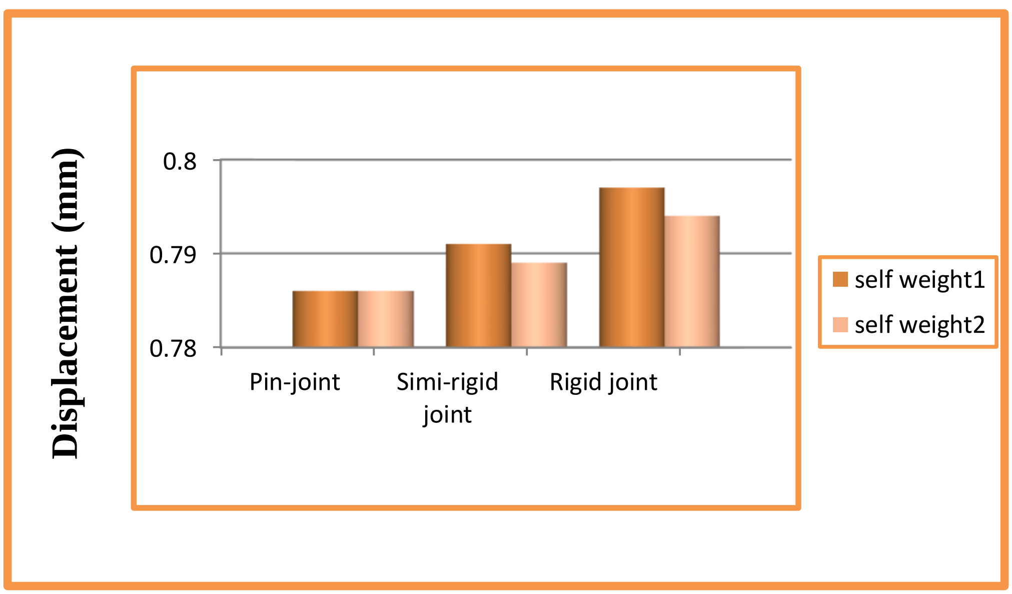


Figure (5.3a) : Vertical Displacement for Curved roof due to self weight $_2$

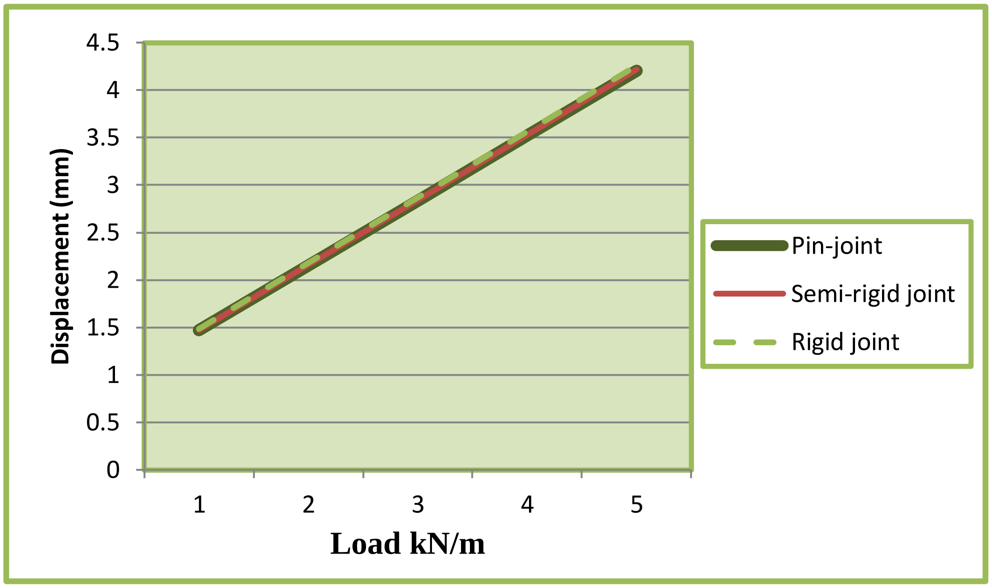


Figure (5.3b) : Vertical Displacement for Curved roof due to uniform distributed load with self weight$_2$

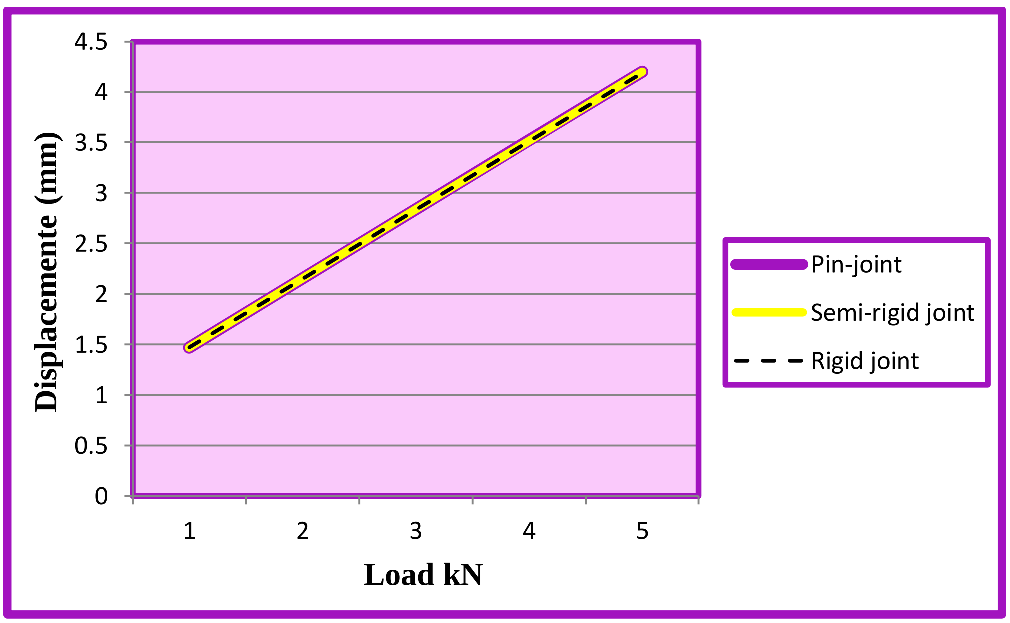


Figure (5.3c) : Vertical Displacement for Curved roof due to concentrated load with self weight$_2$

The steel P.M interaction ratios (AISC 360-10) due to case (a) for self weight$_1$ presented in table (5.11), but for self weight$_2$ all members are less than 0.5 percentage for pinned, semi-rigid, and rigid joints.

The design for rigid and semi-rigid joints obtained due to case (b) and (c) of load with self weight$_2$ compared with the same results of the pin-jointed dome from the SAP2000-16 program in tables (5.12) and (5.13). The summary of the design results presented in table (5.14).

Table (5.11): Steel P.M interaction ratios (AISC 360-10)

for Curved roof due to self weight$_1$

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
2, 27	2	0.903	0.852	0.876
3, 28	2	1.755	1.706	1.716
4, 29	2	1.755	1.707	1.711
7, 22	2	0.837	0.788	0.816
8, 23	2	1.847	1.804	1.824
9, 24	2	1.953	1.924	1.960
12, 17	2	0.672	0.625	0.653
13, 18	2	1.512	1.472	1.496
14, 19	2	1.354	1.337	1.383
61, 77	2	2.600	2.557	2.604
62, 78	2	0.516	0.476	0.502
64, 80	2	2.081	2.028	2.028
65, 73	2	2.617	2.582	2.640
66, 74	2	0.851	0.815	0.848
69	1	2.637	2.604	2.664

Cont.				
70	1	0.953	0.918	0.952
41, 53	2	0.505	0.499	0.504
47	1	0.650	0.644	0.644
102, 184	2	0.944	0.939	0.954
104, 182	2	0.662	0.661	0.685
122, 164	2	0.668	0.668	0.693
124, 162	2	0.643	0.643	0.664
142, 144	2	0.647	0.646	0.668
117, 199	2	0.590	0.578	0.580
119, 197	2	1.554	1.542	1.550
120, 198	2	0.585	0.566	0.563
139, 177	2	0.660	0.651	0.641

Table (5.12): Steel P.M interaction ratios (AISC 360-10) for Curved roof due to distributed load with self weight$_2$

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
3, 28	2	0.685	0.671	0.663
4, 29	2	0.682	0.668	0.660
8, 23	2	0.711	0.701	0.701
9, 24	2	0.724	0.715	0.719

Cont.				
13, 18	2	0.566	0.557	0.562
47	1	0.584	0.529	0.474
61, 77	2	1.011	0.996	0.996
64, 80	2	0.829	0.816	0.826
65, 73	2	1.019	1.008	1.020
69	1	1.027	1.016	1.030
119, 197	2	0.692	0.689	0.711

Table (5.13): Steel P.M interaction ratios (AISC 360-10) for Curved roof due to concentrated load with self weight$_2$

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
3, 28	2	0.685	0.673	0.669
4, 29	2	0.682	0.671	0.668
8, 23	2	0.711	0.709	0.699
9, 24	2	0.724	0.714	0.713
13, 18	2	0.566	0.555	0.556
47	1	0.267	0.266	0.264
61, 77	2	1.011	0.997	1.002
64, 80	2	0.829	0.816	0.819
65, 73	2	1.019	1.006	1.012

Cont.				
69	1	1.027	1.014	1.021
119, 197	2	0.692	0.688	0.699

Table (5.14): The summary of the design results for curved roof

The cases	Types of joint	A	B	C	D
Case (a) due to self weight$_1$	Pinned	Flexure	21	24	120
	Semi-rigid	Flexure	21	24	120
	Rigid	Flexure	21	24	120
Case (a) due to self weight$_2$	Pinned	-	-	-	45
	Semi-rigid	-	-	-	45
	Rigid	-	-	-	45
Case (b)	Pinned	Flexure	5	5	45
	Semi-rigid	Flexure	3	5	45
	Rigid	Flexure	3	5	45
Case (c)	Pinned	Flexure	5	5	45
	Semi-rigid	Flexure	3	5	45
	Rigid	Flexure	5	5	45

Where : A show the type of all failures.

B give the numbers of steel frames failed stress/capacity check.

C explain the numbers of members over stressed.

D give the numbers of warning.

5.5- Example four : Circular arc roof :

In this example the joints considered to be pinned, semi-rigid, and rigid. The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load are compared with the results of the pin-jointed dome from the SAP2000 -16 program in tables (5.15a), (5.15b), and (5.15c) respectively. The cases are:

a- The vertical displacements (mm) due to self weight.

b- The vertical displacements (mm) due to uniform distributed load with self weight.

c- The vertical displacements (mm) due to concentrated load with self weight.

Table (5.15a): The vertical displacements (mm) for Circular arc roof due to self weight

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
self weight$_1$	1.980	1.984	1.990
self weight$_2$	1.980	1.983	1.988

Where : The self weight$_1$ obtained due to cross-section area $4.273*E^{-4}$ m^2 .

and self weight$_2$ obtained due to cross-section area $3.845*E^{-3}$ m^2.

The maximum displacement at node 17 .

Table (5.15b) : The vertical displacements (mm) for Circular arc roof due to uniform distributed load (1.765*(0.75L)) with self weight $_2$

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi -rigid joint (mm)	Dis. of Rigid joint (mm)
0.75L	4.004	4.016	4.040
1.5*(0.75L)	5.016	5.033	5.066

Cont.			
2*(0.75L)	6.028	6.050	6.092
2.5*(0.75L)	7.040	7.067	7.118
3*(0.75L)	8.052	8.083	8.144

Table (5.15 c) : The vertical displacements (mm) for Circular arc roof due to concentrated load with self weight 2

Load (kN/m)	**Dis. of Pin - joint (mm)**	**Dis. of Semi - rigid joint (mm)**	**Dis. of Rigid joint (mm)**
$0.75L^2$	4.004	4.006	4.010
$1.5*(0.75L^2)$	5.016	5.018	5.021
$2*(0.75L^2)$	6.028	6.030	6.032
$2.5*(0.75L^2)$	7.040	7.041	7.043
$3*(0.75L^2)$	8.052	8.053	8.054

The maximum displacement at node 91 and 92 for case (b) and (c). The results of the rigid and semi-rigid joint obtained for vertical displacement due to three cases of load when compared with the results of the pin-jointed dome from the SAP2000 -16 are plotted in figures (5.4a) , (5.4b), and (5.4c) below **:**

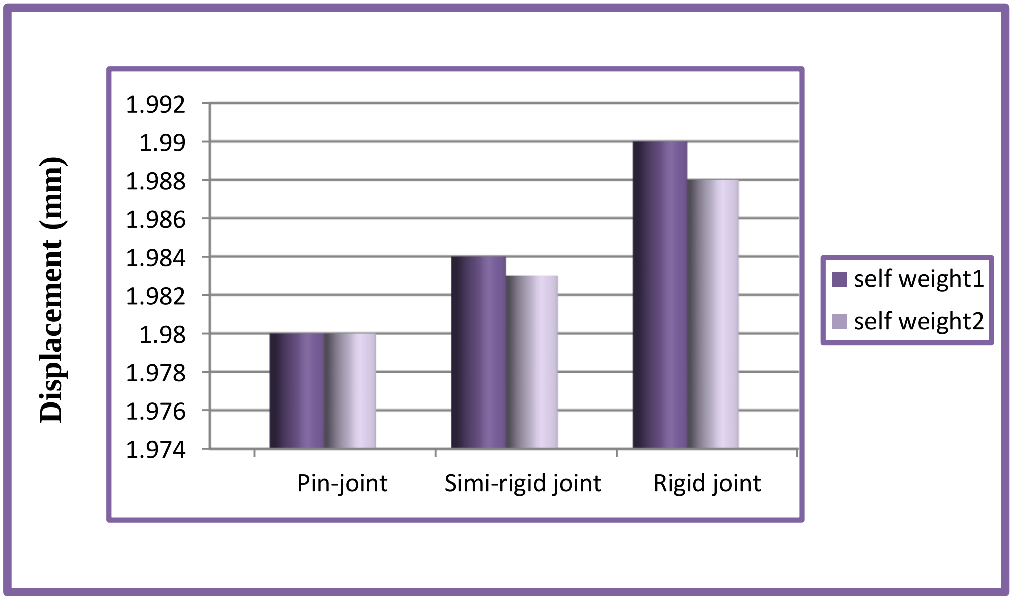


Figure (5.4a) : Vertical Displacement for Circular arc roof due to self weight

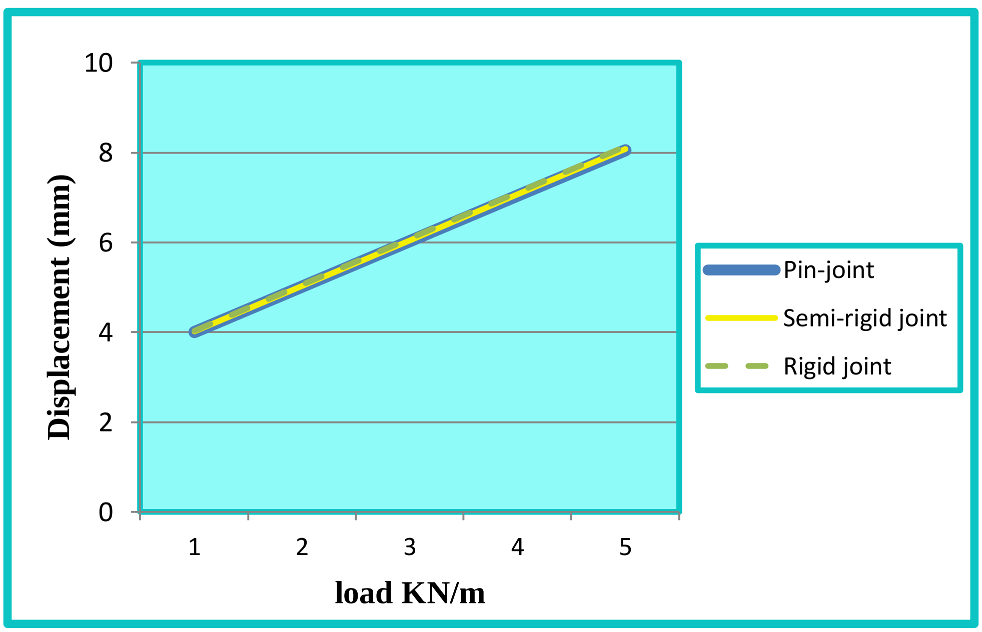


Figure (5.4b) : Vertical Displacement for Circular arc roof due to uniform distributed load with self weight 2

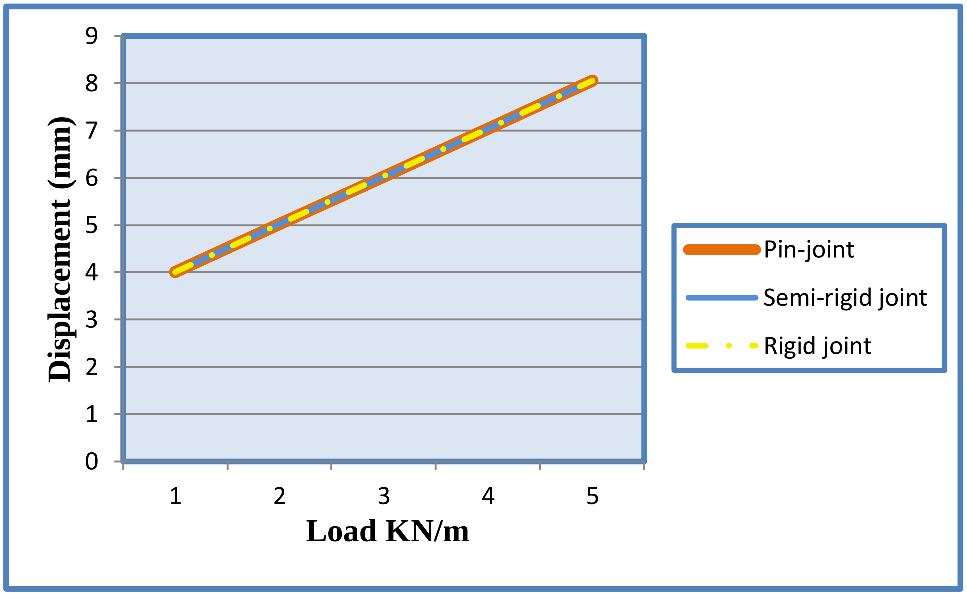


Figure (5.4c) : Vertical Displacement for Circular arc roof due to uniform distributed load with self weight $_2$

The steel P.M interaction ratios (AISC 360-10) due to case (a) for self weight$_1$ presented in table (5.16), but for self weight$_2$ all members are less than 0.5 percentage for pinned, semi-rigid, and rigid joints and there is no warrnig.

The design for rigid and semi-rigid joints obtained due to case (b) and (c) of load with self weight$_2$ compared with the results of the pin-jointed dome from the SAP2000-16 program in tables (5.17) and (5.18). The summary of the design results presented in table (5.19).

Table (5.16) : Steel P.M interaction ratios (AISC 360-10) for Circular arc roof due to self weight$_1$

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
3, 8 53, 58	4	1.179	1.147	1.145

cont.				
4, 7 54, 57	4	1.770	1.735	1.727
5, 6 55, 56	4	2.025	1.989	1.979
13, 18 43, 48	4	1.265	1.240	1.248
14, 17 44, 47	4	1.354	1.337	1.383
15, 16 45, 46	4	2.382	2.356	2.359
23, 28 33, 38	4	1.312	1.290	1.301
24, 27 34, 37	4	2.139	2.117	2.125
25, 26 35, 36	4	2.513	2.491	2.499
116, 124 152, 160	4	3.227	3.189	3.193
117, 123 153, 159	4	2.293	2.261	2.264
118, 122	4	1.175	1.148	1.150

Cont.				
154, 158				
134, 141	2	3.238	3.213	3.231
135, 140	2	2.308	2.283	2.295
136, 139	2	1.292	1.270	1.276
125, 133	4	3.222	3.194	3.208
143, 151				
126, 132	4	2.291	2.265	2.275
144, 150				
127, 131	4	1.263	1.240	1.245
145, 149				

Table (5.17) : Steel P.M interaction ratios (AISC 360-10) for Circular arc roof due to distributed load with self weight$_2$

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
4, 7	4	0.557	0.548	0.540
54, 57				
5, 6	4	0.637	0.628	0.619
55, 56				
14, 17	4	0.641	0.636	0.635
44, 47				

Cont.				
15, 16 45, 46	4	0.745	0.741	0.738
24, 27 34, 37	4	0.667	0.664	0.667
25, 26 35, 36	4	0.784	0.782	0.783
116, 124 152, 160	4	1.009	1.000	1.000
117, 123 153, 159	4	0.721	0.713	0.711
125, 133 143, 151	4	1.003	0.998	1.006
126, 132 144, 150	4	0.717	0.713	0.714
134, 141	2	1.006	1.003	1.014
135, 140	2	0.722	0.718	0.721

Table (5.18) : Steel P.M interaction ratios (AISC 360-10) for Circular arc roof due to concentrated load with self weight2

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
4, 7 54, 57	4	0.551	0.548	0.548
5, 6 55, 56	4	0.637	0.631	0.627
14, 17 44, 47	4	0.641	0.636	0.633
15, 16 45, 46	4	0.745	0.740	0.736
24, 27 34, 37	4	0.667	0.662	0.660
25, 26 35, 36	4	0.784	0.779	0.775
116, 124 152, 160	4	1.009	1.002	1.005
117, 123 153, 159	4	0.721	0.715	0.712
125, 133 143, 151	4	1.003	0.996	1.001

Cont.				
126, 132	4	0.717	0.711	0.710
144, 150				
134, 141	2	1.006	1.000	1.005
135, 140	2	0.722	0.716	0.715

Table (5.19) : The summary of the design results for Circular arc roof

The cases	Types of joint	A	B	C	D
Case (a) due to self weight$_1$	Pinned	Flexure	72	72	148
	Semi-rigid	Flexure	72	72	148
	Rigid	Flexure	72	72	148
Case (b)	Pinned	Flexure	10	10	-
	Semi-rigid	Flexure	2	10	-
	Rigid	Flexure	10	10	-
Case (c)	Pinned	Flexure	10	10	-
	Semi-rigid	Flexure	4	10	-
	Rigid	Flexure	10	10	-

Where : A show the type of all failures.

B give the numbers of steel frames failed stress/capacity check.

C explain the numbers of members over stressed.

D give the numbers of warning**.**

5.6- Example five: Circular dome roof:

The joints of circular dome roof considered to be pinned, semi-rigid, and rigid. The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load are compared with the results of the pin-joints from the SAP2000-16 program in tables (5.20.1 a), (5.20.1 b), and (5.20.1c) respectively. The percentage difference in the results presented in tables (5.20.2 a),(5.20.2 b), and (5.20.2 c) respectively. The cases are:

a- The vertical displacements (mm) due to self weight.

b- The vertical displacements (mm) due to uniform distributed load with self weight.

c- The vertical displacements (mm) due to concentrated load with self weight.

Table (5.20.1 a) : The vertical displacements (mm) for Circular dome roof due to self weight

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
self weight$_1$	18.642	17.306	15.670
self weight$_2$	18.642	18.615	15.857

Where : The self weight$_1$ obtained due to cross-section area 0.0032 m^2.

and self weight$_2$ obtained due to cross-section area 0.0288 m^2.

The maximum displacement at node 97.

Table (5.20.2 a) : The difference % in the displacements for Circular dome roof due to self weight

(X - Y) / X %	(X - Z) / X %	(Y - Z) / Y %
7.18	15.94	9.45
8.15	14.94	14.82

Where : X is dis. of pin - joint (mm) , Y is dis. of semi-rigid joint (mm), and Z is dis. of rigid joint (mm)

Table (5.20.1b) : The vertical displacements (mm) for Circular dome roof due to uniform distributed load (7.2*(0.75L)) with self weight 2

Load (kN/m)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
0.75L	21.209	21.164	18.978
3*(0.75L)	35.504	35.390	30.188
5*(0.75L)	49.800	49.616	41.398
7*(0.75L)	64.584	64.329	53.112
9*(0.75L)	78.391	78.067	63.818

Table (5.20.2 b) : The difference% in the displacements for Circular dome roof due to uniform distributed load (7.2*(0.75L)) with self weight 2

(X - Y) / X %	(X - Z) / X %	(Y - Z) / Y %
0.21	10.52	10.33
0.32	14.97	14.70
0.37	16.87	16.56

Cont.		
0.40	17.76	17.44
0.41	18.59	18.25

Where : X is dis. of pin - joint (mm) , Y is dis. of semi-rigid joint (mm), and Z is dis. of rigid joint (mm)

Table (5.20.1 c) : The vertical displacements (mm) for Circular dome roof duo to concentrated load with self weight $_2$

Load (kN)	Dis. of Pin-joint (mm)	Dis. of Semi-rigid joint (mm)	Dis. of Rigid joint (mm)
$0.75L^2$	21.209	21.164	18.920
$3*(0.75L^2)$	35.504	35.388	30.014
$5*(0.75L^2)$	49.800	49.612	41.108
$7*(0.75L^2)$	64.096	63.837	52.202
$9*(0.75L^2)$	78.391	78.061	63.296

Table (5.20.2 c) : The difference % in the displacements for Circular dome roof duo to concentrated load with self weight $_2$

(X - Y) / X %	(X - Z) / X %	(Y - Z) / Y %
0.21	10.79	10.60
0.32	15.46	15.19
0.38	17.45	17.14
0.40	18.56	18.23
0.42	19.26	18.92

Where : X is dis. of pin - joint (mm) , Y is dis. of semi-rigid joint (mm), and Z is dis. of rigid joint (mm).

