STRUCTURE BEHAVIOUR OF DOMES

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ANALYSIS OF STRUCTURE BEHAVIOUR OF DOMES

NUR NADIA AMIRA BINTI ROSELY

Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor (Hons.) of Civil Engineering

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JULY 2015

SUPERVISOR'S DECLARATION

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DEDICATION

I dedicate this thesis to:

My beloved father and mother,
Rosely Talib & Che Rokiah Che Yusof
And my family members.

ACKNOLEDGEMENT

Alhamdulillah, praise to Allah The Almighty. Praise and blessing be upon the Holy Prophet Muhammad S.W.T. With His will and His bless of Allah S.W.T, Alhamdulilah I am able to finish my Final Year Project.

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ABSTRACT

This study is about the analysis structural behaviour in domes. Generally important to define the concept concerning the loss of stability and the method to determine the collapse load of the structure. As single layer dome show an important nonlinear behaviour with considerable softening. The purpose of this research is to analyse the several type of domes using Formian the programming language of formex algebra to evaluate the structural behaviour by import the formex file into finite element software LUSAS analysis programming. In this research, will included the comparison between five models of domes with the same span, rise, sweep angle, radius and central angle in term structure behaviour. The structure behaviour involve are maximum buckling, maximum starin and maximum stress. The type of dome that were used are a ribbed dome, two schwedler domes and two lamella domes with same specification. Various type of configuration pattern of dome will be used to analyse.

ABSTRAK

Kajian ini adalah mengenai analisis kelakuan struktur dalam kubah. Secara umumnya penting untuk menentukan konsep mengenai kehilangan kestabilan dan kaedah untuk menentukan beban runtuh struktur. Sebagai kubah lapisan tunggal, menunjukkan tingkah laku tidak linear penting dengan penurunan yang agak besar. Tujuan kajian ini adalah untuk menganalisis beberapa jenis kubah menggunakan Formian bahasa pengaturcaraan algebra formex untuk menilai tingkah laku struktur oleh import fail formex kepada perisian unsur pengaturcaraan analisis LUSAS. Dalam kajian ini, perbandingan dari sudut kelakuan struktur antara lima model kubah dengan lebar yang sama, ketinggian yang sama, sudut jejari yang sama dan sudut pusat yang sama. Kelakuan struktur yang terlibat adalah lengkungan maksimum, strain maksimum dan tegasan maksimum. Jenis kubah yang digunakan adalah satu kubah ribbed, dua kubah schwedler dan dua kubah lamella dengan spesifikasi yang sama. Jenis Pelbagai corak konfigurasi kubah akan digunakan untuk menganalisis.

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LIST OF SYMBOLS

σ	-	Stress
ε	-	Strain

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

A space structure is a network of structural frame members, such as tubes and interconnected the member connection points which is commonly called as nodes. Therefore, the whole structure behaves as one structural element which is difference in the typical framing members of beams and columns, as in building, structural elements will completely separately force paths and often act independently on each other.

A space structure refers to a structural system where the load transfer mechanism that involves three dimensions. It is can be used in the large span areas with minor interior supports, such as regularly seen as mosque domes. Besides, space structure is strong because of the triangle inherent rigidity. Hence, variety type of space structure can be illustrated by using the Formian which is the conceptual tool for computer aided processing, in order to analyse the space structure configuration.

In structural engineering, a space structural also known as space frame which is a truss-like, lightweight structure that connected from interlocking struts. Thus, it is a necessary to ensure the space structure connection system are satisfactory the requirement of design. There are several types of connector or joint in term of prefabricated of space structure system which are called as nodular, modular and compositive. Meanwhile, the strut members are interconnected at spaced apart nodes in the frame. The flexing loads or the bending moments are transfer as tension and compression loads along the length of each strut. A dome is a space structure covering more or less curvature square or circular area. As for single layer dome space structures are regularly used in moderate span of buildings, sport halls and exhibition centers. The structural system consists of elements that are arched in all direction. The best known example is the Dome of Revolution. It is one of the earliest sphere segment of the shell structure which is built in roman times and formed by a surface generated by a curve of any form revolting about a vertical line.

A dome can be split up to two different direction which are, vertical section separated by longitudinal arch lines also called as meridians and horizontal sections separated by hoops or parallels. The structural behavior of the structure is similar as the arches under uniform loading, the dome is also under compression everywhere and the stresses act along the arch and the hoop lines. To define the different between types of domes, the comparison need to be analye in term of the structural behavior.

In this research, there are include the studies of formian which is to illustrate the domes type of space structure in order to proceed the analysis on the structure behavior. Formian is known as programming language of formex algebra. The term configuration mean that the arrangement of parts, which is can be described using a numerical model. So, the configuration processing can be explain as the creation or manipulation of numerical models that represent configuration. It is a convenient medium of using the concepts of formex configuration processing will be used to illustrate the configuration as the analysis.

1.2 PROBLEM STATEMENT

Nowadays, space structures are often built all over