The maximum displacement at node 96 for case (b) and (c). The results of the rigid and semi-rigid joints obtained for vertical displacement due to three cases of load when compared with the results of the pin-jointed dome from the SAP2000 - 16 are plotted in figures (5.5a) , (5.5b), and (5.5c) below **:**

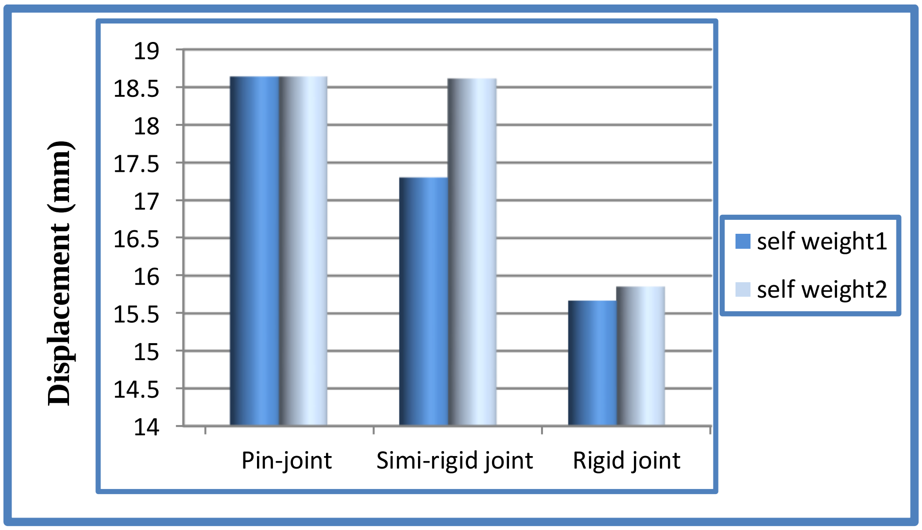


Figure (5.5.a) : Vertical Displacement for Circular Dome roof due to self weight

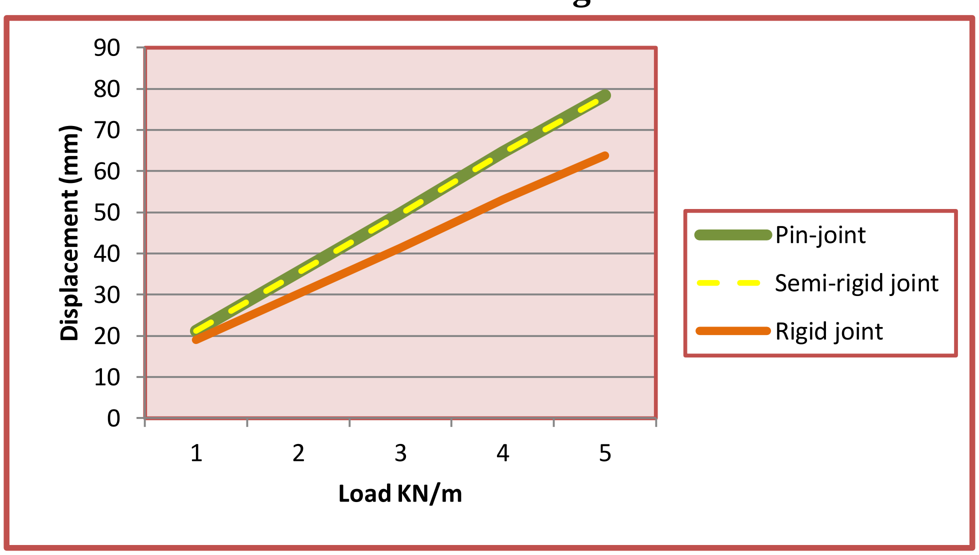


Figure (5.5b) : Vertical Displacement for Circular Dome roof due to uniform distributed load with self weight

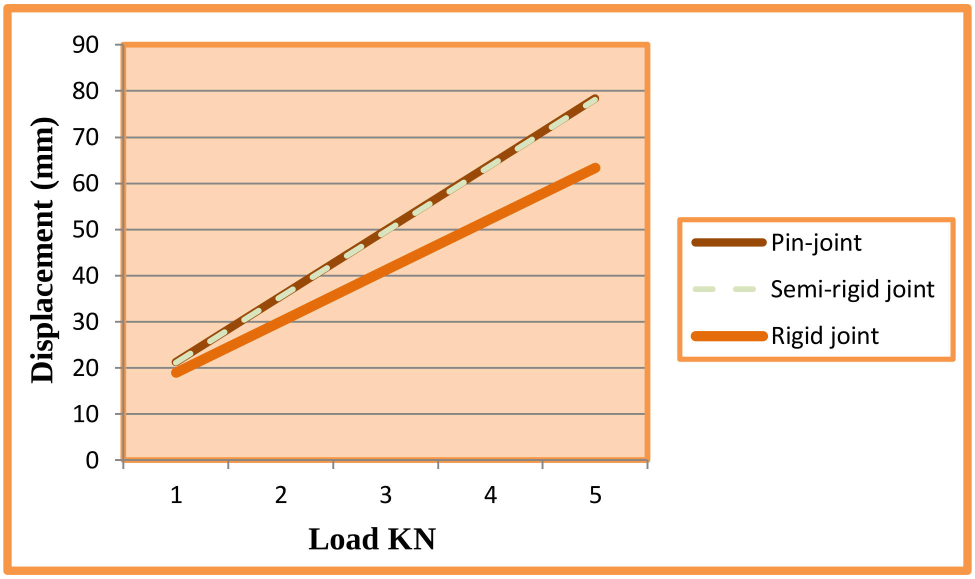


Figure (5.5c) : Vertical Displacement for Circular Dome roof due to uniform distributed load with self weight

The steel P.M interaction ratios (AISC 360-10) due to case (a) for self weight$_1$ presented in table (5.21), but for self weight$_2$ all members are less than 0.5 percentages for pinned, semi-rigid, and rigid joints.

The design for rigid and semi-rigid joints obtained due to case (b) and (c) of load with self weight$_2$ compared with the results of the pin-jointed dome from the SAP2000-16 program in tables (5.22) and (5.23). The summary of the design results presented in table (5.24).

Table (5.21) : Steel P.M interaction ratios (AISC 360-10) for Circular dome roof due to self weight$_1$

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
	24	1.009	1.008	1.069
	24	2.449	2.406	2.381
	24	2.765	2.599	2.582

Table (5.22) : Steel P.M interaction ratios (AISC 360-10) for Circular dome roof due to distributed load with self weight2

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
	24	0.749	0.751	0.978
	24	0.997	0.995	1.002
	24	0.462	0.461	0.618
	24	0.745	0.741	0.541
	24	0.064	0.064	0.549

Table (5.23) : Steel P.M interaction ratios (AISC 360-10) for Circular dome roof due to concentrated load with self weight2

Member No.	No. of members	Ratios		
		Pinned	Semi-rigid	Rigid
	24	0.749	0.751	0.969
	24	0.997	0.995	0.992
	24	0.462	0.461	0.630
	24	0.064	0.064	0.534

Table (5.24) : The summary of the design results for Circular dome roof

The cases	Types of joint	A	B	C	D
Case (a) due to self weight$_1$	Pinned	Flexure	72	72	148
	Semi-rigid	Flexure	72	72	148
	Rigid	Flexure	72	72	148
Case (b)	Pinned	Flexure	-	24	-
	Semi-rigid	Flexure	-	24	-
	Rigid	Flexure	24	48	-
Case (c)	Pinned	Flexure	-	24	-
	Semi-rigid	Flexure	-	24	-
	Rigid	Flexure	-	48	-

Where : A show the type of all failures.

B give the numbers of steel frames failed stress/capacity check.

C explain the numbers of members over stressed.

D give the numbers of warning

5.7- Comparison of results:

The results of the displacements for case (a) show that, displacement of the rigid joints is the largest one that in examples 1to 4 but in example 5 is the smallest one with difference (15.94 %) for self weight$_1$ and (14.94 %) for self weight$_2$.

Case (b) and (c) show that there are small differences in the results, this for examples 1 to 4 , but example 5 show the displacements of the semi-rigid are less than the result of the pinned and greater than these of the rigid with a difference of (18.59 %) for case (b) and (19.26 %) for case (c) .

The result of the design for three cases show that semi-rigid is the best one. In examples 3 to 5 the self $weight_1$ changed with the self $weigh_2$ because when the case (a) was designed some steel frames failed stress/capacity check.

Chapter Six

Conclusion and recommendation

6.1- Conclusions:

From the analysis and discation of the results of the analyzed and the designed it is concluded that:

* The five stadia dome roofs were analyzed and designed as case studies by assuming their joints to be pinned, semi-rigid, and rigid.

* The comparison of the pin-jointed frames was obtained for vertical displacement due to increments of vertical load neglecting self weight and it showed very good agreement.

* The results of the rigid and semi-rigid jointed frames for vertical displacement were compared with the results of the pin-jointed frames and were in close agreement.

* The comparison of the displacements of the dome for the three types of joints shows that:-

For self weight only (case (a)) taken into account:

(1) The displacement of the rigid jointed dome is the largest in examples 1 to 4.

(2) For the circular dome roof (example 5), the displacement of the rigid jointed dome is the smallest with difference (15.94 %) for self $weight_1$ and (14.94 %) for self $weight_2$.

For self weight plus u.d.l (cases (b)) or concentrated load (case (c)):

(1) The displacements are in very close agreement for all joint types in examples 1 to 4.

(2) For the circular dome roof, the displacement of the rigid jointed dome is the smallest (same as for self-weight only) with a difference of (18.59 %) for case (b) and (19.26 %) for case (c) .

* To obtain structures that will be safe and stable and fit for purposes all the domes were designed according the AISC 360-10 code. As a result of this:

(1) For self weight alone a large number of members failed, as shown in chapter five, and the x-sectional dimensions had to be changed. The cross-section area of curved and circular arc roofs changed to $3.845{*}E^{-3}\ m^2$, but the cross-section area of circular dome roof changed to $0.0288\ m^2$.

(2) Failure of members, for self-weight plus applied load, was used as a measure of the fitness for purpose.

(3) In all examples, the semi-rigid jointed frames had the minimum number of members failure with increase in load.

Thus, assuming semi-rigid joints is the best choice for different types of domes.

6.2- Recommendations:

A. From the work presented in this research, the following future work directions are suggested:

1- Study of the effect of assuming that the joints are pinned, semi-rigid, or rigid by adopting a nonlinear finite formulation of space frame elements.

2- Study of the effect of joints type on the performance of multy story frame by adopting a linear and nonlinear finite formulation of space frame elements.

3- More studies to be done considering other types of stadia dome roofs.

4- Study of the effect of the reactions in the foundations of stadia dome roof whern adopting rigid joints.

5- Studying the analysis of retractable stadia dome roof because it is suitable for Sudanese and African weather.

B. From the results obtained and presented it is recommended that:

1- The self weight of the dome must be added to the vertical load that is applied to the stadia dome roofs to have actual roof loads in the design.

2- Semi-rigid joints are to be used in the design of the stadia dome roof types presented in this study.

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Appendices

Appendix A

Input and Sample of Output Data

A.1- Input data:

A.1.1- Example one: Flat roof:

Table: Frame Section Properties 01 - General

Section Name	Material	Shape	t3 m	tw m	Area m2	Tors Const m4
FSEC2	A992Fy50	Pipe	0.028286	0.014000	0.000628	6.284E-08

Table: Material Properties 02 - Basic Mechanical Properties

Material	Unit Weight KN/m3	Unit Mass KN-s2/m4	E1 KN/m2	G12 KN/m2	U12	A1 1/C
A992Fy50	7.6973E+01	7.8490E+00	205000000.0	78846153.85	0.300000	1.1700E-05

Table: Connectivity - Frame

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
1	1	2	No	1.00000	0.50000	0.00000	0.00000
2	2	3	No	1.00000	1.50000	0.00000	0.00000
3	3	4	No	1.00000	2.50000	0.00000	0.00000
4	4	5	No	1.00000	3.50000	0.00000	0.00000
5	5	6	No	1.00000	4.50000	0.00000	0.00000
6	7	8	No	1.00000	0.50000	-1.00000	0.00000
7	8	9	No	1.00000	1.50000	-1.00000	0.00000
8	9	10	No	1.00000	2.50000	-1.00000	0.00000
9	10	11	No	1.00000	3.50000	-1.00000	0.00000
10	11	12	No	1.00000	4.50000	-1.00000	0.00000
11	13	14	No	1.00000	0.50000	-2.00000	0.00000
12	14	15	No	1.00000	1.50000	-2.00000	0.00000
13	15	16	No	1.00000	2.50000	-2.00000	0.00000
14	16	17	No	1.00000	3.50000	-2.00000	0.00000
15	17	18	No	1.00000	4.50000	-2.00000	0.00000
16	19	20	No	1.00000	0.50000	-3.00000	0.00000
17	20	21	No	1.00000	1.50000	-3.00000	0.00000
18	21	22	No	1.00000	2.50000	-3.00000	0.00000
19	22	23	No	1.00000	3.50000	-3.00000	0.00000
20	23	24	No	1.00000	4.50000	-3.00000	0.00000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
21	1	7	No	1.00000	0.00000	-0.50000	0.00000
22	2	8	No	1.00000	1.00000	-0.50000	0.00000
23	3	9	No	1.00000	2.00000	-0.50000	0.00000
24	4	10	No	1.00000	3.00000	-0.50000	0.00000
25	5	11	No	1.00000	4.00000	-0.50000	0.00000
26	6	12	No	1.00000	5.00000	-0.50000	0.00000
27	7	13	No	1.00000	0.00000	-1.50000	0.00000
28	8	14	No	1.00000	1.00000	-1.50000	0.00000
29	9	15	No	1.00000	2.00000	-1.50000	0.00000
30	10	16	No	1.00000	3.00000	-1.50000	0.00000
31	11	17	No	1.00000	4.00000	-1.50000	0.00000
32	12	18	No	1.00000	5.00000	-1.50000	0.00000
33	13	19	No	1.00000	0.00000	-2.50000	0.00000
34	14	20	No	1.00000	1.00000	-2.50000	0.00000
35	15	21	No	1.00000	2.00000	-2.50000	0.00000
36	16	22	No	1.00000	3.00000	-2.50000	0.00000
37	17	23	No	1.00000	4.00000	-2.50000	0.00000
38	18	24	No	1.00000	5.00000	-2.50000	0.00000
39	25	26	No	1.00000	1.00000	-0.50000	-1.00000
40	26	27	No	1.00000	2.00000	-0.50000	-1.00000
41	27	28	No	1.00000	3.00000	-0.50000	-1.00000
42	28	29	No	1.00000	4.00000	-0.50000	-1.00000
43	30	31	No	1.00000	1.00000	-1.50000	-1.00000
44	31	32	No	1.00000	2.00000	-1.50000	-1.00000
45	32	33	No	1.00000	3.00000	-1.50000	-1.00000
46	33	34	No	1.00000	4.00000	-1.50000	-1.00000
47	35	36	No	1.00000	1.00000	-2.50000	-1.00000
48	36	37	No	1.00000	2.00000	-2.50000	-1.00000
49	37	38	No	1.00000	3.00000	-2.50000	-1.00000
50	38	39	No	1.00000	4.00000	-2.50000	-1.00000
51	25	30	No	1.00000	0.50000	-1.00000	-1.00000
52	26	31	No	1.00000	1.50000	-1.00000	-1.00000
53	27	32	No	1.00000	2.50000	-1.00000	-1.00000
54	28	33	No	1.00000	3.50000	-1.00000	-1.00000
55	29	34	No	1.00000	4.50000	-1.00000	-1.00000
56	30	35	No	1.00000	0.50000	-2.00000	-1.00000
57	31	36	No	1.00000	1.50000	-2.00000	-1.00000
58	32	37	No	1.00000	2.50000	-2.00000	-1.00000
59	33	38	No	1.00000	3.50000	-2.00000	-1.00000
60	34	39	No	1.00000	4.50000	-2.00000	-1.00000
61	25	1	No	1.22474	0.25000	-0.25000	-0.50000
62	25	7	No	1.22474	0.25000	-0.75000	-0.50000
63	25	2	No	1.22474	0.75000	-0.25000	-0.50000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
64	25	8	No	1.22474	0.75000	-0.75000	-0.50000
65	26	2	No	1.22474	1.25000	-0.25000	-0.50000
66	26	8	No	1.22474	1.25000	-0.75000	-0.50000
67	26	3	No	1.22474	1.75000	-0.25000	-0.50000
68	26	9	No	1.22474	1.75000	-0.75000	-0.50000
69	27	3	No	1.22474	2.25000	-0.25000	-0.50000
70	27	9	No	1.22474	2.25000	-0.75000	-0.50000
71	27	4	No	1.22474	2.75000	-0.25000	-0.50000
72	27	10	No	1.22474	2.75000	-0.75000	-0.50000
73	28	4	No	1.22474	3.25000	-0.25000	-0.50000
74	28	10	No	1.22474	3.25000	-0.75000	-0.50000
75	28	5	No	1.22474	3.75000	-0.25000	-0.50000
76	28	11	No	1.22474	3.75000	-0.75000	-0.50000
77	29	5	No	1.22474	4.25000	-0.25000	-0.50000
78	29	11	No	1.22474	4.25000	-0.75000	-0.50000
79	29	6	No	1.22474	4.75000	-0.25000	-0.50000
80	29	12	No	1.22474	4.75000	-0.75000	-0.50000
81	30	7	No	1.22474	0.25000	-1.25000	-0.50000
82	30	13	No	1.22474	0.25000	-1.75000	-0.50000
83	30	8	No	1.22474	0.75000	-1.25000	-0.50000
84	30	14	No	1.22474	0.75000	-1.75000	-0.50000
85	31	8	No	1.22474	1.25000	-1.25000	-0.50000
86	31	14	No	1.22474	1.25000	-1.75000	-0.50000
87	31	9	No	1.22474	1.75000	-1.25000	-0.50000
88	31	15	No	1.22474	1.75000	-1.75000	-0.50000
89	32	9	No	1.22474	2.25000	-1.25000	-0.50000
90	32	15	No	1.22474	2.25000	-1.75000	-0.50000
91	32	10	No	1.22474	2.75000	-1.25000	-0.50000
92	32	16	No	1.22474	2.75000	-1.75000	-0.50000
93	33	10	No	1.22474	3.25000	-1.25000	-0.50000
94	33	16	No	1.22474	3.25000	-1.75000	-0.50000
95	33	11	No	1.22474	3.75000	-1.25000	-0.50000
96	33	17	No	1.22474	3.75000	-1.75000	-0.50000
97	34	11	No	1.22474	4.25000	-1.25000	-0.50000
98	34	17	No	1.22474	4.25000	-1.75000	-0.50000
99	34	12	No	1.22474	4.75000	-1.25000	-0.50000
100	34	18	No	1.22474	4.75000	-1.75000	-0.50000
101	35	13	No	1.22474	0.25000	-2.25000	-0.50000
102	35	19	No	1.22474	0.25000	-2.75000	-0.50000
103	35	14	No	1.22474	0.75000	-2.25000	-0.50000
104	35	20	No	1.22474	0.75000	-2.75000	-0.50000
105	36	14	No	1.22474	1.25000	-2.25000	-0.50000
106	36	20	No	1.22474	1.25000	-2.75000	-0.50000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
107	36	15	No	1.22474	1.75000	-2.25000	-0.50000
108	36	21	No	1.22474	1.75000	-2.75000	-0.50000
109	37	15	No	1.22474	2.25000	-2.25000	-0.50000
110	37	21	No	1.22474	2.25000	-2.75000	-0.50000
111	37	16	No	1.22474	2.75000	-2.25000	-0.50000
112	37	22	No	1.22474	2.75000	-2.75000	-0.50000
113	38	16	No	1.22474	3.25000	-2.25000	-0.50000
114	38	22	No	1.22474	3.25000	-2.75000	-0.50000
115	38	17	No	1.22474	3.75000	-2.25000	-0.50000
116	38	23	No	1.22474	3.75000	-2.75000	-0.50000
117	39	17	No	1.22474	4.25000	-2.25000	-0.50000
118	39	23	No	1.22474	4.25000	-2.75000	-0.50000
119	39	18	No	1.22474	4.75000	-2.25000	-0.50000
120	39	24	No	1.22474	4.75000	-2.75000	-0.50000

Table: Joint Coordinates

Joint	Coord Sys	Coord Type	X or R m	Y m	Z m	Special Jt	Global X m	Global Y m	Global Z m
1	GLOBAL	Cartesian	0.00000	0.00000	0.00000	No	0.00000	0.00000	0.00000
2	GLOBAL	Cartesian	1.00000	0.00000	0.00000	No	1.00000	0.00000	0.00000
3	GLOBAL	Cartesian	2.00000	0.00000	0.00000	No	2.00000	0.00000	0.00000
4	GLOBAL	Cartesian	3.00000	0.00000	0.00000	No	3.00000	0.00000	0.00000
5	GLOBAL	Cartesian	4.00000	0.00000	0.00000	No	4.00000	0.00000	0.00000
6	GLOBAL	Cartesian	5.00000	0.00000	0.00000	No	5.00000	0.00000	0.00000
7	GLOBAL	Cartesian	0.00000	-1.00000	0.00000	No	0.00000	-1.00000	0.00000
8	GLOBAL	Cartesian	1.00000	-1.00000	0.00000	No	1.00000	-1.00000	0.00000
9	GLOBAL	Cartesian	2.00000	-1.00000	0.00000	No	2.00000	-1.00000	0.00000
10	GLOBAL	Cartesian	3.00000	-1.00000	0.00000	No	3.00000	-1.00000	0.00000
11	GLOBAL	Cartesian	4.00000	-1.00000	0.00000	No	4.00000	-1.00000	0.00000
12	GLOBAL	Cartesian	5.00000	-1.00000	0.00000	No	5.00000	-1.00000	0.00000
13	GLOBAL	Cartesian	0.00000	-2.00000	0.00000	No	0.00000	-2.00000	0.00000
14	GLOBAL	Cartesian	1.00000	-2.00000	0.00000	No	1.00000	-2.00000	0.00000
15	GLOBAL	Cartesian	2.00000	-2.00000	0.00000	No	2.00000	-2.00000	0.00000
16	GLOBAL	Cartesian	3.00000	-2.00000	0.00000	No	3.00000	-2.00000	0.00000
17	GLOBAL	Cartesian	4.00000	-2.00000	0.00000	No	4.00000	-2.00000	0.00000
18	GLOBAL	Cartesian	5.00000	-2.00000	0.00000	No	5.00000	-2.00000	0.00000
19	GLOBAL	Cartesian	0.00000	-3.00000	0.00000	No	0.00000	-3.00000	0.00000
20	GLOBAL	Cartesian	1.00000	-3.00000	0.00000	No	1.00000	-3.00000	0.00000
21	GLOBAL	Cartesian	2.00000	-3.00000	0.00000	No	2.00000	-3.00000	0.00000
22	GLOBAL	Cartesian	3.00000	-3.00000	0.00000	No	3.00000	-3.00000	0.00000
23	GLOBAL	Cartesian	4.00000	-3.00000	0.00000	No	4.00000	-3.00000	0.00000
24	GLOBAL	Cartesian	5.00000	-3.00000	0.00000	No	5.00000	-3.00000	0.00000
25	GLOBAL	Cartesian	0.50000	-0.50000	-1.00000	No	0.50000	-0.50000	-1.00000
26	GLOBAL	Cartesian	1.50000	-0.50000	-1.00000	No	1.50000	-0.50000	-1.00000
27	GLOBAL	Cartesian	2.50000	-0.50000	-1.00000	No	2.50000	-0.50000	-1.00000
28	GLOBAL	Cartesian	3.50000	-0.50000	-1.00000	No	3.50000	-0.50000	-1.00000
29	GLOBAL	Cartesian	4.50000	-0.50000	-1.00000	No	4.50000	-0.50000	-1.00000

Joint	Coord Sys	Coord Type	X or R m	Y m	Z m	Special Jt	Global X m	Global Y m	Global Z m
30	GLOBAL	Cartesian	0.50000	-1.50000	-1.00000	No	0.50000	-1.50000	-1.00000
31	GLOBAL	Cartesian	1.50000	-1.50000	-1.00000	No	1.50000	-1.50000	-1.00000
32	GLOBAL	Cartesian	2.50000	-1.50000	-1.00000	No	2.50000	-1.50000	-1.00000
33	GLOBAL	Cartesian	3.50000	-1.50000	-1.00000	No	3.50000	-1.50000	-1.00000
34	GLOBAL	Cartesian	4.50000	-1.50000	-1.00000	No	4.50000	-1.50000	-1.00000
35	GLOBAL	Cartesian	0.50000	-2.50000	-1.00000	No	0.50000	-2.50000	-1.00000
36	GLOBAL	Cartesian	1.50000	-2.50000	-1.00000	No	1.50000	-2.50000	-1.00000
37	GLOBAL	Cartesian	2.50000	-2.50000	-1.00000	No	2.50000	-2.50000	-1.00000
38	GLOBAL	Cartesian	3.50000	-2.50000	-1.00000	No	3.50000	-2.50000	-1.00000
39	GLOBAL	Cartesian	4.50000	-2.50000	-1.00000	No	4.50000	-2.50000	-1.00000

Table: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
25	Yes	Yes	Yes	Yes	Yes	Yes
29	Yes	Yes	Yes	Yes	Yes	Yes
35	Yes	Yes	Yes	Yes	Yes	Yes
39	Yes	Yes	Yes	Yes	Yes	Yes

A.1.2- Example two: Ascending roof towards the field:

Table: Frame Section Properties 01 - General

SectionName	Material	Shape	t3 m	tw m	Area m2	Tors const m4
FSEC2	A992Fy50	Pipe	0.028286	0.014000	0.000628	6.284E-08

Table: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight KN/m3	UnitMass KN-s2/m4	E1 KN/m2	G12 KN/m2	U12	A1 1/C
A992Fy50	7.6973E+01	7.8490E+00	205000000.0	78846153.85	0.300000	1.1700E-05

Table: Connectivity - Frame

Frame	JointI	JointJ	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
1	1	2	No	1.11803	0.50000	0.00000	0.25000
2	2	3	No	1.11803	1.50000	0.00000	0.75000
3	3	4	No	1.11803	2.50000	0.00000	1.25000
4	4	5	No	1.11803	3.50000	0.00000	1.75000
5	5	6	No	1.11803	4.50000	0.00000	2.25000
6	7	8	No	1.11803	0.50000	-1.00000	0.25000
7	8	9	No	1.11803	1.50000	-1.00000	0.75000
8	9	10	No	1.11803	2.50000	-1.00000	1.25000

Frame	JointI	JointJ	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
9	10	11	No	1.11803	3.50000	-1.00000	1.75000
10	11	12	No	1.11803	4.50000	-1.00000	2.25000
11	13	14	No	1.11803	0.50000	-2.00000	0.25000
12	14	15	No	1.11803	1.50000	-2.00000	0.75000
13	15	16	No	1.11803	2.50000	-2.00000	1.25000
14	16	17	No	1.11803	3.50000	-2.00000	1.75000
15	17	18	No	1.11803	4.50000	-2.00000	2.25000
16	19	20	No	1.11803	0.50000	-3.00000	0.25000
17	20	21	No	1.11803	1.50000	-3.00000	0.75000
18	21	22	No	1.11803	2.50000	-3.00000	1.25000
19	22	23	No	1.11803	3.50000	-3.00000	1.75000
20	23	24	No	1.11803	4.50000	-3.00000	2.25000
21	1	7	No	1.00000	0.00000	-0.50000	0.00000
22	2	8	No	1.00000	1.00000	-0.50000	0.50000
23	3	9	No	1.00000	2.00000	-0.50000	1.00000
24	4	10	No	1.00000	3.00000	-0.50000	1.50000
25	5	11	No	1.00000	4.00000	-0.50000	2.00000
26	6	12	No	1.00000	5.00000	-0.50000	2.50000
27	7	13	No	1.00000	0.00000	-1.50000	0.00000
28	8	14	No	1.00000	1.00000	-1.50000	0.50000
29	9	15	No	1.00000	2.00000	-1.50000	1.00000
30	10	16	No	1.00000	3.00000	-1.50000	1.50000
31	11	17	No	1.00000	4.00000	-1.50000	2.00000
32	12	18	No	1.00000	5.00000	-1.50000	2.50000
33	13	19	No	1.00000	0.00000	-2.50000	0.00000
34	14	20	No	1.00000	1.00000	-2.50000	0.50000
35	15	21	No	1.00000	2.00000	-2.50000	1.00000
36	16	22	No	1.00000	3.00000	-2.50000	1.50000
37	17	23	No	1.00000	4.00000	-2.50000	2.00000
38	18	24	No	1.00000	5.00000	-2.50000	2.50000
39	25	26	No	1.11803	1.00000	-0.50000	-0.75000
40	26	27	No	1.11803	2.00000	-0.50000	-0.25000
41	27	28	No	1.11803	3.00000	-0.50000	0.25000
42	28	29	No	1.11803	4.00000	-0.50000	0.75000
43	30	31	No	1.11803	1.00000	-1.50000	-0.75000
44	31	32	No	1.11803	2.00000	-1.50000	-0.25000
45	32	33	No	1.11803	3.00000	-1.50000	0.25000
46	33	34	No	1.11803	4.00000	-1.50000	0.75000
47	35	36	No	1.11803	1.00000	-2.50000	-0.75000
48	36	37	No	1.11803	2.00000	-2.50000	-0.25000
49	37	38	No	1.11803	3.00000	-2.50000	0.25000
50	38	39	No	1.11803	4.00000	-2.50000	0.75000
51	25	30	No	1.00000	0.50000	-1.00000	-1.00000

Frame	JointI	JointJ	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
52	26	31	No	1.00000	1.50000	-1.00000	-0.50000
53	27	32	No	1.00000	2.50000	-1.00000	0.00000
54	28	33	No	1.00000	3.50000	-1.00000	0.50000
55	29	34	No	1.00000	4.50000	-1.00000	1.00000
56	30	35	No	1.00000	0.50000	-2.00000	-1.00000
57	31	36	No	1.00000	1.50000	-2.00000	-0.50000
58	32	37	No	1.00000	2.50000	-2.00000	0.00000
59	33	38	No	1.00000	3.50000	-2.00000	0.50000
60	34	39	No	1.00000	4.50000	-2.00000	1.00000
61	25	1	No	1.22474	0.25000	-0.25000	-0.50000
62	25	7	No	1.22474	0.25000	-0.75000	-0.50000
63	25	2	No	1.65831	0.75000	-0.25000	-0.25000
64	25	8	No	1.65831	0.75000	-0.75000	-0.25000
65	26	2	No	1.22474	1.25000	-0.25000	0.00000
66	26	8	No	1.22474	1.25000	-0.75000	0.00000
67	26	3	No	1.65831	1.75000	-0.25000	0.25000
68	26	9	No	1.65831	1.75000	-0.75000	0.25000
69	27	3	No	1.22474	2.25000	-0.25000	0.50000
70	27	9	No	1.22474	2.25000	-0.75000	0.50000
71	27	4	No	1.65831	2.75000	-0.25000	0.75000
72	27	10	No	1.65831	2.75000	-0.75000	0.75000
73	28	4	No	1.22474	3.25000	-0.25000	1.00000
74	28	10	No	1.22474	3.25000	-0.75000	1.00000
75	28	5	No	1.65831	3.75000	-0.25000	1.25000
76	28	11	No	1.65831	3.75000	-0.75000	1.25000
77	29	5	No	1.22474	4.25000	-0.25000	1.50000
78	29	11	No	1.22474	4.25000	-0.75000	1.50000
79	29	6	No	1.65831	4.75000	-0.25000	1.75000
80	29	12	No	1.65831	4.75000	-0.75000	1.75000
81	30	7	No	1.22474	0.25000	-1.25000	-0.50000
82	30	13	No	1.22474	0.25000	-1.75000	-0.50000
83	30	8	No	1.65831	0.75000	-1.25000	-0.25000
84	30	14	No	1.65831	0.75000	-1.75000	-0.25000
85	31	8	No	1.22474	1.25000	-1.25000	0.00000
86	31	14	No	1.22474	1.25000	-1.75000	0.00000
87	31	9	No	1.65831	1.75000	-1.25000	0.25000
88	31	15	No	1.65831	1.75000	-1.75000	0.25000
89	32	9	No	1.22474	2.25000	-1.25000	0.50000
90	32	15	No	1.22474	2.25000	-1.75000	0.50000
91	32	10	No	1.65831	2.75000	-1.25000	0.75000
92	32	16	No	1.65831	2.75000	-1.75000	0.75000
93	33	10	No	1.22474	3.25000	-1.25000	1.00000
94	33	16	No	1.22474	3.25000	-1.75000	1.00000

Frame	JointI	JointJ	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
95	33	11	No	1.65831	3.75000	-1.25000	1.25000
96	33	17	No	1.65831	3.75000	-1.75000	1.25000
97	34	11	No	1.22474	4.25000	-1.25000	1.50000
98	34	17	No	1.22474	4.25000	-1.75000	1.50000
99	34	12	No	1.65831	4.75000	-1.25000	1.75000
100	34	18	No	1.65831	4.75000	-1.75000	1.75000
101	35	13	No	1.22474	0.25000	-2.25000	-0.50000
102	35	19	No	1.22474	0.25000	-2.75000	-0.50000
103	35	14	No	1.65831	0.75000	-2.25000	-0.25000
104	35	20	No	1.65831	0.75000	-2.75000	-0.25000
105	36	14	No	1.22474	1.25000	-2.25000	0.00000
106	36	20	No	1.22474	1.25000	-2.75000	0.00000
107	36	15	No	1.65831	1.75000	-2.25000	0.25000
108	36	21	No	1.65831	1.75000	-2.75000	0.25000
109	37	15	No	1.22474	2.25000	-2.25000	0.50000
110	37	21	No	1.22474	2.25000	-2.75000	0.50000
111	37	16	No	1.65831	2.75000	-2.25000	0.75000
112	37	22	No	1.65831	2.75000	-2.75000	0.75000
113	38	16	No	1.22474	3.25000	-2.25000	1.00000
114	38	22	No	1.22474	3.25000	-2.75000	1.00000
115	38	17	No	1.65831	3.75000	-2.25000	1.25000
116	38	23	No	1.65831	3.75000	-2.75000	1.25000
117	39	17	No	1.22474	4.25000	-2.25000	1.50000
118	39	23	No	1.22474	4.25000	-2.75000	1.50000
119	39	18	No	1.65831	4.75000	-2.25000	1.75000
120	39	24	No	1.65831	4.75000	-2.75000	1.75000

Table: Joint Coordinates

Joint	Coord Sys	Coord Type	X or R m	Y m	Z m	Special Jt	Global X m	Global Y m	Global Z m
1	GLOBAL	Cartesian	0.00000	0.00000	0.00000	No	0.00000	0.00000	0.00000
2	GLOBAL	Cartesian	1.00000	0.00000	0.50000	No	1.00000	0.00000	0.50000
3	GLOBAL	Cartesian	2.00000	0.00000	1.00000	No	2.00000	0.00000	1.00000
4	GLOBAL	Cartesian	3.00000	0.00000	1.50000	No	3.00000	0.00000	1.50000
5	GLOBAL	Cartesian	4.00000	0.00000	2.00000	No	4.00000	0.00000	2.00000
6	GLOBAL	Cartesian	5.00000	0.00000	2.50000	No	5.00000	0.00000	2.50000
7	GLOBAL	Cartesian	0.00000	-1.00000	0.00000	No	0.00000	-1.00000	0.00000
8	GLOBAL	Cartesian	1.00000	-1.00000	0.50000	No	1.00000	-1.00000	0.50000
9	GLOBAL	Cartesian	2.00000	-1.00000	1.00000	No	2.00000	-1.00000	1.00000
10	GLOBAL	Cartesian	3.00000	-1.00000	1.50000	No	3.00000	-1.00000	1.50000
11	GLOBAL	Cartesian	4.00000	-1.00000	2.00000	No	4.00000	-1.00000	2.00000
12	GLOBAL	Cartesian	5.00000	-1.00000	2.50000	No	5.00000	-1.00000	2.50000
13	GLOBAL	Cartesian	0.00000	-2.00000	0.00000	No	0.00000	-2.00000	0.00000
14	GLOBAL	Cartesian	1.00000	-2.00000	0.50000	No	1.00000	-2.00000	0.50000

Joint	Coord Sys	Coord Type	X or R m	Y m	Z m	Special Jt	Global X m	Global Y m	Global Z m
15	GLOBAL	Cartesian	2.00000	-2.00000	1.00000	No	2.00000	-2.00000	1.00000
16	GLOBAL	Cartesian	3.00000	-2.00000	1.50000	No	3.00000	-2.00000	1.50000
17	GLOBAL	Cartesian	4.00000	-2.00000	2.00000	No	4.00000	-2.00000	2.00000
18	GLOBAL	Cartesian	5.00000	-2.00000	2.50000	No	5.00000	-2.00000	2.50000
19	GLOBAL	Cartesian	0.00000	-3.00000	0.00000	No	0.00000	-3.00000	0.00000
20	GLOBAL	Cartesian	1.00000	-3.00000	0.50000	No	1.00000	-3.00000	0.50000
21	GLOBAL	Cartesian	2.00000	-3.00000	1.00000	No	2.00000	-3.00000	1.00000
22	GLOBAL	Cartesian	3.00000	-3.00000	1.50000	No	3.00000	-3.00000	1.50000
23	GLOBAL	Cartesian	4.00000	-3.00000	2.00000	No	4.00000	-3.00000	2.00000
24	GLOBAL	Cartesian	5.00000	-3.00000	2.50000	No	5.00000	-3.00000	2.50000
25	GLOBAL	Cartesian	0.50000	-0.50000	-1.00000	No	0.50000	-0.50000	-1.00000
26	GLOBAL	Cartesian	1.50000	-0.50000	-0.50000	No	1.50000	-0.50000	-0.50000
27	GLOBAL	Cartesian	2.50000	-0.50000	0.00000	No	2.50000	-0.50000	0.00000
28	GLOBAL	Cartesian	3.50000	-0.50000	0.50000	No	3.50000	-0.50000	0.50000
29	GLOBAL	Cartesian	4.50000	-0.50000	1.00000	No	4.50000	-0.50000	1.00000
30	GLOBAL	Cartesian	0.50000	-1.50000	-1.00000	No	0.50000	-1.50000	-1.00000
31	GLOBAL	Cartesian	1.50000	-1.50000	-0.50000	No	1.50000	-1.50000	-0.50000
32	GLOBAL	Cartesian	2.50000	-1.50000	0.00000	No	2.50000	-1.50000	0.00000
33	GLOBAL	Cartesian	3.50000	-1.50000	0.50000	No	3.50000	-1.50000	0.50000
34	GLOBAL	Cartesian	4.50000	-1.50000	1.00000	No	4.50000	-1.50000	1.00000
35	GLOBAL	Cartesian	0.50000	-2.50000	-1.00000	No	0.50000	-2.50000	-1.00000
36	GLOBAL	Cartesian	1.50000	-2.50000	-0.50000	No	1.50000	-2.50000	-0.50000
37	GLOBAL	Cartesian	2.50000	-2.50000	0.00000	No	2.50000	-2.50000	0.00000
38	GLOBAL	Cartesian	3.50000	-2.50000	0.50000	No	3.50000	-2.50000	0.50000
39	GLOBAL	Cartesian	4.50000	-2.50000	1.00000	No	4.50000	-2.50000	1.00000

Table: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
25	Yes	Yes	Yes	Yes	Yes	Yes
29	Yes	Yes	Yes	Yes	Yes	Yes
35	Yes	Yes	Yes	Yes	Yes	Yes
39	Yes	Yes	Yes	Yes	Yes	Yes

A.1.3- Example three: Curved roof:

Table: Frame Section Properties 01 - General

SectionName	Material	Shape	t3 m	Area m2	Tors Const m4	tw m
FSEC3	A992Fy50	Pipe	0.069978	0.003845	2.354E-06	0.034500

Table: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	KN/m3	KN-s2/m4	KN/m2	KN/m2		1/C
A992Fy50	7.6973E+01	7.8490E+00	205000000.0	78846153.85	0.300000	1.1700E-05

Table: Connectivity - Frame

Frame	JointI	JointJ	IsCurved	Length	CentroidX	CentroidY	CentroidZ
				m	m	m	m
1	1	2	No	4.47214	2.00000	0.00000	1.00000
2	2	3	No	4.12311	6.00000	0.00000	2.50000
3	3	4	No	4.03113	10.00000	0.00000	3.25000
4	4	5	No	4.01123	14.00000	0.00000	3.35000
5	5	6	No	4.00500	18.00000	0.00000	3.10000
6	7	8	No	4.47214	2.00000	-2.00000	1.00000
7	8	9	No	4.12311	6.00000	-2.00000	2.50000
8	9	10	No	4.03113	10.00000	-2.00000	3.25000
9	10	11	No	4.01123	14.00000	-2.00000	3.35000
10	11	12	No	4.00500	18.00000	-2.00000	3.10000
11	13	14	No	4.47214	2.00000	-4.00000	1.00000
12	14	15	No	4.12311	6.00000	-4.00000	2.50000
13	15	16	No	4.03113	10.00000	-4.00000	3.25000
14	16	17	No	4.01123	14.00000	-4.00000	3.35000
15	17	18	No	4.00500	18.00000	-4.00000	3.10000
16	19	20	No	4.47214	2.00000	-6.00000	1.00000
17	20	21	No	4.12311	6.00000	-6.00000	2.50000
18	21	22	No	4.03113	10.00000	-6.00000	3.25000
19	22	23	No	4.01123	14.00000	-6.00000	3.35000
20	23	24	No	4.00500	18.00000	-6.00000	3.10000
21	25	26	No	4.47214	2.00000	-8.00000	1.00000
22	26	27	No	4.12311	6.00000	-8.00000	2.50000
23	27	28	No	4.03113	10.00000	-8.00000	3.25000
24	28	29	No	4.01123	14.00000	-8.00000	3.35000
25	29	30	No	4.00500	18.00000	-8.00000	3.10000
26	31	32	No	4.47214	2.00000	-10.00000	1.00000
27	32	33	No	4.12311	6.00000	-10.00000	2.50000
28	33	34	No	4.03113	10.00000	-10.00000	3.25000
29	34	35	No	4.01123	14.00000	-10.00000	3.35000
30	35	36	No	4.00500	18.00000	-10.00000	3.10000
31	1	7	No	2.00000	0.00000	-1.00000	0.00000
32	2	8	No	2.00000	4.00000	-1.00000	2.00000
33	3	9	No	2.00000	8.00000	-1.00000	3.00000
34	4	10	No	2.00000	12.00000	-1.00000	3.50000
35	5	11	No	2.00000	16.00000	-1.00000	3.20000
36	6	12	No	2.00000	20.00000	-1.00000	3.00000
37	7	13	No	2.00000	0.00000	-3.00000	0.00000
38	8	14	No	2.00000	4.00000	-3.00000	2.00000

Frame	JointI	JointJ	IsCurved	Length	CentroidX	CentroidY	CentroidZ
				m	m	m	m
39	9	15	No	2.00000	8.00000	-3.00000	3.00000
40	10	16	No	2.00000	12.00000	-3.00000	3.50000
41	11	17	No	2.00000	16.00000	-3.00000	3.20000
42	12	18	No	2.00000	20.00000	-3.00000	3.00000
43	13	19	No	2.00000	0.00000	-5.00000	0.00000
44	14	20	No	2.00000	4.00000	-5.00000	2.00000
45	15	21	No	2.00000	8.00000	-5.00000	3.00000
46	16	22	No	2.00000	12.00000	-5.00000	3.50000
47	17	23	No	2.00000	16.00000	-5.00000	3.20000
48	18	24	No	2.00000	20.00000	-5.00000	3.00000
49	19	25	No	2.00000	0.00000	-7.00000	0.00000
50	20	26	No	2.00000	4.00000	-7.00000	2.00000
51	21	27	No	2.00000	8.00000	-7.00000	3.00000
52	22	28	No	2.00000	12.00000	-7.00000	3.50000
53	23	29	No	2.00000	16.00000	-7.00000	3.20000
54	24	30	No	2.00000	20.00000	-7.00000	3.00000
55	25	31	No	2.00000	0.00000	-9.00000	0.00000
56	26	32	No	2.00000	4.00000	-9.00000	2.00000
57	27	33	No	2.00000	8.00000	-9.00000	3.00000
58	28	34	No	2.00000	12.00000	-9.00000	3.50000
59	29	35	No	2.00000	16.00000	-9.00000	3.20000
60	30	36	No	2.00000	20.00000	-9.00000	3.00000
61	37	38	No	4.47214	4.00000	-1.00000	0.00000
62	38	39	No	4.12311	8.00000	-1.00000	1.50000
63	39	40	No	4.03113	12.00000	-1.00000	2.25000
64	40	41	No	4.01123	16.00000	-1.00000	2.35000
65	45	42	No	4.47214	4.00000	-3.00000	0.00000
66	42	43	No	4.12311	8.00000	-3.00000	1.50000
67	43	44	No	4.03113	12.00000	-3.00000	2.25000
68	44	46	No	4.01123	16.00000	-3.00000	2.35000
69	50	47	No	4.47214	4.00000	-5.00000	0.00000
70	47	48	No	4.12311	8.00000	-5.00000	1.50000
71	48	49	No	4.03113	12.00000	-5.00000	2.25000
72	49	51	No	4.01123	16.00000	-5.00000	2.35000
73	55	52	No	4.47214	4.00000	-7.00000	0.00000
74	52	53	No	4.12311	8.00000	-7.00000	1.50000
75	53	54	No	4.03113	12.00000	-7.00000	2.25000
76	54	56	No	4.01123	16.00000	-7.00000	2.35000
77	60	57	No	4.47214	4.00000	-9.00000	0.00000
78	57	58	No	4.12311	8.00000	-9.00000	1.50000
79	58	59	No	4.03113	12.00000	-9.00000	2.25000
80	59	61	No	4.01123	16.00000	-9.00000	2.35000
81	37	45	No	2.00000	2.00000	-2.00000	-1.00000
82	38	42	No	2.00000	6.00000	-2.00000	1.00000
83	39	43	No	2.00000	10.00000	-2.00000	2.00000
84	40	44	No	2.00000	14.00000	-2.00000	2.50000
85	41	46	No	2.00000	18.00000	-2.00000	2.20000

Frame	JointI	JointJ	IsCurved	Length	CentroidX	CentroidY	CentroidZ
				m	m	m	m
86	45	50	No	2.00000	2.00000	-4.00000	-1.00000
87	42	47	No	2.00000	6.00000	-4.00000	1.00000
88	43	48	No	2.00000	10.00000	-4.00000	2.00000
89	44	49	No	2.00000	14.00000	-4.00000	2.50000
90	46	51	No	2.00000	18.00000	-4.00000	2.20000
91	50	55	No	2.00000	2.00000	-6.00000	-1.00000
92	47	52	No	2.00000	6.00000	-6.00000	1.00000
93	48	53	No	2.00000	10.00000	-6.00000	2.00000
94	49	54	No	2.00000	14.00000	-6.00000	2.50000
95	51	56	No	2.00000	18.00000	-6.00000	2.20000
96	55	60	No	2.00000	2.00000	-8.00000	-1.00000
97	52	57	No	2.00000	6.00000	-8.00000	1.00000
98	53	58	No	2.00000	10.00000	-8.00000	2.00000
99	54	59	No	2.00000	14.00000	-8.00000	2.50000
100	56	61	No	2.00000	18.00000	-8.00000	2.20000
101	37	1	No	2.44949	1.00000	-0.50000	-0.50000
102	37	2	No	3.74166	3.00000	-0.50000	0.50000
103	37	7	No	2.44949	1.00000	-1.50000	-0.50000
104	37	8	No	3.74166	3.00000	-1.50000	0.50000
105	38	2	No	2.44949	5.00000	-0.50000	1.50000
106	38	3	No	3.00000	7.00000	-0.50000	2.00000
107	38	8	No	2.44949	5.00000	-1.50000	1.50000
108	38	9	No	3.00000	7.00000	-1.50000	2.00000
109	39	3	No	2.44949	9.00000	-0.50000	2.50000
110	39	4	No	2.69258	11.00000	-0.50000	2.75000
111	39	9	No	2.44949	9.00000	-1.50000	2.50000
112	39	10	No	2.69258	11.00000	-1.50000	2.75000
113	40	4	No	2.44949	13.00000	-0.50000	3.00000
114	40	5	No	2.34307	15.00000	-0.50000	2.85000
115	40	10	No	2.44949	13.00000	-1.50000	3.00000
116	40	11	No	2.34307	15.00000	-1.50000	2.85000
117	41	5	No	2.44949	17.00000	-0.50000	2.70000
118	41	6	No	2.37487	19.00000	-0.50000	2.60000
119	41	11	No	2.44949	17.00000	-1.50000	2.70000
120	41	12	No	2.37487	19.00000	-1.50000	2.60000
121	45	7	No	2.44949	1.00000	-2.50000	-0.50000
122	45	8	No	3.74166	3.00000	-2.50000	0.50000
123	45	13	No	2.44949	1.00000	-3.50000	-0.50000
124	45	14	No	3.74166	3.00000	-3.50000	0.50000
125	42	8	No	2.44949	5.00000	-2.50000	1.50000
126	42	9	No	3.00000	7.00000	-2.50000	2.00000
127	42	14	No	2.44949	5.00000	-3.50000	1.50000
128	42	15	No	3.00000	7.00000	-3.50000	2.00000
129	43	9	No	2.44949	9.00000	-2.50000	2.50000
130	43	10	No	2.69258	11.00000	-2.50000	2.75000
131	43	15	No	2.44949	9.00000	-3.50000	2.50000
132	43	16	No	2.69258	11.00000	-3.50000	2.75000

Frame	JointI	JointJ	IsCurved	Length	CentroidX	CentroidY	CentroidZ
				m	m	m	m
133	44	10	No	2.44949	13.00000	-2.50000	3.00000
134	44	11	No	2.34307	15.00000	-2.50000	2.85000
135	44	16	No	2.44949	13.00000	-3.50000	3.00000
136	44	17	No	2.34307	15.00000	-3.50000	2.85000
137	46	11	No	2.44949	17.00000	-2.50000	2.70000
138	46	12	No	2.37487	19.00000	-2.50000	2.60000
139	46	17	No	2.44949	17.00000	-3.50000	2.70000
140	46	18	No	2.37487	19.00000	-3.50000	2.60000
141	50	13	No	2.44949	1.00000	-4.50000	-0.50000
142	50	14	No	3.74166	3.00000	-4.50000	0.50000
143	50	19	No	2.44949	1.00000	-5.50000	-0.50000
144	50	20	No	3.74166	3.00000	-5.50000	0.50000
145	47	14	No	2.44949	5.00000	-4.50000	1.50000
146	47	15	No	3.00000	7.00000	-4.50000	2.00000
147	47	20	No	2.44949	5.00000	-5.50000	1.50000
148	47	21	No	3.00000	7.00000	-5.50000	2.00000
149	48	15	No	2.44949	9.00000	-4.50000	2.50000
150	48	16	No	2.69258	11.00000	-4.50000	2.75000
151	48	21	No	2.44949	9.00000	-5.50000	2.50000
152	48	22	No	2.69258	11.00000	-5.50000	2.75000
153	49	16	No	2.44949	13.00000	-4.50000	3.00000
154	49	17	No	2.34307	15.00000	-4.50000	2.85000
155	49	22	No	2.44949	13.00000	-5.50000	3.00000
156	49	23	No	2.34307	15.00000	-5.50000	2.85000
157	51	17	No	2.44949	17.00000	-4.50000	2.70000
158	51	18	No	2.37487	19.00000	-4.50000	2.60000
159	51	23	No	2.44949	17.00000	-5.50000	2.70000
160	51	24	No	2.37487	19.00000	-5.50000	2.60000
161	55	19	No	2.44949	1.00000	-6.50000	-0.50000
162	55	20	No	3.74166	3.00000	-6.50000	0.50000
163	55	25	No	2.44949	1.00000	-7.50000	-0.50000
164	55	26	No	3.74166	3.00000	-7.50000	0.50000
165	52	20	No	2.44949	5.00000	-6.50000	1.50000
166	52	21	No	3.00000	7.00000	-6.50000	2.00000
167	52	26	No	2.44949	5.00000	-7.50000	1.50000
168	52	27	No	3.00000	7.00000	-7.50000	2.00000
169	53	21	No	2.44949	9.00000	-6.50000	2.50000
170	53	22	No	2.69258	11.00000	-6.50000	2.75000
171	53	27	No	2.44949	9.00000	-7.50000	2.50000
172	53	28	No	2.69258	11.00000	-7.50000	2.75000
173	54	22	No	2.44949	13.00000	-6.50000	3.00000
174	54	23	No	2.34307	15.00000	-6.50000	2.85000
175	54	28	No	2.44949	13.00000	-7.50000	3.00000
176	54	29	No	2.34307	15.00000	-7.50000	2.85000
177	56	23	No	2.44949	17.00000	-6.50000	2.70000
178	56	24	No	2.37487	19.00000	-6.50000	2.60000
179	56	29	No	2.44949	17.00000	-7.50000	2.70000

Frame	JointI	JointJ	IsCurved	Length m	CentroidX m	CentroidY m	CentroidZ m
180	56	30	No	2.37487	19.00000	-7.50000	2.60000
181	60	25	No	2.44949	1.00000	-8.50000	-0.50000
182	60	26	No	3.74166	3.00000	-8.50000	0.50000
183	60	31	No	2.44949	1.00000	-9.50000	-0.50000
184	60	32	No	3.74166	3.00000	-9.50000	0.50000
185	57	26	No	2.44949	5.00000	-8.50000	1.50000
186	57	27	No	3.00000	7.00000	-8.50000	2.00000
187	57	32	No	2.44949	5.00000	-9.50000	1.50000
188	57	33	No	3.00000	7.00000	-9.50000	2.00000
189	58	27	No	2.44949	9.00000	-8.50000	2.50000
190	58	28	No	2.69258	11.00000	-8.50000	2.75000
191	58	33	No	2.44949	9.00000	-9.50000	2.50000
192	58	34	No	2.69258	11.00000	-9.50000	2.75000
193	59	28	No	2.44949	13.00000	-8.50000	3.00000
194	59	29	No	2.34307	15.00000	-8.50000	2.85000
195	59	34	No	2.44949	13.00000	-9.50000	3.00000
196	59	35	No	2.34307	15.00000	-9.50000	2.85000
197	61	29	No	2.44949	17.00000	-8.50000	2.70000
198	61	30	No	2.37487	19.00000	-8.50000	2.60000
199	61	35	No	2.44949	17.00000	-9.50000	2.70000
200	61	36	No	2.37487	19.00000	-9.50000	2.60000

Table: Joint Coordinates

Global Z m	Global Y m	Global X m	Special Jt	Z m	Y m	X or R m	Coord Type	Coord Sys	Joint
0.00000	0.00000	0.00000	No	0.00000	0.00000	0.00000	Cartesian	GLOBAL	1
2.00000	0.00000	4.00000	No	2.00000	0.00000	4.00000	Cartesian	GLOBAL	2
3.00000	0.00000	8.00000	No	3.00000	0.00000	8.00000	Cartesian	GLOBAL	3
3.50000	0.00000	12.00000	No	3.50000	0.00000	12.00000	Cartesian	GLOBAL	4
3.20000	0.00000	16.00000	No	3.20000	0.00000	16.00000	Cartesian	GLOBAL	5
3.00000	0.00000	20.00000	No	3.00000	0.00000	20.00000	Cartesian	GLOBAL	6
0.00000	-2.00000	0.00000	No	0.00000	-2.00000	0.00000	Cartesian	GLOBAL	7
2.00000	-2.00000	4.00000	No	2.00000	-2.00000	4.00000	Cartesian	GLOBAL	8
3.00000	-2.00000	8.00000	No	3.00000	-2.00000	8.00000	Cartesian	GLOBAL	9
3.50000	-2.00000	12.00000	No	3.50000	-2.00000	12.00000	Cartesian	GLOBAL	10
3.20000	-2.00000	16.00000	No	3.20000	-2.00000	16.00000	Cartesian	GLOBAL	11
3.00000	-2.00000	20.00000	No	3.00000	-2.00000	20.00000	Cartesian	GLOBAL	12
0.00000	-4.00000	0.00000	No	0.00000	-4.00000	0.00000	Cartesian	GLOBAL	13
2.00000	-4.00000	4.00000	No	2.00000	-4.00000	4.00000	Cartesian	GLOBAL	14
3.00000	-4.00000	8.00000	No	3.00000	-4.00000	8.00000	Cartesian	GLOBAL	15
3.50000	-4.00000	12.00000	No	3.50000	-4.00000	12.00000	Cartesian	GLOBAL	16
3.20000	-4.00000	16.00000	No	3.20000	-4.00000	16.00000	Cartesian	GLOBAL	17
3.00000	-4.00000	20.00000	No	3.00000	-4.00000	20.00000	Cartesian	GLOBAL	18
0.00000	-6.00000	0.00000	No	0.00000	-6.00000	0.00000	Cartesian	GLOBAL	19
2.00000	-6.00000	4.00000	No	2.00000	-6.00000	4.00000	Cartesian	GLOBAL	20

Global Z m	Global Y m	Global X m	Special Jt	Z m	Y m	X or R m	Coord Type	Coord Sys	Joint
3.00000	-6.00000	8.00000	No	3.00000	-6.00000	8.00000	Cartesian	GLOBAL	21
3.50000	-6.00000	12.00000	No	3.50000	-6.00000	12.00000	Cartesian	GLOBAL	22
3.20000	-6.00000	16.00000	No	3.20000	-6.00000	16.00000	Cartesian	GLOBAL	23
3.00000	-6.00000	20.00000	No	3.00000	-6.00000	20.00000	Cartesian	GLOBAL	24
0.00000	-8.00000	0.00000	No	0.00000	-8.00000	0.00000	Cartesian	GLOBAL	25
2.00000	-8.00000	4.00000	No	2.00000	-8.00000	4.00000	Cartesian	GLOBAL	26
3.00000	-8.00000	8.00000	No	3.00000	-8.00000	8.00000	Cartesian	GLOBAL	27
3.50000	-8.00000	12.00000	No	3.50000	-8.00000	12.00000	Cartesian	GLOBAL	28
3.20000	-8.00000	16.00000	No	3.20000	-8.00000	16.00000	Cartesian	GLOBAL	29
3.00000	-8.00000	20.00000	No	3.00000	-8.00000	20.00000	Cartesian	GLOBAL	30
0.00000	-10.00000	0.00000	No	0.00000	-10.00000	0.00000	Cartesian	GLOBAL	31
2.00000	-10.00000	4.00000	No	2.00000	-10.00000	4.00000	Cartesian	GLOBAL	32
3.00000	-10.00000	8.00000	No	3.00000	-10.00000	8.00000	Cartesian	GLOBAL	33
3.50000	-10.00000	12.00000	No	3.50000	-10.00000	12.00000	Cartesian	GLOBAL	34
3.20000	-10.00000	16.00000	No	3.20000	-10.00000	16.00000	Cartesian	GLOBAL	35
3.00000	-10.00000	20.00000	No	3.00000	-10.00000	20.00000	Cartesian	GLOBAL	36
-1.00000	-1.00000	2.00000	No	-1.00000	-1.00000	2.00000	Cartesian	GLOBAL	37
1.00000	-1.00000	6.00000	No	1.00000	-1.00000	6.00000	Cartesian	GLOBAL	38
2.00000	-1.00000	10.00000	No	2.00000	-1.00000	10.00000	Cartesian	GLOBAL	39
2.50000	-1.00000	14.00000	No	2.50000	-1.00000	14.00000	Cartesian	GLOBAL	40
2.20000	-1.00000	18.00000	No	2.20000	-1.00000	18.00000	Cartesian	GLOBAL	41
1.00000	-3.00000	6.00000	No	1.00000	-3.00000	6.00000	Cartesian	GLOBAL	42
2.00000	-3.00000	10.00000	No	2.00000	-3.00000	10.00000	Cartesian	GLOBAL	43
2.50000	-3.00000	14.00000	No	2.50000	-3.00000	14.00000	Cartesian	GLOBAL	44
-1.00000	-3.00000	2.00000	No	-1.00000	-3.00000	2.00000	Cartesian	GLOBAL	45
2.20000	-3.00000	18.00000	No	2.20000	-3.00000	18.00000	Cartesian	GLOBAL	46
1.00000	-5.00000	6.00000	No	1.00000	-5.00000	6.00000	Cartesian	GLOBAL	47
2.00000	-5.00000	10.00000	No	2.00000	-5.00000	10.00000	Cartesian	GLOBAL	48
2.50000	-5.00000	14.00000	No	2.50000	-5.00000	14.00000	Cartesian	GLOBAL	49
-1.00000	-5.00000	2.00000	No	-1.00000	-5.00000	2.00000	Cartesian	GLOBAL	50
2.20000	-5.00000	18.00000	No	2.20000	-5.00000	18.00000	Cartesian	GLOBAL	51
1.00000	-7.00000	6.00000	No	1.00000	-7.00000	6.00000	Cartesian	GLOBAL	52
2.00000	-7.00000	10.00000	No	2.00000	-7.00000	10.00000	Cartesian	GLOBAL	53
2.50000	-7.00000	14.00000	No	2.50000	-7.00000	14.00000	Cartesian	GLOBAL	54
-1.00000	-7.00000	2.00000	No	-1.00000	-7.00000	2.00000	Cartesian	GLOBAL	55
2.20000	-7.00000	18.00000	No	2.20000	-7.00000	18.00000	Cartesian	GLOBAL	56
1.00000	-9.00000	6.00000	No	1.00000	-9.00000	6.00000	Cartesian	GLOBAL	57
2.00000	-9.00000	10.00000	No	2.00000	-9.00000	10.00000	Cartesian	GLOBAL	58
2.50000	-9.00000	14.00000	No	2.50000	-9.00000	14.00000	Cartesian	GLOBAL	59
-1.00000	-9.00000	2.00000	No	-1.00000	-9.00000	2.00000	Cartesian	GLOBAL	60
2.20000	-9.00000	18.00000	No	2.20000	-9.00000	18.00000	Cartesian	GLOBAL	61

Table: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
1	Yes	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes	Yes	Yes
19	Yes	Yes	Yes	Yes	Yes	Yes
25	Yes	Yes	Yes	Yes	Yes	Yes
31	Yes	Yes	Yes	Yes	Yes	Yes
36	Yes	Yes	Yes	Yes	Yes	Yes
37	Yes	Yes	Yes	Yes	Yes	Yes
41	Yes	Yes	Yes	Yes	Yes	Yes
45	Yes	Yes	Yes	Yes	Yes	Yes
50	Yes	Yes	Yes	Yes	Yes	Yes
55	Yes	Yes	Yes	Yes	Yes	Yes
60	Yes	Yes	Yes	Yes	Yes	Yes
61	Yes	Yes	Yes	Yes	Yes	Yes

A.1.4- Example four: Circular arc roof :

Table: Frame Section Properties 01 - General

SectionName	Material	Shape	t3 m	tw m	Area m2	TorsConst m4
FSEC3	A992Fy50	Pipe	0.069978	0.034500	0.003845	2.354E-06

Table: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight KN/m3	UnitMass KN-s2/m4	E1 KN/m2	G12 KN/m2	U12	A1 1/C
A992Fy50	7.6973E+01	7.8490E+00	205000000.0	78846153.85	0.300000	1.1700E-05

Table: Connectivity - Frame

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
1	1	2	No	3.16228	1.50000	0.00000	0.50000
2	2	3	No	3.16228	4.50000	0.00000	1.50000
3	3	4	No	3.04138	7.50000	0.00000	2.25000
4	4	5	No	3.01040	10.50000	0.00000	2.62500
5	5	6	No	3.01040	13.50000	0.00000	2.87500
6	6	7	No	3.01040	16.50000	0.00000	2.87500

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
7	7	8	No	3.01040	19.50000	0.00000	2.62500
8	8	9	No	3.04138	22.50000	0.00000	2.25000
9	9	10	No	3.16228	25.50000	0.00000	1.50000
10	10	11	No	3.16228	28.50000	0.00000	0.50000
11	12	13	No	3.16228	1.50000	-3.00000	0.50000
12	13	14	No	3.16228	4.50000	-3.00000	1.50000
13	14	15	No	3.04138	7.50000	-3.00000	2.25000
14	15	16	No	3.01040	10.50000	-3.00000	2.62500
15	16	17	No	3.01040	13.50000	-3.00000	2.87500
16	17	18	No	3.01040	16.50000	-3.00000	2.87500
17	18	19	No	3.01040	19.50000	-3.00000	2.62500
18	19	20	No	3.04138	22.50000	-3.00000	2.25000
19	20	21	No	3.16228	25.50000	-3.00000	1.50000
20	21	22	No	3.16228	28.50000	-3.00000	0.50000
21	23	24	No	3.16228	1.50000	-6.00000	0.50000
22	24	25	No	3.16228	4.50000	-6.00000	1.50000
23	25	26	No	3.04138	7.50000	-6.00000	2.25000
24	26	27	No	3.01040	10.50000	-6.00000	2.62500
25	27	28	No	3.01040	13.50000	-6.00000	2.87500
26	28	29	No	3.01040	16.50000	-6.00000	2.87500
27	29	30	No	3.01040	19.50000	-6.00000	2.62500
28	30	31	No	3.04138	22.50000	-6.00000	2.25000
29	31	32	No	3.16228	25.50000	-6.00000	1.50000
30	32	33	No	3.16228	28.50000	-6.00000	0.50000
31	34	35	No	3.16228	1.50000	-9.00000	0.50000
32	35	36	No	3.16228	4.50000	-9.00000	1.50000
33	36	37	No	3.04138	7.50000	-9.00000	2.25000
34	37	38	No	3.01040	10.50000	-9.00000	2.62500
35	38	39	No	3.01040	13.50000	-9.00000	2.87500
36	39	40	No	3.01040	16.50000	-9.00000	2.87500
37	40	41	No	3.01040	19.50000	-9.00000	2.62500
38	41	42	No	3.04138	22.50000	-9.00000	2.25000
39	42	43	No	3.16228	25.50000	-9.00000	1.50000
40	43	44	No	3.16228	28.50000	-9.00000	0.50000
41	45	46	No	3.16228	1.50000	-12.00000	0.50000
42	46	47	No	3.16228	4.50000	-12.00000	1.50000
43	47	48	No	3.04138	7.50000	-12.00000	2.25000
44	48	49	No	3.01040	10.50000	-12.00000	2.62500
45	49	50	No	3.01040	13.50000	-12.00000	2.87500
46	50	51	No	3.01040	16.50000	-12.00000	2.87500
47	51	52	No	3.01040	19.50000	-12.00000	2.62500
48	52	53	No	3.04138	22.50000	-12.00000	2.25000
49	53	54	No	3.16228	25.50000	-12.00000	1.50000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
50	54	55	No	3.16228	28.50000	-12.00000	0.50000
51	56	57	No	3.16228	1.50000	-15.00000	0.50000
52	57	58	No	3.16228	4.50000	-15.00000	1.50000
53	58	59	No	3.04138	7.50000	-15.00000	2.25000
54	59	60	No	3.01040	10.50000	-15.00000	2.62500
55	60	61	No	3.01040	13.50000	-15.00000	2.87500
56	61	62	No	3.01040	16.50000	-15.00000	2.87500
57	62	63	No	3.01040	19.50000	-15.00000	2.62500
58	63	64	No	3.04138	22.50000	-15.00000	2.25000
59	64	65	No	3.16228	25.50000	-15.00000	1.50000
60	65	66	No	3.16228	28.50000	-15.00000	0.50000
61	1	12	No	3.00000	0.00000	-1.50000	0.00000
62	2	13	No	3.00000	3.00000	-1.50000	1.00000
63	3	14	No	3.00000	6.00000	-1.50000	2.00000
64	4	15	No	3.00000	9.00000	-1.50000	2.50000
65	5	16	No	3.00000	12.00000	-1.50000	2.75000
66	6	17	No	3.00000	15.00000	-1.50000	3.00000
67	7	18	No	3.00000	18.00000	-1.50000	2.75000
68	8	19	No	3.00000	21.00000	-1.50000	2.50000
69	9	20	No	3.00000	24.00000	-1.50000	2.00000
70	10	21	No	3.00000	27.00000	-1.50000	1.00000
71	11	22	No	3.00000	30.00000	-1.50000	0.00000
72	12	23	No	3.00000	0.00000	-4.50000	0.00000
73	13	24	No	3.00000	3.00000	-4.50000	1.00000
74	14	25	No	3.00000	6.00000	-4.50000	2.00000
75	15	26	No	3.00000	9.00000	-4.50000	2.50000
76	16	27	No	3.00000	12.00000	-4.50000	2.75000
77	17	28	No	3.00000	15.00000	-4.50000	3.00000
78	18	29	No	3.00000	18.00000	-4.50000	2.75000
79	19	30	No	3.00000	21.00000	-4.50000	2.50000
80	20	31	No	3.00000	24.00000	-4.50000	2.00000
81	21	32	No	3.00000	27.00000	-4.50000	1.00000
82	22	33	No	3.00000	30.00000	-4.50000	0.00000
83	23	34	No	3.00000	0.00000	-7.50000	0.00000
84	24	35	No	3.00000	3.00000	-7.50000	1.00000
85	25	36	No	3.00000	6.00000	-7.50000	2.00000
86	26	37	No	3.00000	9.00000	-7.50000	2.50000
87	27	38	No	3.00000	12.00000	-7.50000	2.75000
88	28	39	No	3.00000	15.00000	-7.50000	3.00000
89	29	40	No	3.00000	18.00000	-7.50000	2.75000
90	30	41	No	3.00000	21.00000	-7.50000	2.50000
91	31	42	No	3.00000	24.00000	-7.50000	2.00000
92	32	43	No	3.00000	27.00000	-7.50000	1.00000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
93	33	44	No	3.00000	30.00000	-7.50000	0.00000
94	34	45	No	3.00000	0.00000	-10.50000	0.00000
95	35	46	No	3.00000	3.00000	-10.50000	1.00000
96	36	47	No	3.00000	6.00000	-10.50000	2.00000
97	37	48	No	3.00000	9.00000	-10.50000	2.50000
98	38	49	No	3.00000	12.00000	-10.50000	2.75000
99	39	50	No	3.00000	15.00000	-10.50000	3.00000
100	40	51	No	3.00000	18.00000	-10.50000	2.75000
101	41	52	No	3.00000	21.00000	-10.50000	2.50000
102	42	53	No	3.00000	24.00000	-10.50000	2.00000
103	43	54	No	3.00000	27.00000	-10.50000	1.00000
104	44	55	No	3.00000	30.00000	-10.50000	0.00000
105	45	56	No	3.00000	0.00000	-13.50000	0.00000
106	46	57	No	3.00000	3.00000	-13.50000	1.00000
107	47	58	No	3.00000	6.00000	-13.50000	2.00000
108	48	59	No	3.00000	9.00000	-13.50000	2.50000
109	49	60	No	3.00000	12.00000	-13.50000	2.75000
110	50	61	No	3.00000	15.00000	-13.50000	3.00000
111	51	62	No	3.00000	18.00000	-13.50000	2.75000
112	52	63	No	3.00000	21.00000	-13.50000	2.50000
113	53	64	No	3.00000	24.00000	-13.50000	2.00000
114	54	65	No	3.00000	27.00000	-13.50000	1.00000
115	55	66	No	3.00000	30.00000	-13.50000	0.00000
116	67	68	No	3.16228	3.00000	-1.50000	-0.50000
117	68	69	No	3.16228	6.00000	-1.50000	0.50000
118	69	70	No	3.04138	9.00000	-1.50000	1.25000
119	70	71	No	3.01040	12.00000	-1.50000	1.62500
120	71	72	No	3.00000	15.00000	-1.50000	1.75000
121	72	73	No	3.01040	18.00000	-1.50000	1.62500
122	73	74	No	3.04138	21.00000	-1.50000	1.25000
123	74	75	No	3.16228	24.00000	-1.50000	0.50000
124	75	76	No	3.16228	27.00000	-1.50000	-0.50000
125	77	78	No	3.16228	3.00000	-4.50000	-0.50000
126	78	79	No	3.16228	6.00000	-4.50000	0.50000
127	79	80	No	3.04138	9.00000	-4.50000	1.25000
128	80	81	No	3.01040	12.00000	-4.50000	1.62500
129	81	82	No	3.00000	15.00000	-4.50000	1.75000
130	82	83	No	3.01040	18.00000	-4.50000	1.62500
131	83	84	No	3.04138	21.00000	-4.50000	1.25000
132	84	85	No	3.16228	24.00000	-4.50000	0.50000
133	85	86	No	3.16228	27.00000	-4.50000	-0.50000
134	87	88	No	3.16228	3.00000	-7.50000	-0.50000
135	88	89	No	3.16228	6.00000	-7.50000	0.50000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
136	89	90	No	3.04138	9.00000	-7.50000	1.25000
137	90	91	No	3.01040	12.00000	-7.50000	1.62500
138	91	92	No	3.00000	15.00000	-7.50000	1.75000
139	92	93	No	3.01040	18.00000	-7.50000	1.62500
140	93	94	No	3.04138	21.00000	-7.50000	1.25000
141	94	95	No	3.16228	24.00000	-7.50000	0.50000
142	95	96	No	3.16228	27.00000	-7.50000	-0.50000
143	97	98	No	3.16228	3.00000	-10.50000	-0.50000
144	98	99	No	3.16228	6.00000	-10.50000	0.50000
145	99	100	No	3.04138	9.00000	-10.50000	1.25000
146	100	101	No	3.01040	12.00000	-10.50000	1.62500
147	101	102	No	3.00000	15.00000	-10.50000	1.75000
148	102	103	No	3.01040	18.00000	-10.50000	1.62500
149	103	104	No	3.04138	21.00000	-10.50000	1.25000
150	104	105	No	3.16228	24.00000	-10.50000	0.50000
151	105	106	No	3.16228	27.00000	-10.50000	-0.50000
152	107	108	No	3.16228	3.00000	-13.50000	-0.50000
153	108	109	No	3.16228	6.00000	-13.50000	0.50000
154	109	110	No	3.04138	9.00000	-13.50000	1.25000
155	110	111	No	3.01040	12.00000	-13.50000	1.62500
156	111	112	No	3.00000	15.00000	-13.50000	1.75000
157	112	113	No	3.01040	18.00000	-13.50000	1.62500
158	113	114	No	3.04138	21.00000	-13.50000	1.25000
159	114	115	No	3.16228	24.00000	-13.50000	0.50000
160	115	116	No	3.16228	27.00000	-13.50000	-0.50000
161	67	77	No	3.00000	1.50000	-3.00000	-1.00000
162	68	78	No	3.00000	4.50000	-3.00000	0.00000
163	69	79	No	3.00000	7.50000	-3.00000	1.00000
164	70	80	No	3.00000	10.50000	-3.00000	1.50000
165	71	81	No	3.00000	13.50000	-3.00000	1.75000
166	72	82	No	3.00000	16.50000	-3.00000	1.75000
167	73	83	No	3.00000	19.50000	-3.00000	1.50000
168	74	84	No	3.00000	22.50000	-3.00000	1.00000
169	75	85	No	3.00000	25.50000	-3.00000	0.00000
170	76	86	No	3.00000	28.50000	-3.00000	-1.00000
171	77	87	No	3.00000	1.50000	-6.00000	-1.00000
172	78	88	No	3.00000	4.50000	-6.00000	0.00000
173	79	89	No	3.00000	7.50000	-6.00000	1.00000
174	80	90	No	3.00000	10.50000	-6.00000	1.50000
175	81	91	No	3.00000	13.50000	-6.00000	1.75000
176	82	92	No	3.00000	16.50000	-6.00000	1.75000
177	83	93	No	3.00000	19.50000	-6.00000	1.50000
178	84	94	No	3.00000	22.50000	-6.00000	1.00000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
179	85	95	No	3.00000	25.50000	-6.00000	0.00000
180	86	96	No	3.00000	28.50000	-6.00000	-1.00000
181	87	97	No	3.00000	1.50000	-9.00000	-1.00000
182	88	98	No	3.00000	4.50000	-9.00000	0.00000
183	89	99	No	3.00000	7.50000	-9.00000	1.00000
184	90	100	No	3.00000	10.50000	-9.00000	1.50000
185	91	101	No	3.00000	13.50000	-9.00000	1.75000
186	92	102	No	3.00000	16.50000	-9.00000	1.75000
187	93	103	No	3.00000	19.50000	-9.00000	1.50000
188	94	104	No	3.00000	22.50000	-9.00000	1.00000
189	95	105	No	3.00000	25.50000	-9.00000	0.00000
190	96	106	No	3.00000	28.50000	-9.00000	-1.00000
191	97	107	No	3.00000	1.50000	-12.00000	-1.00000
192	98	108	No	3.00000	4.50000	-12.00000	0.00000
193	99	109	No	3.00000	7.50000	-12.00000	1.00000
194	100	110	No	3.00000	10.50000	-12.00000	1.50000
195	101	111	No	3.00000	13.50000	-12.00000	1.75000
196	102	112	No	3.00000	16.50000	-12.00000	1.75000
197	103	113	No	3.00000	19.50000	-12.00000	1.50000
198	104	114	No	3.00000	22.50000	-12.00000	1.00000
199	105	115	No	3.00000	25.50000	-12.00000	0.00000
200	106	116	No	3.00000	28.50000	-12.00000	-1.00000
201	67	1	No	2.34521	0.75000	-0.75000	-0.50000
202	67	2	No	2.91548	2.25000	-0.75000	0.00000
203	67	12	No	2.34521	0.75000	-2.25000	-0.50000
204	67	13	No	2.91548	2.25000	-2.25000	0.00000
205	68	2	No	2.34521	3.75000	-0.75000	0.50000
206	68	3	No	2.91548	5.25000	-0.75000	1.00000
207	68	13	No	2.34521	3.75000	-2.25000	0.50000
208	68	14	No	2.91548	5.25000	-2.25000	1.00000
209	69	3	No	2.34521	6.75000	-0.75000	1.50000
210	69	4	No	2.59808	8.25000	-0.75000	1.75000
211	69	14	No	2.34521	6.75000	-2.25000	1.50000
212	69	15	No	2.59808	8.25000	-2.25000	1.75000
213	70	4	No	2.34521	9.75000	-0.75000	2.00000
214	70	5	No	2.46221	11.25000	-0.75000	2.12500
215	70	15	No	2.34521	9.75000	-2.25000	2.00000
216	70	16	No	2.46221	11.25000	-2.25000	2.12500
217	71	5	No	2.34521	12.75000	-0.75000	2.25000
218	71	6	No	2.46221	14.25000	-0.75000	2.37500
219	71	16	No	2.34521	12.75000	-2.25000	2.25000
220	71	17	No	2.46221	14.25000	-2.25000	2.37500
221	72	6	No	2.46221	15.75000	-0.75000	2.37500

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
222	72	7	No	2.34521	17.25000	-0.75000	2.25000
223	72	17	No	2.46221	15.75000	-2.25000	2.37500
224	72	18	No	2.34521	17.25000	-2.25000	2.25000
225	73	7	No	2.46221	18.75000	-0.75000	2.12500
226	73	8	No	2.34521	20.25000	-0.75000	2.00000
227	73	18	No	2.46221	18.75000	-2.25000	2.12500
228	73	19	No	2.34521	20.25000	-2.25000	2.00000
229	74	8	No	2.59808	21.75000	-0.75000	1.75000
230	74	9	No	2.34521	23.25000	-0.75000	1.50000
231	74	19	No	2.59808	21.75000	-2.25000	1.75000
232	74	20	No	2.34521	23.25000	-2.25000	1.50000
233	75	9	No	2.91548	24.75000	-0.75000	1.00000
234	75	10	No	2.34521	26.25000	-0.75000	0.50000
235	75	20	No	2.91548	24.75000	-2.25000	1.00000
236	75	21	No	2.34521	26.25000	-2.25000	0.50000
237	76	10	No	2.91548	27.75000	-0.75000	0.00000
238	76	11	No	2.34521	29.25000	-0.75000	-0.50000
239	76	21	No	2.91548	27.75000	-2.25000	0.00000
240	76	22	No	2.34521	29.25000	-2.25000	-0.50000
241	77	12	No	2.34521	0.75000	-3.75000	-0.50000
242	77	13	No	2.91548	2.25000	-3.75000	0.00000
243	77	23	No	2.34521	0.75000	-5.25000	-0.50000
244	77	24	No	2.91548	2.25000	-5.25000	0.00000
245	78	13	No	2.34521	3.75000	-3.75000	0.50000
246	78	14	No	2.91548	5.25000	-3.75000	1.00000
247	78	24	No	2.34521	3.75000	-5.25000	0.50000
248	78	25	No	2.91548	5.25000	-5.25000	1.00000
249	79	14	No	2.34521	6.75000	-3.75000	1.50000
250	79	15	No	2.59808	8.25000	-3.75000	1.75000
251	79	25	No	2.34521	6.75000	-5.25000	1.50000
252	79	26	No	2.59808	8.25000	-5.25000	1.75000
253	80	15	No	2.34521	9.75000	-3.75000	2.00000
254	80	16	No	2.46221	11.25000	-3.75000	2.12500
255	80	26	No	2.34521	9.75000	-5.25000	2.00000
256	80	27	No	2.46221	11.25000	-5.25000	2.12500
257	81	16	No	2.34521	12.75000	-3.75000	2.25000
258	81	17	No	2.46221	14.25000	-3.75000	2.37500
259	81	27	No	2.34521	12.75000	-5.25000	2.25000
260	81	28	No	2.46221	14.25000	-5.25000	2.37500
261	82	17	No	2.46221	15.75000	-3.75000	2.37500
262	82	18	No	2.34521	17.25000	-3.75000	2.25000
263	82	28	No	2.46221	15.75000	-5.25000	2.37500
264	82	29	No	2.34521	17.25000	-5.25000	2.25000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
265	83	18	No	2.46221	18.75000	-3.75000	2.12500
266	83	19	No	2.34521	20.25000	-3.75000	2.00000
267	83	29	No	2.46221	18.75000	-5.25000	2.12500
268	83	30	No	2.34521	20.25000	-5.25000	2.00000
269	84	19	No	2.59808	21.75000	-3.75000	1.75000
270	84	20	No	2.34521	23.25000	-3.75000	1.50000
271	84	30	No	2.59808	21.75000	-5.25000	1.75000
272	84	31	No	2.34521	23.25000	-5.25000	1.50000
273	85	20	No	2.91548	24.75000	-3.75000	1.00000
274	85	21	No	2.34521	26.25000	-3.75000	0.50000
275	85	31	No	2.91548	24.75000	-5.25000	1.00000
276	85	32	No	2.34521	26.25000	-5.25000	0.50000
277	86	21	No	2.91548	27.75000	-3.75000	0.00000
278	86	22	No	2.34521	29.25000	-3.75000	-0.50000
279	86	32	No	2.91548	27.75000	-5.25000	0.00000
280	86	33	No	2.34521	29.25000	-5.25000	-0.50000
281	87	23	No	2.34521	0.75000	-6.75000	-0.50000
282	87	24	No	2.91548	2.25000	-6.75000	0.00000
283	87	34	No	2.34521	0.75000	-8.25000	-0.50000
284	87	35	No	2.91548	2.25000	-8.25000	0.00000
285	88	24	No	2.34521	3.75000	-6.75000	0.50000
286	88	25	No	2.91548	5.25000	-6.75000	1.00000
287	88	35	No	2.34521	3.75000	-8.25000	0.50000
288	88	36	No	2.91548	5.25000	-8.25000	1.00000
289	89	25	No	2.34521	6.75000	-6.75000	1.50000
290	89	26	No	2.59808	8.25000	-6.75000	1.75000
291	89	36	No	2.34521	6.75000	-8.25000	1.50000
292	89	37	No	2.59808	8.25000	-8.25000	1.75000
293	90	26	No	2.34521	9.75000	-6.75000	2.00000
294	90	27	No	2.46221	11.25000	-6.75000	2.12500
295	90	37	No	2.34521	9.75000	-8.25000	2.00000
296	90	38	No	2.46221	11.25000	-8.25000	2.12500
297	91	27	No	2.34521	12.75000	-6.75000	2.25000
298	91	28	No	2.46221	14.25000	-6.75000	2.37500
299	91	38	No	2.34521	12.75000	-8.25000	2.25000
300	91	39	No	2.46221	14.25000	-8.25000	2.37500
301	92	28	No	2.46221	15.75000	-6.75000	2.37500
302	92	29	No	2.34521	17.25000	-6.75000	2.25000
303	92	39	No	2.46221	15.75000	-8.25000	2.37500
304	92	40	No	2.34521	17.25000	-8.25000	2.25000
305	93	29	No	2.46221	18.75000	-6.75000	2.12500
306	93	30	No	2.34521	20.25000	-6.75000	2.00000
307	93	40	No	2.46221	18.75000	-8.25000	2.12500

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
308	93	41	No	2.34521	20.25000	-8.25000	2.00000
309	94	30	No	2.59808	21.75000	-6.75000	1.75000
310	94	31	No	2.34521	23.25000	-6.75000	1.50000
311	94	41	No	2.59808	21.75000	-8.25000	1.75000
312	94	42	No	2.34521	23.25000	-8.25000	1.50000
313	95	31	No	2.91548	24.75000	-6.75000	1.00000
314	95	32	No	2.34521	26.25000	-6.75000	0.50000
315	95	42	No	2.91548	24.75000	-8.25000	1.00000
316	95	43	No	2.34521	26.25000	-8.25000	0.50000
317	96	32	No	2.91548	27.75000	-6.75000	0.00000
318	96	33	No	2.34521	29.25000	-6.75000	-0.50000
319	96	43	No	2.91548	27.75000	-8.25000	0.00000
320	96	44	No	2.34521	29.25000	-8.25000	-0.50000
321	97	34	No	2.34521	0.75000	-9.75000	-0.50000
322	97	35	No	2.91548	2.25000	-9.75000	0.00000
323	97	45	No	2.34521	0.75000	-11.25000	-0.50000
324	97	46	No	2.91548	2.25000	-11.25000	0.00000
325	98	35	No	2.34521	3.75000	-9.75000	0.50000
326	98	36	No	2.91548	5.25000	-9.75000	1.00000
327	98	46	No	2.34521	3.75000	-11.25000	0.50000
328	98	47	No	2.91548	5.25000	-11.25000	1.00000
329	99	36	No	2.34521	6.75000	-9.75000	1.50000
330	99	37	No	2.59808	8.25000	-9.75000	1.75000
331	99	47	No	2.34521	6.75000	-11.25000	1.50000
332	99	48	No	2.59808	8.25000	-11.25000	1.75000
333	100	37	No	2.34521	9.75000	-9.75000	2.00000
334	100	38	No	2.46221	11.25000	-9.75000	2.12500
335	100	48	No	2.34521	9.75000	-11.25000	2.00000
336	100	49	No	2.46221	11.25000	-11.25000	2.12500
337	101	38	No	2.34521	12.75000	-9.75000	2.25000
338	101	39	No	2.46221	14.25000	-9.75000	2.37500
339	101	49	No	2.34521	12.75000	-11.25000	2.25000
340	101	50	No	2.46221	14.25000	-11.25000	2.37500
341	102	39	No	2.46221	15.75000	-9.75000	2.37500
342	102	40	No	2.34521	17.25000	-9.75000	2.25000
343	102	50	No	2.46221	15.75000	-11.25000	2.37500
344	102	51	No	2.34521	17.25000	-11.25000	2.25000
345	103	40	No	2.46221	18.75000	-9.75000	2.12500
346	103	41	No	2.34521	20.25000	-9.75000	2.00000
347	103	51	No	2.46221	18.75000	-11.25000	2.12500
348	103	52	No	2.34521	20.25000	-11.25000	2.00000
349	104	41	No	2.59808	21.75000	-9.75000	1.75000
350	104	42	No	2.34521	23.25000	-9.75000	1.50000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
351	104	52	No	2.59808	21.75000	-11.25000	1.75000
352	104	53	No	2.34521	23.25000	-11.25000	1.50000
353	105	42	No	2.91548	24.75000	-9.75000	1.00000
354	105	43	No	2.34521	26.25000	-9.75000	0.50000
355	105	53	No	2.91548	24.75000	-11.25000	1.00000
356	105	54	No	2.34521	26.25000	-11.25000	0.50000
357	106	43	No	2.91548	27.75000	-9.75000	0.00000
358	106	44	No	2.34521	29.25000	-9.75000	-0.50000
359	106	54	No	2.91548	27.75000	-11.25000	0.00000
360	106	55	No	2.34521	29.25000	-11.25000	-0.50000
361	107	45	No	2.34521	0.75000	-12.75000	-0.50000
362	107	46	No	2.91548	2.25000	-12.75000	0.00000
363	107	56	No	2.34521	0.75000	-14.25000	-0.50000
364	107	57	No	2.91548	2.25000	-14.25000	0.00000
365	108	46	No	2.34521	3.75000	-12.75000	0.50000
366	108	47	No	2.91548	5.25000	-12.75000	1.00000
367	108	57	No	2.34521	3.75000	-14.25000	0.50000
368	108	58	No	2.91548	5.25000	-14.25000	1.00000
369	109	47	No	2.34521	6.75000	-12.75000	1.50000
370	109	48	No	2.59808	8.25000	-12.75000	1.75000
371	109	58	No	2.34521	6.75000	-14.25000	1.50000
372	109	59	No	2.59808	8.25000	-14.25000	1.75000
373	110	48	No	2.34521	9.75000	-12.75000	2.00000
374	110	49	No	2.46221	11.25000	-12.75000	2.12500
375	110	59	No	2.34521	9.75000	-14.25000	2.00000
376	110	60	No	2.46221	11.25000	-14.25000	2.12500
377	111	49	No	2.34521	12.75000	-12.75000	2.25000
378	111	50	No	2.46221	14.25000	-12.75000	2.37500
379	111	60	No	2.34521	12.75000	-14.25000	2.25000
380	111	61	No	2.46221	14.25000	-14.25000	2.37500
381	112	50	No	2.46221	15.75000	-12.75000	2.37500
382	112	51	No	2.34521	17.25000	-12.75000	2.25000
383	112	61	No	2.46221	15.75000	-14.25000	2.37500
384	112	62	No	2.34521	17.25000	-14.25000	2.25000
385	113	51	No	2.46221	18.75000	-12.75000	2.12500
386	113	52	No	2.34521	20.25000	-12.75000	2.00000
387	113	62	No	2.46221	18.75000	-14.25000	2.12500
388	113	63	No	2.34521	20.25000	-14.25000	2.00000
389	114	52	No	2.59808	21.75000	-12.75000	1.75000
390	114	53	No	2.34521	23.25000	-12.75000	1.50000
391	114	63	No	2.59808	21.75000	-14.25000	1.75000
392	114	64	No	2.34521	23.25000	-14.25000	1.50000
393	115	53	No	2.91548	24.75000	-12.75000	1.00000

Frame	Joint I	Joint J	Is Curved	Length m	Centroid X m	Centroid Y m	Centroid Z m
394	115	54	No	2.34521	26.25000	-12.75000	0.50000
395	115	64	No	2.91548	24.75000	-14.25000	1.00000
396	115	65	No	2.34521	26.25000	-14.25000	0.50000
397	116	54	No	2.91548	27.75000	-12.75000	0.00000
398	116	55	No	2.34521	29.25000	-12.75000	-0.50000
399	116	65	No	2.91548	27.75000	-14.25000	0.00000
400	116	66	No	2.34521	29.25000	-14.25000	-0.50000

Table: Joint Coordinates

Joint	Coord sys	Coord Type	XorR m	Y m	Z m	Special Jt	Global X m	Global Y m	Global Z m
1	GLOBAL	Cartesian	0.00000	0.00000	0.00000	No	0.00000	0.00000	0.00000
2	GLOBAL	Cartesian	3.00000	0.00000	1.00000	No	3.00000	0.00000	1.00000
3	GLOBAL	Cartesian	6.00000	0.00000	2.00000	No	6.00000	0.00000	2.00000
4	GLOBAL	Cartesian	9.00000	0.00000	2.50000	No	9.00000	0.00000	2.50000
5	GLOBAL	Cartesian	12.00000	0.00000	2.75000	No	12.00000	0.00000	2.75000
6	GLOBAL	Cartesian	15.00000	0.00000	3.00000	No	15.00000	0.00000	3.00000
7	GLOBAL	Cartesian	18.00000	0.00000	2.75000	No	18.00000	0.00000	2.75000
8	GLOBAL	Cartesian	21.00000	0.00000	2.50000	No	21.00000	0.00000	2.50000
9	GLOBAL	Cartesian	24.00000	0.00000	2.00000	No	24.00000	0.00000	2.00000
10	GLOBAL	Cartesian	27.00000	0.00000	1.00000	No	27.00000	0.00000	1.00000
11	GLOBAL	Cartesian	30.00000	0.00000	0.00000	No	30.00000	0.00000	0.00000
12	GLOBAL	Cartesian	0.00000	-3.00000	0.00000	No	0.00000	-3.00000	0.00000
13	GLOBAL	Cartesian	3.00000	-3.00000	1.00000	No	3.00000	-3.00000	1.00000
14	GLOBAL	Cartesian	6.00000	-3.00000	2.00000	No	6.00000	-3.00000	2.00000
15	GLOBAL	Cartesian	9.00000	-3.00000	2.50000	No	9.00000	-3.00000	2.50000
16	GLOBAL	Cartesian	12.00000	-3.00000	2.75000	No	12.00000	-3.00000	2.75000
17	GLOBAL	Cartesian	15.00000	-3.00000	3.00000	No	15.00000	-3.00000	3.00000
18	GLOBAL	Cartesian	18.00000	-3.00000	2.75000	No	18.00000	-3.00000	2.75000
19	GLOBAL	Cartesian	21.00000	-3.00000	2.50000	No	21.00000	-3.00000	2.50000
20	GLOBAL	Cartesian	24.00000	-3.00000	2.00000	No	24.00000	-3.00000	2.00000
21	GLOBAL	Cartesian	27.00000	-3.00000	1.00000	No	27.00000	-3.00000	1.00000
22	GLOBAL	Cartesian	30.00000	-3.00000	0.00000	No	30.00000	-3.00000	0.00000
23	GLOBAL	Cartesian	0.00000	-6.00000	0.00000	No	0.00000	-6.00000	0.00000
24	GLOBAL	Cartesian	3.00000	-6.00000	1.00000	No	3.00000	-6.00000	1.00000
25	GLOBAL	Cartesian	6.00000	-6.00000	2.00000	No	6.00000	-6.00000	2.00000
26	GLOBAL	Cartesian	9.00000	-6.00000	2.50000	No	9.00000	-6.00000	2.50000
27	GLOBAL	Cartesian	12.00000	-6.00000	2.75000	No	12.00000	-6.00000	2.75000
28	GLOBAL	Cartesian	15.00000	-6.00000	3.00000	No	15.00000	-6.00000	3.00000
29	GLOBAL	Cartesian	18.00000	-6.00000	2.75000	No	18.00000	-6.00000	2.75000
30	GLOBAL	Cartesian	21.00000	-6.00000	2.50000	No	21.00000	-6.00000	2.50000
31	GLOBAL	Cartesian	24.00000	-6.00000	2.00000	No	24.00000	-6.00000	2.00000
32	GLOBAL	Cartesian	27.00000	-6.00000	1.00000	No	27.00000	-6.00000	1.00000
33	GLOBAL	Cartesian	30.00000	-6.00000	0.00000	No	30.00000	-6.00000	0.00000
34	GLOBAL	Cartesian	0.00000	-9.00000	0.00000	No	0.00000	-9.00000	0.00000
35	GLOBAL	Cartesian	3.00000	-9.00000	1.00000	No	3.00000	-9.00000	1.00000
36	GLOBAL	Cartesian	6.00000	-9.00000	2.00000	No	6.00000	-9.00000	2.00000
37	GLOBAL	Cartesian	9.00000	-9.00000	2.50000	No	9.00000	-9.00000	2.50000

Joint	Coord sys	Coord Type	XorR m	Y m	Z m	Special Jt	Global X m	Global Y m	Global Z m
38	GLOBAL	Cartesian	12.00000	-9.00000	2.75000	No	12.00000	-9.00000	2.75000
39	GLOBAL	Cartesian	15.00000	-9.00000	3.00000	No	15.00000	-9.00000	3.00000
40	GLOBAL	Cartesian	18.00000	-9.00000	2.75000	No	18.00000	-9.00000	2.75000
41	GLOBAL	Cartesian	21.00000	-9.00000	2.50000	No	21.00000	-9.00000	2.50000
42	GLOBAL	Cartesian	24.00000	-9.00000	2.00000	No	24.00000	-9.00000	2.00000
43	GLOBAL	Cartesian	27.00000	-9.00000	1.00000	No	27.00000	-9.00000	1.00000
44	GLOBAL	Cartesian	30.00000	-9.00000	0.00000	No	30.00000	-9.00000	0.00000
45	GLOBAL	Cartesian	0.00000	-12.00000	0.00000	No	0.00000	-12.00000	0.00000
46	GLOBAL	Cartesian	3.00000	-12.00000	1.00000	No	3.00000	-12.00000	1.00000
47	GLOBAL	Cartesian	6.00000	-12.00000	2.00000	No	6.00000	-12.00000	2.00000
48	GLOBAL	Cartesian	9.00000	-12.00000	2.50000	No	9.00000	-12.00000	2.50000
49	GLOBAL	Cartesian	12.00000	-12.00000	2.75000	No	12.00000	-12.00000	2.75000
50	GLOBAL	Cartesian	15.00000	-12.00000	3.00000	No	15.00000	-12.00000	3.00000
51	GLOBAL	Cartesian	18.00000	-12.00000	2.75000	No	18.00000	-12.00000	2.75000
52	GLOBAL	Cartesian	21.00000	-12.00000	2.50000	No	21.00000	-12.00000	2.50000
53	GLOBAL	Cartesian	24.00000	-12.00000	2.00000	No	24.00000	-12.00000	2.00000
54	GLOBAL	Cartesian	27.00000	-12.00000	1.00000	No	27.00000	-12.00000	1.00000
55	GLOBAL	Cartesian	30.00000	-12.00000	0.00000	No	30.00000	-12.00000	0.00000
56	GLOBAL	Cartesian	0.00000	-15.00000	0.00000	No	0.00000	-15.00000	0.00000
57	GLOBAL	Cartesian	3.00000	-15.00000	1.00000	No	3.00000	-15.00000	1.00000
58	GLOBAL	Cartesian	6.00000	-15.00000	2.00000	No	6.00000	-15.00000	2.00000
59	GLOBAL	Cartesian	9.00000	-15.00000	2.50000	No	9.00000	-15.00000	2.50000
60	GLOBAL	Cartesian	12.00000	-15.00000	2.75000	No	12.00000	-15.00000	2.75000
61	GLOBAL	Cartesian	15.00000	-15.00000	3.00000	No	15.00000	-15.00000	3.00000
62	GLOBAL	Cartesian	18.00000	-15.00000	2.75000	No	18.00000	-15.00000	2.75000
63	GLOBAL	Cartesian	21.00000	-15.00000	2.50000	No	21.00000	-15.00000	2.50000
64	GLOBAL	Cartesian	24.00000	-15.00000	2.00000	No	24.00000	-15.00000	2.00000
65	GLOBAL	Cartesian	27.00000	-15.00000	1.00000	No	27.00000	-15.00000	1.00000
66	GLOBAL	Cartesian	30.00000	-15.00000	0.00000	No	30.00000	-15.00000	0.00000
67	GLOBAL	Cartesian	1.50000	-1.50000	-1.00000	No	1.50000	-1.50000	-1.00000
68	GLOBAL	Cartesian	4.50000	-1.50000	0.00000	No	4.50000	-1.50000	0.00000
69	GLOBAL	Cartesian	7.50000	-1.50000	1.00000	No	7.50000	-1.50000	1.00000
70	GLOBAL	Cartesian	10.50000	-1.50000	1.50000	No	10.50000	-1.50000	1.50000
71	GLOBAL	Cartesian	13.50000	-1.50000	1.75000	No	13.50000	-1.50000	1.75000
72	GLOBAL	Cartesian	16.50000	-1.50000	1.75000	No	16.50000	-1.50000	1.75000
73	GLOBAL	Cartesian	19.50000	-1.50000	1.50000	No	19.50000	-1.50000	1.50000
74	GLOBAL	Cartesian	22.50000	-1.50000	1.00000	No	22.50000	-1.50000	1.00000
75	GLOBAL	Cartesian	25.50000	-1.50000	0.00000	No	25.50000	-1.50000	0.00000
76	GLOBAL	Cartesian	28.50000	-1.50000	-1.00000	No	28.50000	-1.50000	-1.00000
77	GLOBAL	Cartesian	1.50000	-4.50000	-1.00000	No	1.50000	-4.50000	-1.00000
78	GLOBAL	Cartesian	4.50000	-4.50000	0.00000	No	4.50000	-4.50000	0.00000
79	GLOBAL	Cartesian	7.50000	-4.50000	1.00000	No	7.50000	-4.50000	1.00000
80	GLOBAL	Cartesian	10.50000	-4.50000	1.50000	No	10.50000	-4.50000	1.50000
81	GLOBAL	Cartesian	13.50000	-4.50000	1.75000	No	13.50000	-4.50000	1.75000
82	GLOBAL	Cartesian	16.50000	-4.50000	1.75000	No	16.50000	-4.50000	1.75000
83	GLOBAL	Cartesian	19.50000	-4.50000	1.50000	No	19.50000	-4.50000	1.50000
84	GLOBAL	Cartesian	22.50000	-4.50000	1.00000	No	22.50000	-4.50000	1.00000
85	GLOBAL	Cartesian	25.50000	-4.50000	0.00000	No	25.50000	-4.50000	0.00000
86	GLOBAL	Cartesian	28.50000	-4.50000	-1.00000	No	28.50000	-4.50000	-1.00000
87	GLOBAL	Cartesian	1.50000	-7.50000	-1.00000	No	1.50000	-7.50000	-1.00000
88	GLOBAL	Cartesian	4.50000	-7.50000	0.00000	No	4.50000	-7.50000	0.00000

Joint	Coord sys	Coord Type	XorR m	Y m	Z m	Special Jt	Global X m	Global Y m	Global Z m
89	GLOBAL	Cartesian	7.50000	-7.50000	1.00000	No	7.50000	-7.50000	1.00000
90	GLOBAL	Cartesian	10.50000	-7.50000	1.50000	No	10.50000	-7.50000	1.50000
91	GLOBAL	Cartesian	13.50000	-7.50000	1.75000	No	13.50000	-7.50000	1.75000
92	GLOBAL	Cartesian	16.50000	-7.50000	1.75000	No	16.50000	-7.50000	1.75000
93	GLOBAL	Cartesian	19.50000	-7.50000	1.50000	No	19.50000	-7.50000	1.50000
94	GLOBAL	Cartesian	22.50000	-7.50000	1.00000	No	22.50000	-7.50000	1.00000
95	GLOBAL	Cartesian	25.50000	-7.50000	0.00000	No	25.50000	-7.50000	0.00000
96	GLOBAL	Cartesian	28.50000	-7.50000	-1.00000	No	28.50000	-7.50000	-1.00000
97	GLOBAL	Cartesian	1.50000	-10.50000	-1.00000	No	1.50000	-10.50000	-1.00000
98	GLOBAL	Cartesian	4.50000	-10.50000	0.00000	No	4.50000	-10.50000	0.00000
99	GLOBAL	Cartesian	7.50000	-10.50000	1.00000	No	7.50000	-10.50000	1.00000
100	GLOBAL	Cartesian	10.50000	-10.50000	1.50000	No	10.50000	-10.50000	1.50000
101	GLOBAL	Cartesian	13.50000	-10.50000	1.75000	No	13.50000	-10.50000	1.75000
102	GLOBAL	Cartesian	16.50000	-10.50000	1.75000	No	16.50000	-10.50000	1.75000
103	GLOBAL	Cartesian	19.50000	-10.50000	1.50000	No	19.50000	-10.50000	1.50000
104	GLOBAL	Cartesian	22.50000	-10.50000	1.00000	No	22.50000	-10.50000	1.00000
105	GLOBAL	Cartesian	25.50000	-10.50000	0.00000	No	25.50000	-10.50000	0.00000
106	GLOBAL	Cartesian	28.50000	-10.50000	-1.00000	No	28.50000	-10.50000	-1.00000
107	GLOBAL	Cartesian	1.50000	-13.50000	-1.00000	No	1.50000	-13.50000	-1.00000
108	GLOBAL	Cartesian	4.50000	-13.50000	0.00000	No	4.50000	-13.50000	0.00000
109	GLOBAL	Cartesian	7.50000	-13.50000	1.00000	No	7.50000	-13.50000	1.00000
110	GLOBAL	Cartesian	10.50000	-13.50000	1.50000	No	10.50000	-13.50000	1.50000
111	GLOBAL	Cartesian	13.50000	-13.50000	1.75000	No	13.50000	-13.50000	1.75000
112	GLOBAL	Cartesian	16.50000	-13.50000	1.75000	No	16.50000	-13.50000	1.75000
113	GLOBAL	Cartesian	19.50000	-13.50000	1.50000	No	19.50000	-13.50000	1.50000
114	GLOBAL	Cartesian	22.50000	-13.50000	1.00000	No	22.50000	-13.50000	1.00000
115	GLOBAL	Cartesian	25.50000	-13.50000	0.00000	No	25.50000	-13.50000	0.00000
116	GLOBAL	Cartesian	28.50000	-13.50000	-1.00000	No	28.50000	-13.50000	-1.00000

Table: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
1	Yes	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes	Yes	Yes
22	Yes	Yes	Yes	Yes	Yes	Yes
23	Yes	Yes	Yes	Yes	Yes	Yes
33	Yes	Yes	Yes	Yes	Yes	Yes
34	Yes	Yes	Yes	Yes	Yes	Yes
44	Yes	Yes	Yes	Yes	Yes	Yes
45	Yes	Yes	Yes	Yes	Yes	Yes
55	Yes	Yes	Yes	Yes	Yes	Yes
56	Yes	Yes	Yes	Yes	Yes	Yes
66	Yes	Yes	Yes	Yes	Yes	Yes
67	Yes	Yes	Yes	Yes	Yes	Yes
76	Yes	Yes	Yes	Yes	Yes	Yes
77	Yes	Yes	Yes	Yes	Yes	Yes
86	Yes	Yes	Yes	Yes	Yes	Yes

Joint	U1	U2	U3	R1	R2	R3
87	Yes	Yes	Yes	Yes	Yes	Yes
96	Yes	Yes	Yes	Yes	Yes	Yes
97	Yes	Yes	Yes	Yes	Yes	Yes
106	Yes	Yes	Yes	Yes	Yes	Yes
107	Yes	Yes	Yes	Yes	Yes	Yes
116	Yes	Yes	Yes	Yes	Yes	Yes

A.1.5- Example five: Circular dome roof:

Table: Frame Section Properties 01 - General

SectionName	Material	Shape	t3 m	tw m	Area m2	Tors Const m4
FSEC3	A992Fy50	Pipe	0.191500	0.094500	0.028797	0.000132

Table: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight KN/m3	UnitMass KN-s2/m4	E1 KN/m2	G12 KN/m2	U12	A1 1/C
A992Fy50	7.6973E+01	7.8490E+00	205000000.0	78846153.85	0.300000	1.1700E-05

Table: Connectivity - Frame

Frame	Joint I	Joint J	Is Curved	Length m	CentroidX m	CentroidY m	Centroid Z m
1	1	2	No	5.97810	-8.68848	20.97584	0.00000
2	2	3	No	5.97810	-13.82137	18.01236	0.00000
3	3	4	No	5.97810	-18.01236	13.82137	0.00000
4	4	5	No	5.97810	-20.97584	8.68848	0.00000
5	5	6	No	5.97810	-22.50985	2.96348	0.00000
6	6	7	No	5.97810	-22.50985	-2.96348	0.00000
7	7	8	No	5.97810	-20.97584	-8.68848	0.00000
8	8	9	No	5.97810	-18.01236	-13.82137	0.00000
9	9	10	No	5.97810	-13.82137	-18.01236	0.00000
10	10	11	No	5.97810	-8.68848	-20.97584	0.00000
11	11	12	No	5.97810	-2.96348	-22.50985	0.00000
12	12	13	No	5.97810	2.96348	-22.50985	0.00000
13	13	14	No	5.97810	8.68848	-20.97584	0.00000
14	14	15	No	5.97810	13.82137	-18.01236	0.00000
15	15	16	No	5.97810	18.01236	-13.82137	0.00000
16	16	17	No	5.97810	20.97584	-8.68848	0.00000
17	17	18	No	5.97810	22.50985	-2.96348	0.00000
18	18	19	No	5.97810	22.50985	2.96348	0.00000
19	19	20	No	5.97810	20.97584	8.68848	0.00000
20	20	21	No	5.97810	18.01236	13.82137	0.00000
21	21	22	No	5.97810	13.82137	18.01236	0.00000

Frame	Joint I	Joint J	Is Curved	Length m	CentroidX m	CentroidY m	Centroid Z m
22	22	23	No	5.97810	8.68848	20.97584	0.00000
23	23	24	No	5.97810	2.96348	22.50985	0.00000
24	24	1	No	5.97810	-2.96348	22.50985	0.00000
25	25	26	No	5.57869	19.57440	8.10798	1.79000
26	26	27	No	5.57869	16.80892	12.89794	1.79000
27	27	28	No	5.57869	12.89794	16.80892	1.79000
28	28	29	No	5.57869	8.10798	19.57440	1.79000
29	29	30	No	5.57869	2.76548	21.00592	1.79000
30	30	31	No	5.57869	-2.76548	21.00592	1.79000
31	31	32	No	5.57869	-8.10798	19.57440	1.79000
32	32	33	No	5.57869	-12.89794	16.80892	1.79000
33	33	34	No	5.57869	-16.80892	12.89794	1.79000
34	34	35	No	5.57869	-19.57440	8.10798	1.79000
35	35	36	No	5.57869	-21.00592	2.76548	1.79000
36	36	37	No	5.57869	-21.00592	-2.76548	1.79000
37	37	38	No	5.57869	-19.57440	-8.10798	1.79000
38	38	39	No	5.57869	-16.80892	-12.89794	1.79000
39	39	40	No	5.57869	-12.89794	-16.80892	1.79000
40	40	41	No	5.57869	-8.10798	-19.57440	1.79000
41	41	42	No	5.57869	-2.76548	-21.00592	1.79000
42	42	43	No	5.57869	2.76548	-21.00592	1.79000
43	43	44	No	5.57869	8.10798	-19.57440	1.79000
44	44	45	No	5.57869	12.89794	-16.80892	1.79000
45	45	46	No	5.57869	16.80892	-12.89794	1.79000
46	46	47	No	5.57869	19.57440	-8.10798	1.79000
47	47	48	No	5.57869	21.00592	-2.76548	1.79000
48	48	25	No	5.57869	21.00592	2.76548	1.79000
49	49	50	No	4.28387	-2.12361	16.13042	3.26000
50	50	51	No	4.28387	-6.22611	15.03116	3.26000
51	51	52	No	4.28387	-9.90431	12.90755	3.26000
52	52	53	No	4.28387	-12.90755	9.90431	3.26000
53	53	54	No	4.28387	-15.03116	6.22611	3.26000
54	54	55	No	4.28387	-16.13042	2.12361	3.26000
55	55	56	No	4.28387	-16.13042	-2.12361	3.26000
56	56	57	No	4.28387	-15.03116	-6.22611	3.26000
57	57	58	No	4.28387	-12.90755	-9.90431	3.26000
58	58	59	No	4.28387	-9.90431	-12.90755	3.26000
59	59	60	No	4.28387	-6.22611	-15.03116	3.26000
60	60	61	No	4.28387	-2.12361	-16.13042	3.26000
61	61	62	No	4.28387	2.12361	-16.13042	3.26000
62	62	63	No	4.28387	6.22611	-15.03116	3.26000
63	63	64	No	4.28387	9.90431	-12.90755	3.26000
64	64	65	No	4.28387	12.90755	-9.90431	3.26000

Frame	Joint I	Joint J	Is Curved	Length m	CentroidX m	CentroidY m	Centroid Z m
65	65	66	No	4.28387	15.03116	-6.22611	3.26000
66	66	67	No	4.28387	16.13042	-2.12361	3.26000
67	67	68	No	4.28387	16.13042	2.12361	3.26000
68	68	69	No	4.28387	15.03116	6.22611	3.26000
69	69	70	No	4.28387	12.90755	9.90431	3.26000
70	70	71	No	4.28387	9.90431	12.90755	3.26000
71	71	72	No	4.28387	6.22611	15.03116	3.26000
72	72	49	No	4.28387	2.12361	16.13042	3.26000
73	73	74	No	2.29204	-3.33122	8.04227	4.27000
74	74	75	No	2.29204	-5.29920	6.90605	4.27000
75	75	76	No	2.29204	-6.90605	5.29920	4.27000
76	76	77	No	2.29204	-8.04227	3.33122	4.27000
77	77	78	No	2.29204	-8.63041	1.13622	4.27000
78	78	79	No	2.29204	-8.63041	-1.13622	4.27000
79	79	80	No	2.29204	-8.04227	-3.33122	4.27000
80	80	81	No	2.29204	-6.90605	-5.29920	4.27000
81	81	82	No	2.29204	-5.29920	-6.90605	4.27000
82	82	83	No	2.29204	-3.33122	-8.04227	4.27000
83	83	84	No	2.29204	-1.13622	-8.63041	4.27000
84	84	85	No	2.29204	1.13622	-8.63041	4.27000
85	85	86	No	2.29204	3.33122	-8.04227	4.27000
86	86	87	No	2.29204	5.29920	-6.90605	4.27000
87	87	88	No	2.29204	6.90605	-5.29920	4.27000
88	88	89	No	2.29204	8.04227	-3.33122	4.27000
89	89	90	No	2.29204	8.63041	-1.13622	4.27000
90	90	91	No	2.29204	8.63041	1.13622	4.27000
91	91	92	No	2.29204	8.04227	3.33122	4.27000
92	92	93	No	2.29204	6.90605	5.29920	4.27000
93	93	94	No	2.29204	5.29920	6.90605	4.27000
94	94	95	No	2.29204	3.33122	8.04227	4.27000
95	95	96	No	2.29204	1.13622	8.63041	4.27000
96	96	73	No	2.29204	-1.13622	8.63041	4.27000
97	5	35	No	2.35478	-21.38077	5.72896	0.89500
98	6	36	No	2.35478	-22.13500	2.711E-15	0.89500
99	5	36	No	6.23658	-21.74485	2.96348	0.89500
100	7	37	No	2.35478	-21.38077	-5.72896	0.89500
101	8	38	No	2.35478	-19.16947	-11.06750	0.89500
102	9	39	No	2.35478	-15.65181	-15.65181	0.89500
103	10	40	No	2.35478	-11.06750	-19.16947	0.89500
104	11	41	No	2.35478	-5.72896	-21.38077	0.89500
105	12	42	No	2.35478	-4.066E-15	-22.13500	0.89500
106	8	39	No	6.23658	-17.47143	-13.28044	0.89500
107	9	40	No	6.23658	-13.43887	-17.34985	0.89500

Frame	Joint I	Joint J	Is Curved	Length m	CentroidX m	CentroidY m	Centroid Z m
108	10	41	No	6.23658	-8.49048	-20.23691	0.89500
109	11	42	No	6.23658	-2.96348	-21.74485	0.89500
110	6	37	No	6.23658	-21.77092	-2.76548	0.89500
111	7	38	No	6.23658	-20.31333	-8.30598	0.89500
112	13	43	No	2.35478	5.72896	-21.38077	0.89500
113	12	43	No	6.23658	2.76548	-21.77092	0.89500
114	14	44	No	2.35478	11.06750	-19.16947	0.89500
115	13	44	No	6.23658	8.30598	-20.31333	0.89500
116	15	45	No	2.35478	15.65181	-15.65181	0.89500
117	14	45	No	6.23658	13.28044	-17.47143	0.89500
118	4	34	No	2.35478	-19.16947	11.06750	0.89500
119	4	35	No	6.23658	-20.23691	8.49048	0.89500
120	34	3	No	6.23658	-17.34985	13.43887	0.89500
121	3	33	No	2.35478	-15.65181	15.65181	0.89500
122	33	2	No	6.23658	-13.28044	17.47143	0.89500
123	2	32	No	2.35478	-11.06750	19.16947	0.89500
124	32	1	No	6.23658	-8.30598	20.31333	0.89500
125	1	31	No	2.35478	-5.72896	21.38077	0.89500
126	31	24	No	6.23658	-2.76548	21.77092	0.89500
127	24	30	No	2.35478	1.355E-15	22.13500	0.89500
128	30	23	No	6.23658	2.96348	21.74485	0.89500
129	23	29	No	2.35478	5.72896	21.38077	0.89500
130	29	22	No	6.23658	8.49048	20.23691	0.89500
131	22	28	No	2.35478	11.06750	19.16947	0.89500
132	28	21	No	6.23658	13.43887	17.34985	0.89500
133	21	27	No	2.35478	15.65181	15.65181	0.89500
134	27	20	No	6.23658	17.47143	13.28044	0.89500
135	20	26	No	2.35478	19.16947	11.06750	0.89500
136	26	19	No	6.23658	20.31333	8.30598	0.89500
137	19	25	No	2.35478	21.38077	5.72896	0.89500
138	25	18	No	6.23658	21.77092	2.76548	0.89500
139	18	48	No	2.35478	22.13500	0.00000	0.89500
140	48	17	No	6.23658	21.74485	-2.96348	0.89500
141	17	47	No	2.35478	21.38077	-5.72896	0.89500
142	47	16	No	6.23658	20.23691	-8.49048	0.89500
143	16	46	No	2.35478	19.16947	-11.06750	0.89500
144	46	15	No	6.23658	17.34985	-13.43887	0.89500
145	35	54	No	5.17325	-18.24634	4.88909	2.52500
146	54	34	No	7.11765	-17.17890	7.46611	2.52500
147	39	58	No	5.17325	-13.35725	-13.35725	2.52500
148	58	38	No	7.11765	-15.05529	-11.14431	2.52500
149	38	57	No	5.17325	-16.35922	-9.44500	2.52500
150	57	37	No	7.11765	-17.42666	-6.86798	2.52500

Frame	Joint I	Joint J	Is Curved	Length m	CentroidX m	CentroidY m	Centroid Z m
151	37	56	No	5.17325	-18.24634	-4.88909	2.52500
152	56	36	No	7.11765	-18.61042	-2.12361	2.52500
153	36	55	No	5.17325	-18.89000	2.313E-15	2.52500
154	55	35	No	7.11765	-18.52592	2.76548	2.52500
155	53	33	No	7.11765	-14.66117	11.65794	2.52500
156	33	52	No	5.17325	-13.35725	13.35725	2.52500
157	40	59	No	5.17325	-9.44500	-16.35922	2.52500
158	59	39	No	7.11765	-11.65794	-14.66117	2.52500
159	41	60	No	5.17325	-4.88909	-18.24634	2.52500
160	60	40	No	7.11765	-7.46611	-17.17890	2.52500
161	42	61	No	5.17325	-3.470E-15	-18.89000	2.52500
162	61	41	No	7.11765	-2.76548	-18.52592	2.52500
163	34	53	No	5.17325	-16.35922	9.44500	2.52500
164	52	32	No	7.11765	-11.14431	15.05529	2.52500
165	32	51	No	5.17325	-9.44500	16.35922	2.52500
166	51	31	No	7.11765	-6.86798	17.42666	2.52500
167	31	50	No	5.17325	-4.88909	18.24634	2.52500
168	50	30	No	7.11765	-2.12361	18.61042	2.52500
169	30	49	No	5.17325	1.157E-15	18.89000	2.52500
170	49	29	No	7.11765	2.76548	18.52592	2.52500
171	29	72	No	5.17325	4.88909	18.24634	2.52500
172	72	28	No	7.11765	7.46611	17.17890	2.52500
173	28	71	No	5.17325	9.44500	16.35922	2.52500
174	71	27	No	7.11765	11.65794	14.66117	2.52500
175	43	62	No	5.17325	4.88909	-18.24634	2.52500
176	62	42	No	7.11765	2.12361	-18.61042	2.52500
177	44	63	No	5.17325	9.44500	-16.35922	2.52500
178	63	43	No	7.11765	6.86798	-17.42666	2.52500
179	45	64	No	5.17325	13.35725	-13.35725	2.52500
180	64	44	No	7.11765	11.14431	-15.05529	2.52500
181	46	65	No	5.17325	16.35922	-9.44500	2.52500
182	65	45	No	7.11765	14.66117	-11.65794	2.52500
183	47	66	No	5.17325	18.24634	-4.88909	2.52500
184	66	46	No	7.11765	17.17890	-7.46611	2.52500
185	48	67	No	5.17325	18.89000	0.00000	2.52500
186	67	47	No	7.11765	18.52592	-2.76548	2.52500
187	25	68	No	5.17325	18.24634	4.88909	2.52500
188	68	48	No	7.11765	18.61042	2.12361	2.52500
189	26	69	No	5.17325	16.35922	9.44500	2.52500
190	69	25	No	7.11765	17.42666	6.86798	2.52500
191	27	70	No	5.17325	13.35725	13.35725	2.52500
192	70	26	No	7.11765	15.05529	11.14431	2.52500
193	49	96	No	7.69656	7.712E-16	12.59500	3.76500

Frame	Joint I	Joint J	Is Curved	Length m	CentroidX m	CentroidY m	Centroid Z m
194	50	73	No	7.69656	-3.25983	12.16584	3.76500
195	73	49	No	8.30998	-1.13622	12.44541	3.76500
196	52	75	No	7.69656	-8.90601	8.90601	3.76500
197	75	51	No	8.30998	-7.20670	10.20994	3.76500
198	51	74	No	7.69656	-6.29750	10.90759	3.76500
199	74	50	No	8.30998	-4.31861	11.72727	3.76500
200	54	77	No	7.69656	-12.16584	3.25983	3.76500
201	77	53	No	8.30998	-11.34615	5.23872	3.76500
202	53	76	No	7.69656	-10.90759	6.29750	3.76500
203	76	52	No	8.30998	-9.60366	7.99681	3.76500
204	59	82	No	7.69656	-6.29750	-10.90759	3.76500
205	82	58	No	8.30998	-7.99681	-9.60366	3.76500
206	58	81	No	7.69656	-8.90601	-8.90601	3.76500
207	81	57	No	8.30998	-10.20994	-7.20670	3.76500
208	57	80	No	7.69656	-10.90759	-6.29750	3.76500
209	80	56	No	8.30998	-11.72727	-4.31861	3.76500
210	56	79	No	7.69656	-12.16584	-3.25983	3.76500
211	79	55	No	8.30998	-12.44541	-1.13622	3.76500
212	55	78	No	7.69656	-12.59500	1.542E-15	3.76500
213	78	54	No	8.30998	-12.31542	2.12361	3.76500
214	72	95	No	7.69656	3.25983	12.16584	3.76500
215	95	71	No	8.30998	5.23872	11.34615	3.76500
216	96	72	No	8.30998	2.12361	12.31542	3.76500
217	92	69	No	7.69656	10.90759	6.29750	3.76500
218	60	83	No	7.69656	-3.25983	-12.16584	3.76500
219	83	59	No	8.30998	-5.23872	-11.34615	3.76500
220	61	84	No	7.69656	-2.314E-15	-12.59500	3.76500
221	84	60	No	8.30998	-2.12361	-12.31542	3.76500
222	62	85	No	7.69656	3.25983	-12.16584	3.76500
223	85	61	No	8.30998	1.13622	-12.44541	3.76500
224	63	86	No	7.69656	6.29750	-10.90759	3.76500
225	86	62	No	8.30998	4.31861	-11.72727	3.76500
226	64	87	No	7.69656	8.90601	-8.90601	3.76500
227	87	63	No	8.30998	7.20670	-10.20994	3.76500
228	65	88	No	7.69656	10.90759	-6.29750	3.76500
229	88	64	No	8.30998	9.60366	-7.99681	3.76500
230	66	89	No	7.69656	12.16584	-3.25983	3.76500
231	89	65	No	8.30998	11.34615	-5.23872	3.76500
232	67	90	No	7.69656	12.59500	0.00000	3.76500
233	90	66	No	8.30998	12.31542	-2.12361	3.76500
234	68	91	No	7.69656	12.16584	3.25983	3.76500
235	91	67	No	8.30998	12.44541	1.13622	3.76500
236	71	94	No	7.69656	6.29750	10.90759	3.76500

Frame	Joint I	Joint J	Is Curved	Length m	CentroidX m	CentroidY m	Centroid Z m
237	94	70	No	8.30998	7.99681	9.60366	3.76500
238	92	68	No	8.30998	11.72727	4.31861	3.76500
239	70	93	No	7.69656	8.90601	8.90601	3.76500
240	93	69	No	8.30998	10.20994	7.20670	3.76500
241	97	78	No	8.78547	-4.39000	5.376E-16	4.42500
242	79	97	No	8.78547	-4.24041	-1.13622	4.42500
243	97	80	No	8.78547	-3.80185	-2.19500	4.42500
244	81	97	No	8.78547	-3.10420	-3.10420	4.42500
245	97	82	No	8.78547	-2.19500	-3.80185	4.42500
246	83	97	No	8.78547	-1.13622	-4.24041	4.42500
247	97	84	No	8.78547	-8.064E-16	-4.39000	4.42500
248	97	77	No	8.78547	-4.24041	1.13622	4.42500
249	97	76	No	8.78547	-3.80185	2.19500	4.42500
250	75	97	No	8.78547	-3.10420	3.10420	4.42500
251	97	74	No	8.78547	-2.19500	3.80185	4.42500
252	73	97	No	8.78547	-1.13622	4.24041	4.42500
253	97	96	No	8.78547	2.688E-16	4.39000	4.42500
254	95	97	No	8.78547	1.13622	4.24041	4.42500
255	97	94	No	8.78547	2.19500	3.80185	4.42500
256	93	97	No	8.78547	3.10420	3.10420	4.42500
257	97	92	No	8.78547	3.80185	2.19500	4.42500
258	97	91	No	8.78547	4.24041	1.13622	4.42500
259	90	97	No	8.78547	4.39000	0.00000	4.42500
260	97	89	No	8.78547	4.24041	-1.13622	4.42500
261	88	97	No	8.78547	3.80185	-2.19500	4.42500
262	97	87	No	8.78547	3.10420	-3.10420	4.42500
263	86	97	No	8.78547	2.19500	-3.80185	4.42500
264	97	85	No	8.78547	1.13622	-4.24041	4.42500

Table: Joint Coordinates

Joint	CoordSys	CoordType	Xor R m	T Degrees	Z m	Special Jt	Global X m	Global Y m	Global Z m
1	GLOBAL	Cylindrical	22.90000	105.000	0.0000	No	-5.92696	22.11970	0.00000
2	GLOBAL	Cylindrical	22.90000	120.000	0.0000	No	-11.45000	19.83198	0.00000
3	GLOBAL	Cylindrical	22.90000	135.000	0.0000	No	-16.19275	16.19275	0.00000
4	GLOBAL	Cylindrical	22.90000	150.000	0.0000	No	-19.83198	11.45000	0.00000
5	GLOBAL	Cylindrical	22.90000	165.000	0.0000	No	-22.11970	5.92696	0.00000
6	GLOBAL	Cylindrical	22.90000	180.000	0.0000	No	-22.90000	2.804E-15	0.00000
7	GLOBAL	Cylindrical	22.90000	195.000	0.0000	No	-22.11970	-5.92696	0.00000
8	GLOBAL	Cylindrical	22.90000	210.000	0.0000	No	-19.83198	-11.45000	0.00000
9	GLOBAL	Cylindrical	22.90000	225.000	0.0000	No	-16.19275	-16.19275	0.00000
10	GLOBAL	Cylindrical	22.90000	240.000	0.0000	No	-11.45000	-19.83198	0.00000
11	GLOBAL	Cylindrical	22.90000	255.000	0.0000	No	-5.92696	-22.11970	0.00000
12	GLOBAL	Cylindrical	22.90000	270.000	0.0000	No	-4.207E-15	-22.90000	0.00000
13	GLOBAL	Cylindrical	22.90000	285.000	0.0000	No	5.92696	-22.11970	0.00000

Joint	CoordSys	CoordType	Xor R m	T Degrees	Z m	Special Jt	Global X m	Global Y m	Global Z m
14	GLOBAL	Cylindrical	22.90000	300.000	0.0000	No	11.45000	-19.83198	0.00000
15	GLOBAL	Cylindrical	22.90000	315.000	0.0000	No	16.19275	-16.19275	0.00000
16	GLOBAL	Cylindrical	22.90000	330.000	0.0000	No	19.83198	-11.45000	0.00000
17	GLOBAL	Cylindrical	22.90000	345.000	0.0000	No	22.11970	-5.92696	0.00000
18	GLOBAL	Cylindrical	22.90000	0.000	0.0000	No	22.90000	0.00000	0.00000
19	GLOBAL	Cylindrical	22.90000	15.000	0.0000	No	22.11970	5.92696	0.00000
20	GLOBAL	Cylindrical	22.90000	30.000	0.0000	No	19.83198	11.45000	0.00000
21	GLOBAL	Cylindrical	22.90000	45.000	0.0000	No	16.19275	16.19275	0.00000
22	GLOBAL	Cylindrical	22.90000	60.000	0.0000	No	11.45000	19.83198	0.00000
23	GLOBAL	Cylindrical	22.90000	75.000	0.0000	No	5.92696	22.11970	0.00000
24	GLOBAL	Cylindrical	22.90000	90.000	0.0000	No	1.402E-15	22.90000	0.00000
25	GLOBAL	Cylindrical	21.37000	15.000	1.7900	No	20.64183	5.53096	1.79000
26	GLOBAL	Cylindrical	21.37000	30.000	1.7900	No	18.50696	10.68500	1.79000
27	GLOBAL	Cylindrical	21.37000	45.000	1.7900	No	15.11087	15.11087	1.79000
28	GLOBAL	Cylindrical	21.37000	60.000	1.7900	No	10.68500	18.50696	1.79000
29	GLOBAL	Cylindrical	21.37000	75.000	1.7900	No	5.53096	20.64183	1.79000
30	GLOBAL	Cylindrical	21.37000	90.000	1.7900	No	1.308E-15	21.37000	1.79000
31	GLOBAL	Cylindrical	21.37000	105.000	1.7900	No	-5.53096	20.64183	1.79000
32	GLOBAL	Cylindrical	21.37000	120.000	1.7900	No	-10.68500	18.50696	1.79000
33	GLOBAL	Cylindrical	21.37000	135.000	1.7900	No	-15.11087	15.11087	1.79000
34	GLOBAL	Cylindrical	21.37000	150.000	1.7900	No	-18.50696	10.68500	1.79000
35	GLOBAL	Cylindrical	21.37000	165.000	1.7900	No	-20.64183	5.53096	1.79000
36	GLOBAL	Cylindrical	21.37000	180.000	1.7900	No	-21.37000	2.617E-15	1.79000
37	GLOBAL	Cylindrical	21.37000	195.000	1.7900	No	-20.64183	-5.53096	1.79000
38	GLOBAL	Cylindrical	21.37000	210.000	1.7900	No	-18.50696	-10.68500	1.79000
39	GLOBAL	Cylindrical	21.37000	225.000	1.7900	No	-15.11087	-15.11087	1.79000
40	GLOBAL	Cylindrical	21.37000	240.000	1.7900	No	-10.68500	-18.50696	1.79000
41	GLOBAL	Cylindrical	21.37000	255.000	1.7900	No	-5.53096	-20.64183	1.79000
42	GLOBAL	Cylindrical	21.37000	270.000	1.7900	No	-3.925E-15	-21.37000	1.79000
43	GLOBAL	Cylindrical	21.37000	285.000	1.7900	No	5.53096	-20.64183	1.79000
44	GLOBAL	Cylindrical	21.37000	300.000	1.7900	No	10.68500	-18.50696	1.79000
45	GLOBAL	Cylindrical	21.37000	315.000	1.7900	No	15.11087	-15.11087	1.79000
46	GLOBAL	Cylindrical	21.37000	330.000	1.7900	No	18.50696	-10.68500	1.79000
47	GLOBAL	Cylindrical	21.37000	345.000	1.7900	No	20.64183	-5.53096	1.79000
48	GLOBAL	Cylindrical	21.37000	0.000	1.7900	No	21.37000	0.00000	1.79000
49	GLOBAL	Cylindrical	16.41000	90.000	3.2600	No	1.005E-15	16.41000	3.26000
50	GLOBAL	Cylindrical	16.41000	105.000	3.2600	No	-4.24722	15.85084	3.26000
51	GLOBAL	Cylindrical	16.41000	120.000	3.2600	No	-8.20500	14.21148	3.26000
52	GLOBAL	Cylindrical	16.41000	135.000	3.2600	No	-11.60362	11.60362	3.26000
53	GLOBAL	Cylindrical	16.41000	150.000	3.2600	No	-14.21148	8.20500	3.26000
54	GLOBAL	Cylindrical	16.41000	165.000	3.2600	No	-15.85084	4.24722	3.26000
55	GLOBAL	Cylindrical	16.41000	180.000	3.2600	No	-16.41000	2.010E-15	3.26000
56	GLOBAL	Cylindrical	16.41000	195.000	3.2600	No	-15.85084	-4.24722	3.26000
57	GLOBAL	Cylindrical	16.41000	210.000	3.2600	No	-14.21148	-8.20500	3.26000
58	GLOBAL	Cylindrical	16.41000	225.000	3.2600	No	-11.60362	-11.60362	3.26000
59	GLOBAL	Cylindrical	16.41000	240.000	3.2600	No	-8.20500	-14.21148	3.26000
60	GLOBAL	Cylindrical	16.41000	255.000	3.2600	No	-4.24722	-15.85084	3.26000
61	GLOBAL	Cylindrical	16.41000	270.000	3.2600	No	-3.014E-15	-16.41000	3.26000
62	GLOBAL	Cylindrical	16.41000	285.000	3.2600	No	4.24722	-15.85084	3.26000
63	GLOBAL	Cylindrical	16.41000	300.000	3.2600	No	8.20500	-14.21148	3.26000
64	GLOBAL	Cylindrical	16.41000	315.000	3.2600	No	11.60362	-11.60362	3.26000

Joint	CoordSys	CoordType	Xor R m	T Degrees	Z m	Special Jt	Global X m	Global Y m	Global Z m
65	GLOBAL	Cylindrical	16.41000	330.000	3.2600	No	14.21148	-8.20500	3.26000
66	GLOBAL	Cylindrical	16.41000	345.000	3.2600	No	15.85084	-4.24722	3.26000
67	GLOBAL	Cylindrical	16.41000	0.000	3.2600	No	16.41000	0.00000	3.26000
68	GLOBAL	Cylindrical	16.41000	15.000	3.2600	No	15.85084	4.24722	3.26000
69	GLOBAL	Cylindrical	16.41000	30.000	3.2600	No	14.21148	8.20500	3.26000
70	GLOBAL	Cylindrical	16.41000	45.000	3.2600	No	11.60362	11.60362	3.26000
71	GLOBAL	Cylindrical	16.41000	60.000	3.2600	No	8.20500	14.21148	3.26000
72	GLOBAL	Cylindrical	16.41000	75.000	3.2600	No	4.24722	15.85084	3.26000
73	GLOBAL	Cylindrical	8.78000	105.000	4.2700	No	-2.27243	8.48083	4.27000
74	GLOBAL	Cylindrical	8.78000	120.000	4.2700	No	-4.39000	7.60370	4.27000
75	GLOBAL	Cylindrical	8.78000	135.000	4.2700	No	-6.20840	6.20840	4.27000
76	GLOBAL	Cylindrical	8.78000	150.000	4.2700	No	-7.60370	4.39000	4.27000
77	GLOBAL	Cylindrical	8.78000	165.000	4.2700	No	-8.48083	2.27243	4.27000
78	GLOBAL	Cylindrical	8.78000	180.000	4.2700	No	-8.78000	1.075E-15	4.27000
79	GLOBAL	Cylindrical	8.78000	195.000	4.2700	No	-8.48083	-2.27243	4.27000
80	GLOBAL	Cylindrical	8.78000	210.000	4.2700	No	-7.60370	-4.39000	4.27000
81	GLOBAL	Cylindrical	8.78000	225.000	4.2700	No	-6.20840	-6.20840	4.27000
82	GLOBAL	Cylindrical	8.78000	240.000	4.2700	No	-4.39000	-7.60370	4.27000
83	GLOBAL	Cylindrical	8.78000	255.000	4.2700	No	-2.27243	-8.48083	4.27000
84	GLOBAL	Cylindrical	8.78000	270.000	4.2700	No	-1.613E-15	-8.78000	4.27000
85	GLOBAL	Cylindrical	8.78000	285.000	4.2700	No	2.27243	-8.48083	4.27000
86	GLOBAL	Cylindrical	8.78000	300.000	4.2700	No	4.39000	-7.60370	4.27000
87	GLOBAL	Cylindrical	8.78000	315.000	4.2700	No	6.20840	-6.20840	4.27000
88	GLOBAL	Cylindrical	8.78000	330.000	4.2700	No	7.60370	-4.39000	4.27000
89	GLOBAL	Cylindrical	8.78000	345.000	4.2700	No	8.48083	-2.27243	4.27000
90	GLOBAL	Cylindrical	8.78000	0.000	4.2700	No	8.78000	0.00000	4.27000
91	GLOBAL	Cylindrical	8.78000	15.000	4.2700	No	8.48083	2.27243	4.27000
92	GLOBAL	Cylindrical	8.78000	30.000	4.2700	No	7.60370	4.39000	4.27000
93	GLOBAL	Cylindrical	8.78000	45.000	4.2700	No	6.20840	6.20840	4.27000
94	GLOBAL	Cylindrical	8.78000	60.000	4.2700	No	4.39000	7.60370	4.27000
95	GLOBAL	Cylindrical	8.78000	75.000	4.2700	No	2.27243	8.48083	4.27000
96	GLOBAL	Cylindrical	8.78000	90.000	4.2700	No	5.376E-16	8.78000	4.27000
97	GLOBAL	Cylindrical	0.00000	0.000	4.5800	No	0.00000	0.00000	4.58000

Table: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
1	Yes	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes	Yes	Yes
4	Yes	Yes	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes	Yes	Yes
9	Yes	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes	Yes	Yes

Joint	U1	U2	U3	R1	R2	R3
13	Yes	Yes	Yes	Yes	Yes	Yes
14	Yes	Yes	Yes	Yes	Yes	Yes
15	Yes	Yes	Yes	Yes	Yes	Yes
16	Yes	Yes	Yes	Yes	Yes	Yes
17	Yes	Yes	Yes	Yes	Yes	Yes
18	Yes	Yes	Yes	Yes	Yes	Yes
19	Yes	Yes	Yes	Yes	Yes	Yes
20	Yes	Yes	Yes	Yes	Yes	Yes
21	Yes	Yes	Yes	Yes	Yes	Yes
22	Yes	Yes	Yes	Yes	Yes	Yes
23	Yes	Yes	Yes	Yes	Yes	Yes
24	Yes	Yes	Yes	Yes	Yes	Yes

A.2- Sample of Output Data: Circular dome roof:

* Rigid joints:

Table: Joint Displacements

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
1	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
5	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
7	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
9	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
10	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
11	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
13	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
14	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
15	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
16	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
17	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
18	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
19	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
20	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
21	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
22	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
23	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
24	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
25	DL	LinStatic	0.007541	0.001122	0.006085	-0.000142	0.001357	-0.000106
26	DL	LinStatic	0.006994	0.003035	0.006085	-0.000489	0.001274	-0.000106

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
27	DL	LinStatic	0.005970	0.004742	0.006085	-0.000802	0.001105	-0.000106
28	DL	LinStatic	0.004539	0.006125	0.006085	-0.001060	0.000859	-0.000106
29	DL	LinStatic	0.002799	0.007091	0.006085	-0.001247	0.000556	-0.000106
30	DL	LinStatic	0.000868	0.007574	0.006085	-0.001348	0.000214	-0.000106
31	DL	LinStatic	-0.001122	0.007541	0.006085	-0.001357	-0.000142	-0.000106
32	DL	LinStatic	-0.003035	0.006994	0.006085	-0.001274	-0.000489	-0.000106
33	DL	LinStatic	-0.004742	0.005970	0.006085	-0.001105	-0.000802	-0.000106
34	DL	LinStatic	-0.006125	0.004539	0.006085	-0.000859	-0.001060	-0.000106
35	DL	LinStatic	-0.007091	0.002799	0.006085	-0.000556	-0.001247	-0.000106
36	DL	LinStatic	-0.007574	0.000868	0.006085	-0.000214	-0.001348	-0.000106
37	DL	LinStatic	-0.007541	-0.001122	0.006085	0.000142	-0.001357	-0.000106
38	DL	LinStatic	-0.006994	-0.003035	0.006085	0.000489	-0.001274	-0.000106
39	DL	LinStatic	-0.005970	-0.004742	0.006085	0.000802	-0.001105	-0.000106
40	DL	LinStatic	-0.004539	-0.006125	0.006085	0.001060	-0.000859	-0.000106
41	DL	LinStatic	-0.002799	-0.007091	0.006085	0.001247	-0.000556	-0.000106
42	DL	LinStatic	-0.000868	-0.007574	0.006085	0.001348	-0.000214	-0.000106
43	DL	LinStatic	0.001122	-0.007541	0.006085	0.001357	0.000142	-0.000106
44	DL	LinStatic	0.003035	-0.006994	0.006085	0.001274	0.000489	-0.000106
45	DL	LinStatic	0.004742	-0.005970	0.006085	0.001105	0.000802	-0.000106
46	DL	LinStatic	0.006125	-0.004539	0.006085	0.000859	0.001060	-0.000106
47	DL	LinStatic	0.007091	-0.002799	0.006085	0.000556	0.001247	-0.000106
48	DL	LinStatic	0.007574	-0.000868	0.006085	0.000214	0.001348	-0.000106
49	DL	LinStatic	0.000590	0.000809	-0.020315	0.008247	-0.000202	-0.000170
50	DL	LinStatic	0.000361	0.000934	-0.020315	0.008018	0.001940	-0.000170
51	DL	LinStatic	0.000106	0.000996	-0.020315	0.007243	0.003949	-0.000170
52	DL	LinStatic	-0.000155	0.000989	-0.020315	0.005974	0.005689	-0.000170
53	DL	LinStatic	-0.000406	0.000916	-0.020315	0.004298	0.007041	-0.000170
54	DL	LinStatic	-0.000629	0.000779	-0.020315	0.002329	0.007914	-0.000170
55	DL	LinStatic	-0.000809	0.000590	-0.020315	0.000202	0.008247	-0.000170
56	DL	LinStatic	-0.000934	0.000361	-0.020315	-0.001940	0.008018	-0.000170
57	DL	LinStatic	-0.000996	0.000106	-0.020315	-0.003949	0.007243	-0.000170
58	DL	LinStatic	-0.000989	-0.000155	-0.020315	-0.005689	0.005974	-0.000170
59	DL	LinStatic	-0.000916	-0.000406	-0.020315	-0.007041	0.004298	-0.000170
60	DL	LinStatic	-0.000779	-0.000629	-0.020315	-0.007914	0.002329	-0.000170
61	DL	LinStatic	-0.000590	-0.000809	-0.020315	-0.008247	0.000202	-0.000170
62	DL	LinStatic	-0.000361	-0.000934	-0.020315	-0.008018	-0.001940	-0.000170
63	DL	LinStatic	-0.000106	-0.000996	-0.020315	-0.007243	-0.003949	-0.000170
64	DL	LinStatic	0.000155	-0.000989	-0.020315	-0.005974	-0.005689	-0.000170
65	DL	LinStatic	0.000406	-0.000916	-0.020315	-0.004298	-0.007041	-0.000170
66	DL	LinStatic	0.000629	-0.000779	-0.020315	-0.002329	-0.007914	-0.000170
67	DL	LinStatic	0.000809	-0.000590	-0.020315	-0.000202	-0.008247	-0.000170
68	DL	LinStatic	0.000934	-0.000361	-0.020315	0.001940	-0.008018	-0.000170
69	DL	LinStatic	0.000996	-0.000106	-0.020315	0.003949	-0.007243	-0.000170
70	DL	LinStatic	0.000989	0.000155	-0.020315	0.005689	-0.005974	-0.000170
71	DL	LinStatic	0.000916	0.000406	-0.020315	0.007041	-0.004298	-0.000170

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
72	DL	LinStatic	0.000779	0.000629	-0.020315	0.007914	-0.002329	-0.000170
73	DL	LinStatic	-0.002066	-0.002678	-0.053729	0.000147	0.000052	0.000188
74	DL	LinStatic	-0.001302	-0.003121	-0.053729	0.000128	0.000088	0.000188
75	DL	LinStatic	-0.000450	-0.003352	-0.053729	0.000101	0.000119	0.000188
76	DL	LinStatic	0.000433	-0.003354	-0.053729	0.000067	0.000141	0.000188
77	DL	LinStatic	0.001286	-0.003128	-0.053729	0.000028	0.000153	0.000188
78	DL	LinStatic	0.002052	-0.002689	-0.053729	-0.000012	0.000155	0.000188
79	DL	LinStatic	0.002678	-0.002066	-0.053729	-0.000052	0.000147	0.000188
80	DL	LinStatic	0.003121	-0.001302	-0.053729	-0.000088	0.000128	0.000188
81	DL	LinStatic	0.003352	-0.000450	-0.053729	-0.000119	0.000101	0.000188
82	DL	LinStatic	0.003354	0.000433	-0.053729	-0.000141	0.000067	0.000188
83	DL	LinStatic	0.003128	0.001286	-0.053729	-0.000153	0.000028	0.000188
84	DL	LinStatic	0.002689	0.002052	-0.053729	-0.000155	-0.000012	0.000188
85	DL	LinStatic	0.002066	0.002678	-0.053729	-0.000147	-0.000052	0.000188
86	DL	LinStatic	0.001302	0.003121	-0.053729	-0.000128	-0.000088	0.000188
87	DL	LinStatic	0.000450	0.003352	-0.053729	-0.000101	-0.000119	0.000188
88	DL	LinStatic	-0.000433	0.003354	-0.053729	-0.000067	-0.000141	0.000188
89	DL	LinStatic	-0.001286	0.003128	-0.053729	-0.000028	-0.000153	0.000188
90	DL	LinStatic	-0.002052	0.002689	-0.053729	0.000012	-0.000155	0.000188
91	DL	LinStatic	-0.002678	0.002066	-0.053729	0.000052	-0.000147	0.000188
92	DL	LinStatic	-0.003121	0.001302	-0.053729	0.000088	-0.000128	0.000188
93	DL	LinStatic	-0.003352	0.000450	-0.053729	0.000119	-0.000101	0.000188
94	DL	LinStatic	-0.003354	-0.000433	-0.053729	0.000141	-0.000067	0.000188
95	DL	LinStatic	-0.003128	-0.001286	-0.053729	0.000153	-0.000028	0.000188
96	DL	LinStatic	-0.002689	-0.002052	-0.053729	0.000155	0.000012	0.000188
97	DL	LinStatic	-4.424E-18	7.156E-18	-0.030319	-1.695E-17	1.227E-17	0.000365

Table: Joint Reactions

Joint	Output Case	Case Type	F1 KN	F2 KN	F3 KN	M1 KN-m	M2 KN-m	M3 KN-m
1	DL	LinStatic	144.714	-539.150	554.255	123.2250	21.1253	5.5058
2	DL	LinStatic	279.325	-483.324	554.255	113.5585	52.2984	5.5058
3	DL	LinStatic	394.901	-394.561	554.255	96.1533	79.9075	5.5058
4	DL	LinStatic	483.564	-278.908	554.255	72.1954	102.0710	5.5058
5	DL	LinStatic	539.274	-144.249	554.255	43.3175	117.2786	5.5058
6	DL	LinStatic	558.233	0.240	554.255	11.4875	124.4938	5.5058
7	DL	LinStatic	539.150	144.714	554.255	-21.1253	123.2250	5.5058
8	DL	LinStatic	483.324	279.325	554.255	-52.2984	113.5585	5.5058
9	DL	LinStatic	394.561	394.901	554.255	-79.9075	96.1533	5.5058
10	DL	LinStatic	278.908	483.564	554.255	-102.0710	72.1954	5.5058
11	DL	LinStatic	144.249	539.274	554.255	-117.2786	43.3175	5.5058
12	DL	LinStatic	-0.240	558.233	554.255	-124.4938	11.4875	5.5058
13	DL	LinStatic	-144.714	539.150	554.255	-123.2250	-21.1253	5.5058
14	DL	LinStatic	-279.325	483.324	554.255	-113.5585	-52.2984	5.5058

Joint	Output Case	Case Type	F1 KN	F2 KN	F3 KN	M1 KN-m	M2 KN-m	M3 KN-m
15	DL	LinStatic	-394.901	394.561	554.255	-96.1533	-79.9075	5.5058
16	DL	LinStatic	-483.564	278.908	554.255	-72.1954	-102.0710	5.5058
17	DL	LinStatic	-539.274	144.249	554.255	-43.3175	-117.2786	5.5058
18	DL	LinStatic	-558.233	-0.240	554.255	-11.4875	-124.4938	5.5058
19	DL	LinStatic	-539.150	-144.714	554.255	21.1253	-123.2250	5.5058
20	DL	LinStatic	-483.324	-279.325	554.255	52.2984	-113.5585	5.5058
21	DL	LinStatic	-394.561	-394.901	554.255	79.9075	-96.1533	5.5058
22	DL	LinStatic	-278.908	-483.564	554.255	102.0710	-72.1954	5.5058
23	DL	LinStatic	-144.249	-539.274	554.255	117.2786	-43.3175	5.5058
24	DL	LinStatic	0.240	-558.233	554.255	124.4938	-11.4875	5.5058

* Semi-rigid joints:

Table: Joint Displacements

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
1	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
5	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
7	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
9	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
10	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
11	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
13	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
14	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
15	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
16	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
17	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
18	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
19	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
20	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
21	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
22	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
23	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
24	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
25	DL	LinStatic	0.010263	0.001454	0.008454	0.000646	-0.001062	0.000370
26	DL	LinStatic	0.009537	0.004061	0.008454	0.000899	-0.000859	0.000370
27	DL	LinStatic	0.008161	0.006391	0.008454	0.001091	-0.000597	0.000370
28	DL	LinStatic	0.006229	0.008285	0.008454	0.001208	-0.000294	0.000370
29	DL	LinStatic	0.003872	0.009615	0.008454	0.001243	0.000028	0.000370

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
30	DL	LinStatic	0.001252	0.010290	0.008454	0.001193	0.000349	0.000370
31	DL	LinStatic	-0.001454	0.010263	0.008454	0.001062	0.000646	0.000370
32	DL	LinStatic	-0.004061	0.009537	0.008454	0.000859	0.000899	0.000370
33	DL	LinStatic	-0.006391	0.008161	0.008454	0.000597	0.001091	0.000370
34	DL	LinStatic	-0.008285	0.006229	0.008454	0.000294	0.001208	0.000370
35	DL	LinStatic	-0.009615	0.003872	0.008454	-0.000028	0.001243	0.000370
36	DL	LinStatic	-0.010290	0.001252	0.008454	-0.000349	0.001193	0.000370
37	DL	LinStatic	-0.010263	-0.001454	0.008454	-0.000646	0.001062	0.000370
38	DL	LinStatic	-0.009537	-0.004061	0.008454	-0.000899	0.000859	0.000370
39	DL	LinStatic	-0.008161	-0.006391	0.008454	-0.001091	0.000597	0.000370
40	DL	LinStatic	-0.006229	-0.008285	0.008454	-0.001208	0.000294	0.000370
41	DL	LinStatic	-0.003872	-0.009615	0.008454	-0.001243	-0.000028	0.000370
42	DL	LinStatic	-0.001252	-0.010290	0.008454	-0.001193	-0.000349	0.000370
43	DL	LinStatic	0.001454	-0.010263	0.008454	-0.001062	-0.000646	0.000370
44	DL	LinStatic	0.004061	-0.009537	0.008454	-0.000859	-0.000899	0.000370
45	DL	LinStatic	0.006391	-0.008161	0.008454	-0.000597	-0.001091	0.000370
46	DL	LinStatic	0.008285	-0.006229	0.008454	-0.000294	-0.001208	0.000370
47	DL	LinStatic	0.009615	-0.003872	0.008454	0.000028	-0.001243	0.000370
48	DL	LinStatic	0.010290	-0.001252	0.008454	0.000349	-0.001193	0.000370
49	DL	LinStatic	0.001034	0.000215	-0.029286	0.002916	-0.000314	4.703E-06
50	DL	LinStatic	0.000943	0.000475	-0.029286	0.002898	0.000451	4.703E-06
51	DL	LinStatic	0.000788	0.000703	-0.029286	0.002683	0.001186	4.703E-06
52	DL	LinStatic	0.000579	0.000883	-0.029286	0.002284	0.001840	4.703E-06
53	DL	LinStatic	0.000331	0.001003	-0.029286	0.001730	0.002368	4.703E-06
54	DL	LinStatic	0.000060	0.001054	-0.029286	0.001058	0.002736	4.703E-06
55	DL	LinStatic	-0.000215	0.001034	-0.029286	0.000314	0.002916	4.703E-06
56	DL	LinStatic	-0.000475	0.000943	-0.029286	-0.000451	0.002898	4.703E-06
57	DL	LinStatic	-0.000703	0.000788	-0.029286	-0.001186	0.002683	4.703E-06
58	DL	LinStatic	-0.000883	0.000579	-0.029286	-0.001840	0.002284	4.703E-06
59	DL	LinStatic	-0.001003	0.000331	-0.029286	-0.002368	0.001730	4.703E-06
60	DL	LinStatic	-0.001054	0.000060	-0.029286	-0.002736	0.001058	4.703E-06
61	DL	LinStatic	-0.001034	-0.000215	-0.029286	-0.002916	0.000314	4.703E-06
62	DL	LinStatic	-0.000943	-0.000475	-0.029286	-0.002898	-0.000451	4.703E-06
63	DL	LinStatic	-0.000788	-0.000703	-0.029286	-0.002683	-0.001186	4.703E-06
64	DL	LinStatic	-0.000579	-0.000883	-0.029286	-0.002284	-0.001840	4.703E-06
65	DL	LinStatic	-0.000331	-0.001003	-0.029286	-0.001730	-0.002368	4.703E-06
66	DL	LinStatic	-0.000060	-0.001054	-0.029286	-0.001058	-0.002736	4.703E-06
67	DL	LinStatic	0.000215	-0.001034	-0.029286	-0.000314	-0.002916	4.703E-06
68	DL	LinStatic	0.000475	-0.000943	-0.029286	0.000451	-0.002898	4.703E-06
69	DL	LinStatic	0.000703	-0.000788	-0.029286	0.001186	-0.002683	4.703E-06
70	DL	LinStatic	0.000883	-0.000579	-0.029286	0.001840	-0.002284	4.703E-06
71	DL	LinStatic	0.001003	-0.000331	-0.029286	0.002368	-0.001730	4.703E-06
72	DL	LinStatic	0.001054	-0.000060	-0.029286	0.002736	-0.001058	4.703E-06
73	DL	LinStatic	-0.001786	-0.003560	-0.065264	0.000733	0.000121	0.000064
74	DL	LinStatic	-0.000804	-0.003901	-0.065264	0.000677	0.000307	0.000064

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
75	DL	LinStatic	0.000233	-0.003976	-0.065264	0.000575	0.000471	0.000064
76	DL	LinStatic	0.001254	-0.003780	-0.065264	0.000433	0.000604	0.000064
77	DL	LinStatic	0.002189	-0.003327	-0.065264	0.000262	0.000696	0.000064
78	DL	LinStatic	0.002976	-0.002647	-0.065264	0.000073	0.000740	0.000064
79	DL	LinStatic	0.003560	-0.001786	-0.065264	-0.000121	0.000733	0.000064
80	DL	LinStatic	0.003901	-0.000804	-0.065264	-0.000307	0.000677	0.000064
81	DL	LinStatic	0.003976	0.000233	-0.065264	-0.000471	0.000575	0.000064
82	DL	LinStatic	0.003780	0.001254	-0.065264	-0.000604	0.000433	0.000064
83	DL	LinStatic	0.003327	0.002189	-0.065264	-0.000696	0.000262	0.000064
84	DL	LinStatic	0.002647	0.002976	-0.065264	-0.000740	0.000073	0.000064
85	DL	LinStatic	0.001786	0.003560	-0.065264	-0.000733	-0.000121	0.000064
86	DL	LinStatic	0.000804	0.003901	-0.065264	-0.000677	-0.000307	0.000064
87	DL	LinStatic	-0.000233	0.003976	-0.065264	-0.000575	-0.000471	0.000064
88	DL	LinStatic	-0.001254	0.003780	-0.065264	-0.000433	-0.000604	0.000064
89	DL	LinStatic	-0.002189	0.003327	-0.065264	-0.000262	-0.000696	0.000064
90	DL	LinStatic	-0.002976	0.002647	-0.065264	-0.000073	-0.000740	0.000064
91	DL	LinStatic	-0.003560	0.001786	-0.065264	0.000121	-0.000733	0.000064
92	DL	LinStatic	-0.003901	0.000804	-0.065264	0.000307	-0.000677	0.000064
93	DL	LinStatic	-0.003976	-0.000233	-0.065264	0.000471	-0.000575	0.000064
94	DL	LinStatic	-0.003780	-0.001254	-0.065264	0.000604	-0.000433	0.000064
95	DL	LinStatic	-0.003327	-0.002189	-0.065264	0.000696	-0.000262	0.000064
96	DL	LinStatic	-0.002647	-0.002976	-0.065264	0.000740	-0.000073	0.000064
97	DL	LinStatic	-1.003E-17	5.464E-17	-0.008936	1.017E-18	-2.952E-17	0.000335

Table: Joint Reactions

Joint	Output Case	Case Type	F1 KN	F2 KN	F3 KN	M1 KN-m	M2 KN-m	M3 KN-m
1	DL	LinStatic	109.391	-408.180	554.255	-1.0302	-0.7903	0.4300
2	DL	LinStatic	211.308	-365.959	554.255	-0.7905	-1.0300	0.4300
3	DL	LinStatic	298.825	-298.799	554.255	-0.4970	-1.1995	0.4300
4	DL	LinStatic	365.978	-211.276	554.255	-0.1696	-1.2873	0.4300
5	DL	LinStatic	408.189	-109.355	554.255	0.1693	-1.2873	0.4300
6	DL	LinStatic	422.584	0.019	554.255	0.4968	-1.1996	0.4300
7	DL	LinStatic	408.180	109.391	554.255	0.7903	-1.0302	0.4300
8	DL	LinStatic	365.959	211.308	554.255	1.0300	-0.7905	0.4300
9	DL	LinStatic	298.799	298.825	554.255	1.1995	-0.4970	0.4300
10	DL	LinStatic	211.276	365.978	554.255	1.2873	-0.1696	0.4300
11	DL	LinStatic	109.355	408.189	554.255	1.2873	0.1693	0.4300
12	DL	LinStatic	-0.019	422.584	554.255	1.1996	0.4968	0.4300
13	DL	LinStatic	-109.391	408.180	554.255	1.0302	0.7903	0.4300
14	DL	LinStatic	-211.308	365.959	554.255	0.7905	1.0300	0.4300
15	DL	LinStatic	-298.825	298.799	554.255	0.4970	1.1995	0.4300
16	DL	LinStatic	-365.978	211.276	554.255	0.1696	1.2873	0.4300
17	DL	LinStatic	-408.189	109.355	554.255	-0.1693	1.2873	0.4300

Joint	Output Case	Case Type	F1 KN	F2 KN	F3 KN	M1 KN-m	M2 KN-m	M3 KN-m
18	DL	LinStatic	-422.584	-0.019	554.255	-0.4968	1.1996	0.4300
19	DL	LinStatic	-408.180	-109.391	554.255	-0.7903	1.0302	0.4300
20	DL	LinStatic	-365.959	-211.308	554.255	-1.0300	0.7905	0.4300
21	DL	LinStatic	-298.799	-298.825	554.255	-1.1995	0.4970	0.4300
22	DL	LinStatic	-211.276	-365.978	554.255	-1.2873	0.1696	0.4300
23	DL	LinStatic	-109.355	-408.189	554.255	-1.2873	-0.1693	0.4300
24	DL	LinStatic	0.019	-422.584	554.255	-1.1996	-0.4968	0.4300

* Pinned joints:

Table: Joint Displacements

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
1	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
5	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
7	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
9	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
10	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
11	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
13	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
14	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
15	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
16	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
17	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
18	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
19	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
20	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
21	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
22	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
23	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
24	DL	LinStatic	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
25	DL	LinStatic	0.010286	0.001457	0.008474	0.000000	0.000000	0.000000
26	DL	LinStatic	0.009558	0.004070	0.008474	0.000000	0.000000	0.000000
27	DL	LinStatic	0.008179	0.006405	0.008474	0.000000	0.000000	0.000000
28	DL	LinStatic	0.006243	0.008303	0.008474	0.000000	0.000000	0.000000
29	DL	LinStatic	0.003881	0.009636	0.008474	0.000000	0.000000	0.000000
30	DL	LinStatic	0.001255	0.010312	0.008474	0.000000	0.000000	0.000000
31	DL	LinStatic	-0.001457	0.010286	0.008474	0.000000	0.000000	0.000000
32	DL	LinStatic	-0.004070	0.009558	0.008474	0.000000	0.000000	0.000000

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
33	DL	LinStatic	-0.006405	0.008179	0.008474	0.000000	0.000000	0.000000
34	DL	LinStatic	-0.008303	0.006243	0.008474	0.000000	0.000000	0.000000
35	DL	LinStatic	-0.009636	0.003881	0.008474	0.000000	0.000000	0.000000
36	DL	LinStatic	-0.010312	0.001255	0.008474	0.000000	0.000000	0.000000
37	DL	LinStatic	-0.010286	-0.001457	0.008474	0.000000	0.000000	0.000000
38	DL	LinStatic	-0.009558	-0.004070	0.008474	0.000000	0.000000	0.000000
39	DL	LinStatic	-0.008179	-0.006405	0.008474	0.000000	0.000000	0.000000
40	DL	LinStatic	-0.006243	-0.008303	0.008474	0.000000	0.000000	0.000000
41	DL	LinStatic	-0.003881	-0.009636	0.008474	0.000000	0.000000	0.000000
42	DL	LinStatic	-0.001255	-0.010312	0.008474	0.000000	0.000000	0.000000
43	DL	LinStatic	0.001457	-0.010286	0.008474	0.000000	0.000000	0.000000
44	DL	LinStatic	0.004070	-0.009558	0.008474	0.000000	0.000000	0.000000
45	DL	LinStatic	0.006405	-0.008179	0.008474	0.000000	0.000000	0.000000
46	DL	LinStatic	0.008303	-0.006243	0.008474	0.000000	0.000000	0.000000
47	DL	LinStatic	0.009636	-0.003881	0.008474	0.000000	0.000000	0.000000
48	DL	LinStatic	0.010312	-0.001255	0.008474	0.000000	0.000000	0.000000
49	DL	LinStatic	0.001038	0.000214	-0.029349	0.000000	0.000000	0.000000
50	DL	LinStatic	0.000947	0.000475	-0.029349	0.000000	0.000000	0.000000
51	DL	LinStatic	0.000792	0.000704	-0.029349	0.000000	0.000000	0.000000
52	DL	LinStatic	0.000583	0.000885	-0.029349	0.000000	0.000000	0.000000
53	DL	LinStatic	0.000334	0.001006	-0.029349	0.000000	0.000000	0.000000
54	DL	LinStatic	0.000062	0.001058	-0.029349	0.000000	0.000000	0.000000
55	DL	LinStatic	-0.000214	0.001038	-0.029349	0.000000	0.000000	0.000000
56	DL	LinStatic	-0.000475	0.000947	-0.029349	0.000000	0.000000	0.000000
57	DL	LinStatic	-0.000704	0.000792	-0.029349	0.000000	0.000000	0.000000
58	DL	LinStatic	-0.000885	0.000583	-0.029349	0.000000	0.000000	0.000000
59	DL	LinStatic	-0.001006	0.000334	-0.029349	0.000000	0.000000	0.000000
60	DL	LinStatic	-0.001058	0.000062	-0.029349	0.000000	0.000000	0.000000
61	DL	LinStatic	-0.001038	-0.000214	-0.029349	0.000000	0.000000	0.000000
62	DL	LinStatic	-0.000947	-0.000475	-0.029349	0.000000	0.000000	0.000000
63	DL	LinStatic	-0.000792	-0.000704	-0.029349	0.000000	0.000000	0.000000
64	DL	LinStatic	-0.000583	-0.000885	-0.029349	0.000000	0.000000	0.000000
65	DL	LinStatic	-0.000334	-0.001006	-0.029349	0.000000	0.000000	0.000000
66	DL	LinStatic	-0.000062	-0.001058	-0.029349	0.000000	0.000000	0.000000
67	DL	LinStatic	0.000214	-0.001038	-0.029349	0.000000	0.000000	0.000000
68	DL	LinStatic	0.000475	-0.000947	-0.029349	0.000000	0.000000	0.000000
69	DL	LinStatic	0.000704	-0.000792	-0.029349	0.000000	0.000000	0.000000
70	DL	LinStatic	0.000885	-0.000583	-0.029349	0.000000	0.000000	0.000000
71	DL	LinStatic	0.001006	-0.000334	-0.029349	0.000000	0.000000	0.000000
72	DL	LinStatic	0.001058	-0.000062	-0.029349	0.000000	0.000000	0.000000
73	DL	LinStatic	-0.001783	-0.003586	-0.065525	0.000000	0.000000	0.000000
74	DL	LinStatic	-0.000795	-0.003925	-0.065525	0.000000	0.000000	0.000000
75	DL	LinStatic	0.000248	-0.003997	-0.065525	0.000000	0.000000	0.000000
76	DL	LinStatic	0.001274	-0.003796	-0.065525	0.000000	0.000000	0.000000
77	DL	LinStatic	0.002214	-0.003337	-0.065525	0.000000	0.000000	0.000000

Joint	Output Case	Case Type	U1 m	U2 m	U3 m	R1 Radians	R2 Radians	R3 Radians
78	DL	LinStatic	0.003002	-0.002651	-0.065525	0.000000	0.000000	0.000000
79	DL	LinStatic	0.003586	-0.001783	-0.065525	0.000000	0.000000	0.000000
80	DL	LinStatic	0.003925	-0.000795	-0.065525	0.000000	0.000000	0.000000
81	DL	LinStatic	0.003997	0.000248	-0.065525	0.000000	0.000000	0.000000
82	DL	LinStatic	0.003796	0.001274	-0.065525	0.000000	0.000000	0.000000
83	DL	LinStatic	0.003337	0.002214	-0.065525	0.000000	0.000000	0.000000
84	DL	LinStatic	0.002651	0.003002	-0.065525	0.000000	0.000000	0.000000
85	DL	LinStatic	0.001783	0.003586	-0.065525	0.000000	0.000000	0.000000
86	DL	LinStatic	0.000795	0.003925	-0.065525	0.000000	0.000000	0.000000
87	DL	LinStatic	-0.000248	0.003997	-0.065525	0.000000	0.000000	0.000000
88	DL	LinStatic	-0.001274	0.003796	-0.065525	0.000000	0.000000	0.000000
89	DL	LinStatic	-0.002214	0.003337	-0.065525	0.000000	0.000000	0.000000
90	DL	LinStatic	-0.003002	0.002651	-0.065525	0.000000	0.000000	0.000000
91	DL	LinStatic	-0.003586	0.001783	-0.065525	0.000000	0.000000	0.000000
92	DL	LinStatic	-0.003925	0.000795	-0.065525	0.000000	0.000000	0.000000
93	DL	LinStatic	-0.003997	-0.000248	-0.065525	0.000000	0.000000	0.000000
94	DL	LinStatic	-0.003796	-0.001274	-0.065525	0.000000	0.000000	0.000000
95	DL	LinStatic	-0.003337	-0.002214	-0.065525	0.000000	0.000000	0.000000
96	DL	LinStatic	-0.002651	-0.003002	-0.065525	0.000000	0.000000	0.000000
97	DL	LinStatic	-8.587E-18	4.250E-17	-0.008306	0.000000	0.000000	0.000000

Table: Joint Reactions

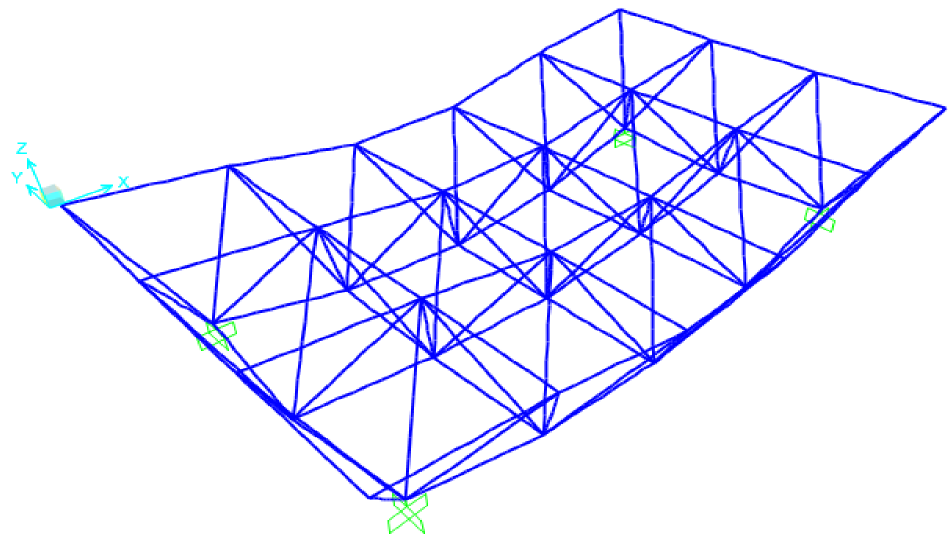
Joint	OutputCase	CaseType	F1 KN	F2 KN	F3 KN	M1 KN-m	M2 KN-m	M3 KN-m
1	DL	LinStatic	109.199	-407.537	554.255	0.0000	0.0000	0.0000
2	DL	LinStatic	210.956	-365.387	554.255	0.0000	0.0000	0.0000
3	DL	LinStatic	298.338	-298.338	554.255	0.0000	0.0000	0.0000
4	DL	LinStatic	365.387	-210.956	554.255	0.0000	0.0000	0.0000
5	DL	LinStatic	407.537	-109.199	554.255	0.0000	0.0000	0.0000
6	DL	LinStatic	421.913	3.360E-11	554.255	0.0000	0.0000	0.0000
7	DL	LinStatic	407.537	109.199	554.255	0.0000	0.0000	0.0000
8	DL	LinStatic	365.387	210.956	554.255	0.0000	0.0000	0.0000
9	DL	LinStatic	298.338	298.338	554.255	0.0000	0.0000	0.0000
10	DL	LinStatic	210.956	365.387	554.255	0.0000	0.0000	0.0000
11	DL	LinStatic	109.199	407.537	554.255	0.0000	0.0000	0.0000
12	DL	LinStatic	-3.789E-11	421.913	554.255	0.0000	0.0000	0.0000
13	DL	LinStatic	-109.199	407.537	554.255	0.0000	0.0000	0.0000
14	DL	LinStatic	-210.956	365.387	554.255	0.0000	0.0000	0.0000
15	DL	LinStatic	-298.338	298.338	554.255	0.0000	0.0000	0.0000
16	DL	LinStatic	-365.387	210.956	554.255	0.0000	0.0000	0.0000
17	DL	LinStatic	-407.537	109.199	554.255	0.0000	0.0000	0.0000
18	DL	LinStatic	-421.913	-4.252E-11	554.255	0.0000	0.0000	0.0000
19	DL	LinStatic	-407.537	-109.199	554.255	0.0000	0.0000	0.0000

Joint	**Outpu** tCase	**CaseType**	**F1 KN**	**F2 KN**	**F3** KN	**M1** KN-m	**M2** KN-m	**M3** KN-m
20	DL	LinStatic	-365.387	-210.956	554.255	0.0000	0.0000	0.0000
21	DL	LinStatic	-298.338	-298.338	554.255	0.0000	0.0000	0.0000
22	DL	LinStatic	-210.956	-365.387	554.255	0.0000	0.0000	0.0000
23	DL	LinStatic	-109.199	-407.537	554.255	0.0000	0.0000	0.0000
24	DL	LinStatic	3.726E-11	-421.913	554.255	0.0000	0.0000	0.0000

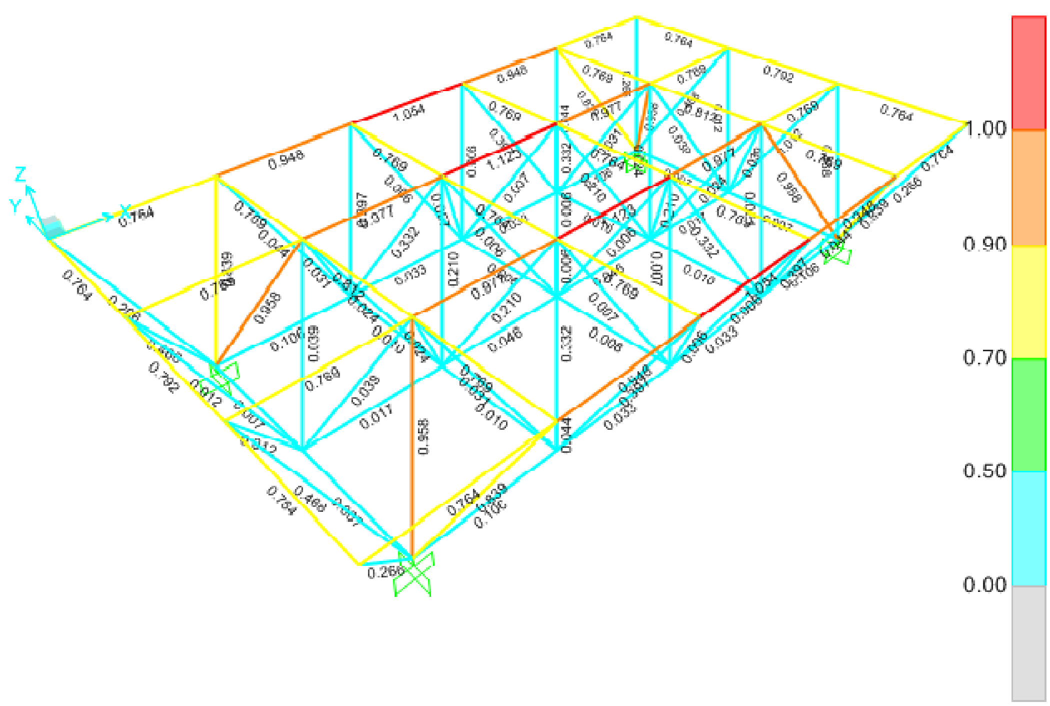
Appendix B

Samples of deformed shapes and steel P.M Interaction ratios (AISC 360-10)

Example one: Flate roof:pinned

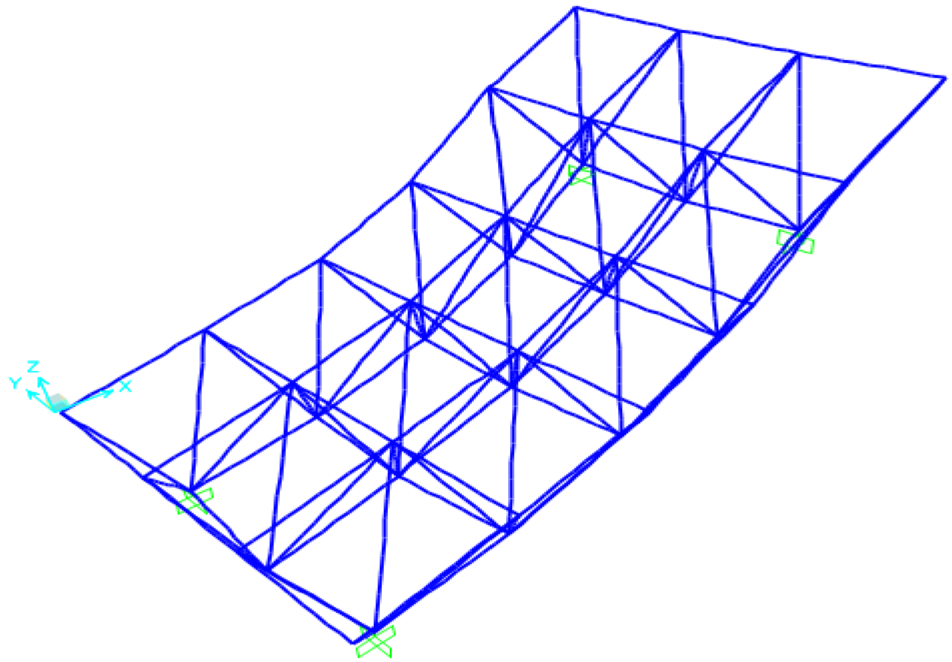


Deformed shape for cace (b)

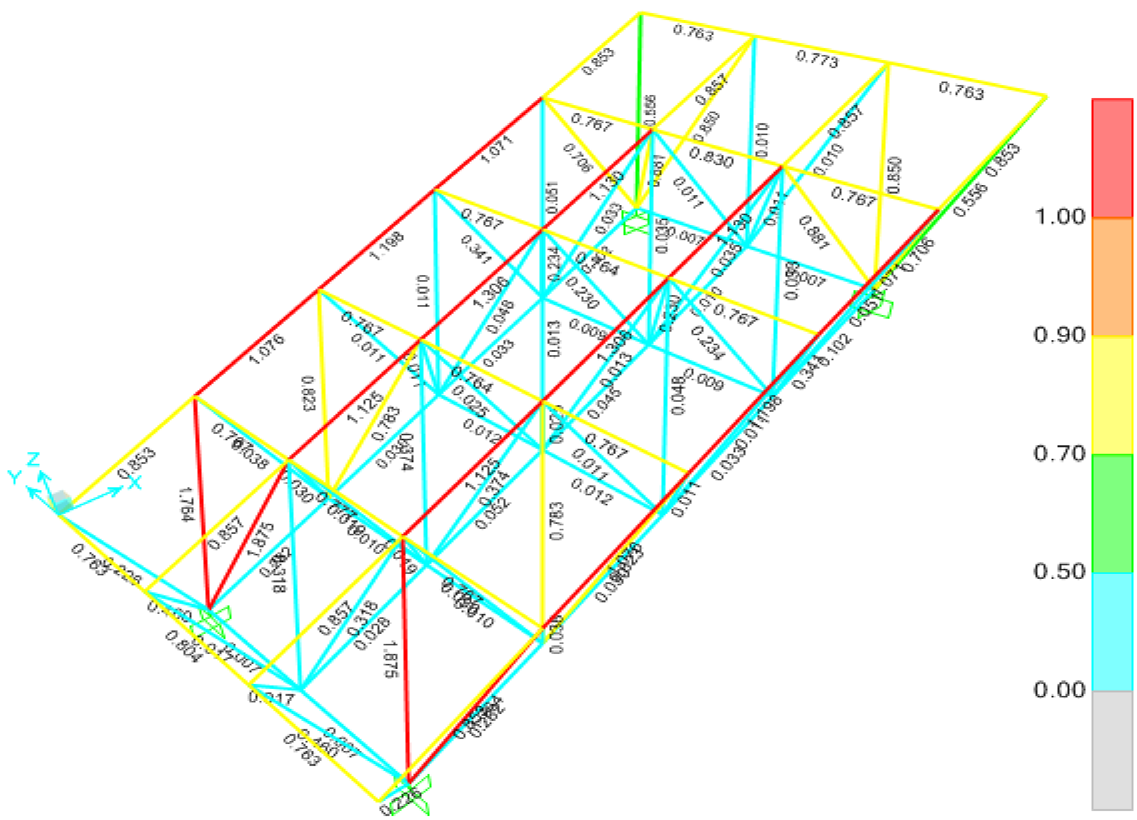


Steel P.M Interaction ratios (AISC 360-10) for cace (b)

Example two: Ascending roof towards the field: pinned

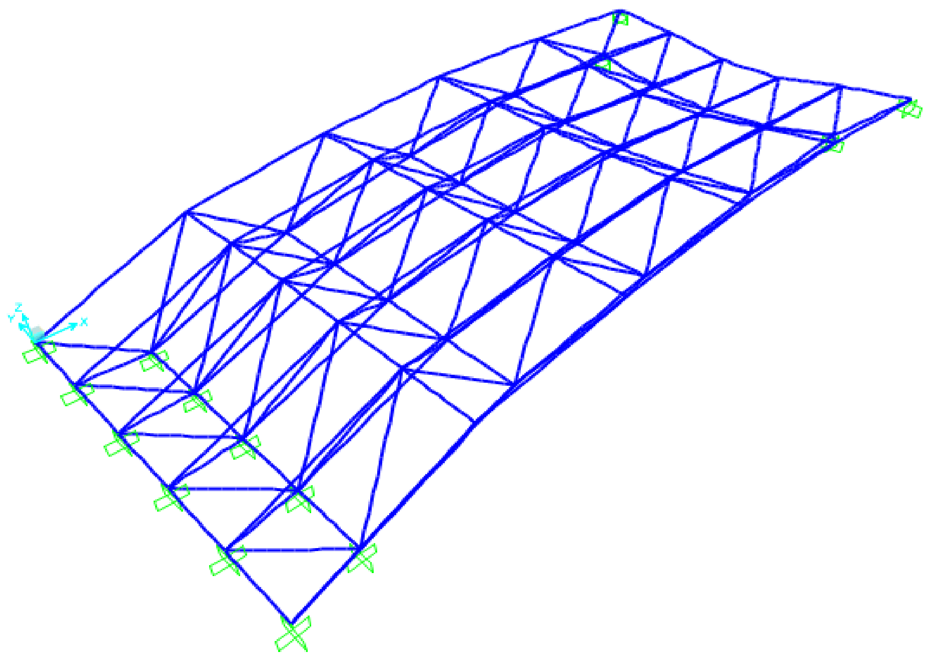


Deformed shape for cace (b)

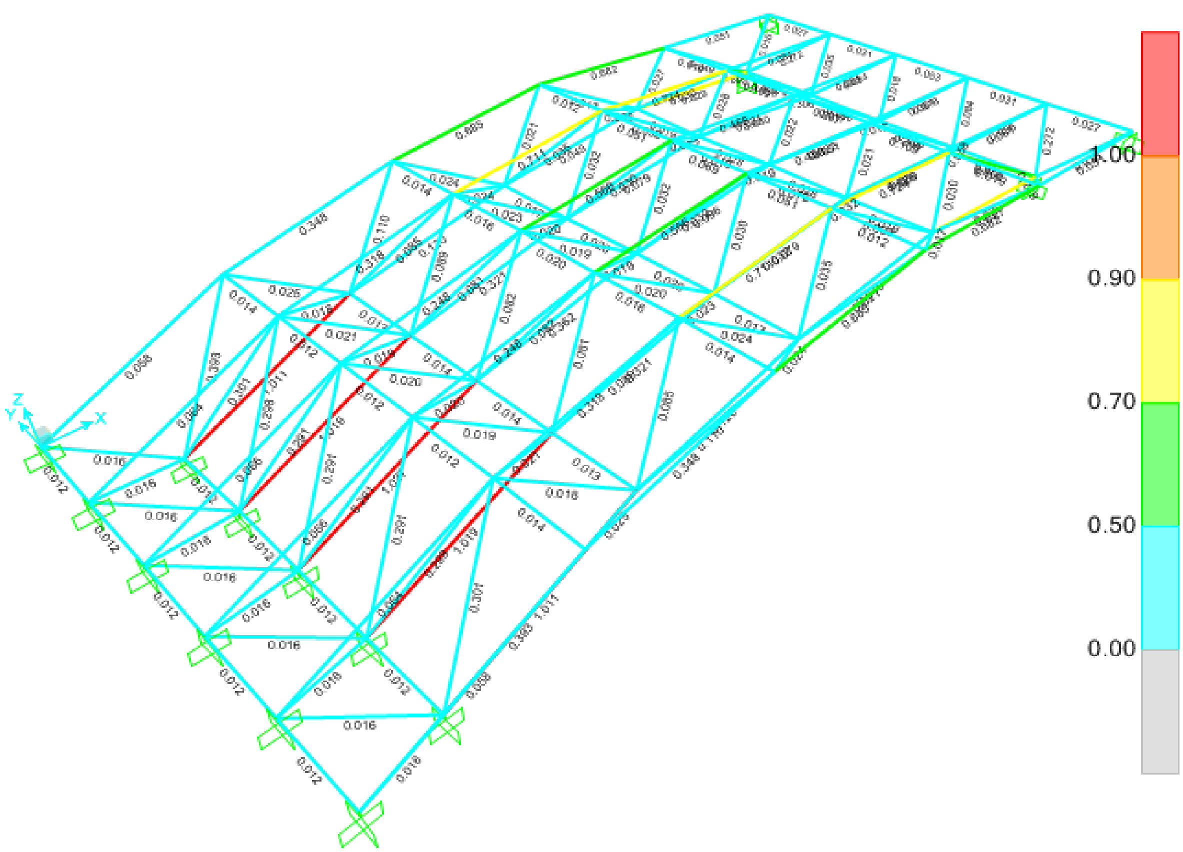


Steel P.M Interaction ratios (AISC 360-10) for cace (b)

Example three: Curved roof: pinned

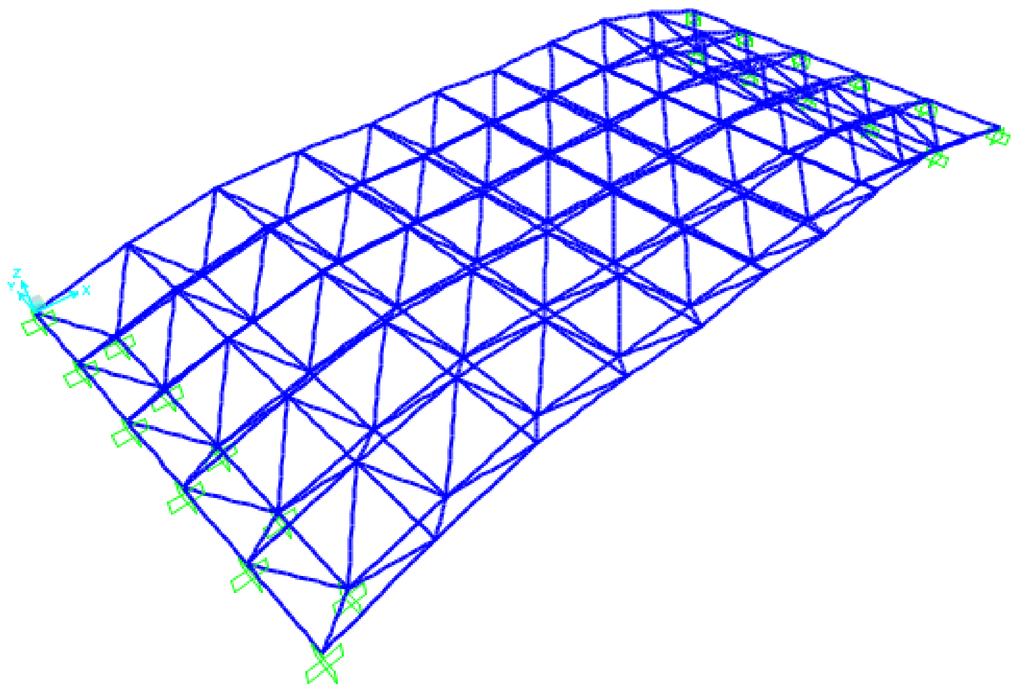


Deformed shape for cace (b)

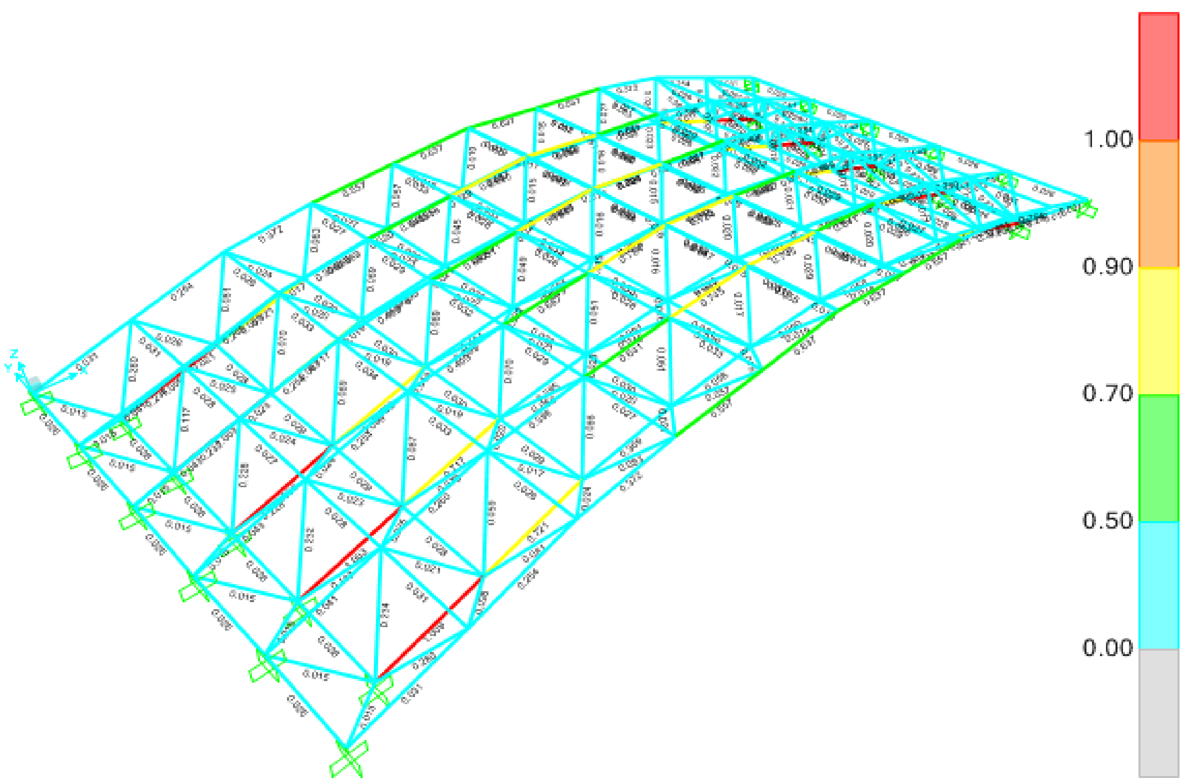


Steel P.M Interaction ratios (AISC 360-10) for cace (b)

Example four: Circular arc roof: pinned

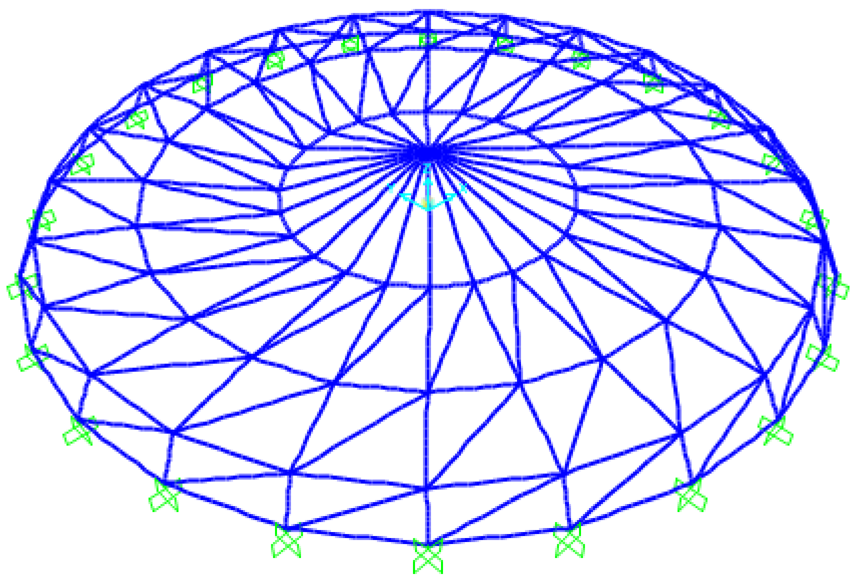


Deformed shape for cace (b)

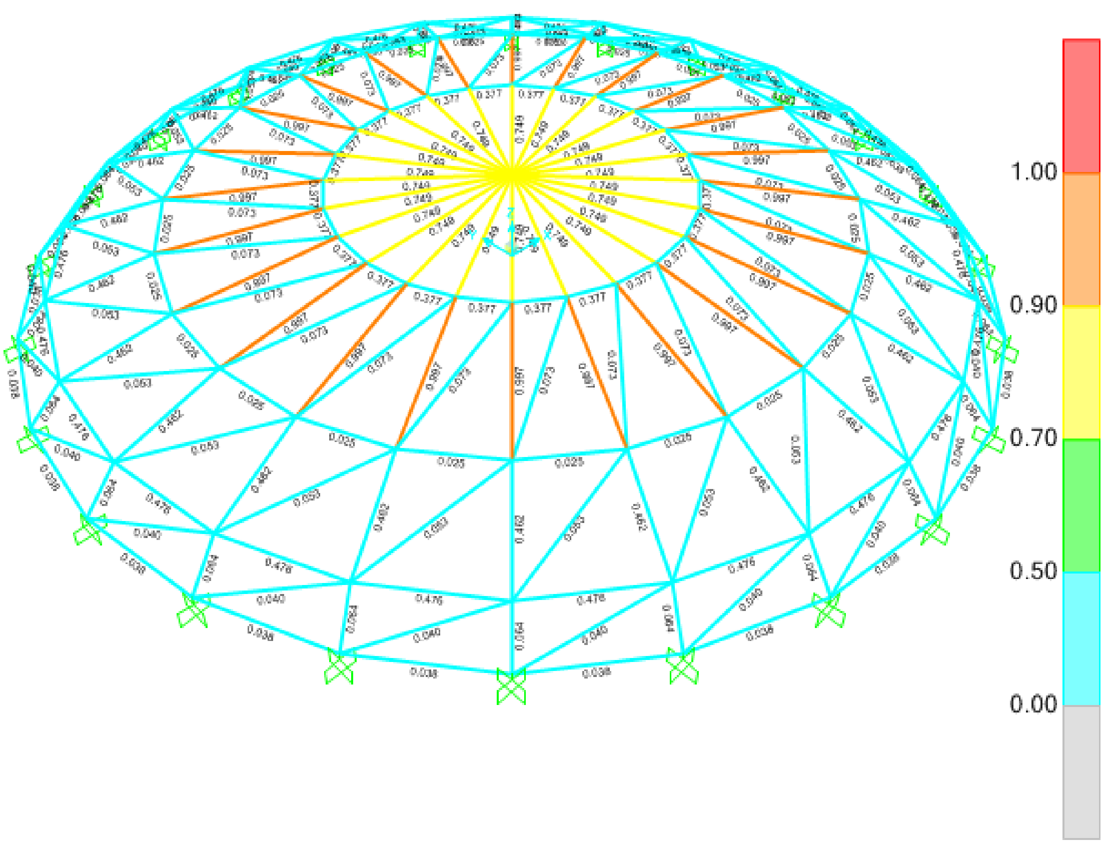


Steel P.M Interaction ratios (AISC 360-10) for cace (b)

Example five: Circular dome roof: pinned



Deformed shape for cace (b)



steel P.M Interaction ratios (AISC 360-10) for cace (b)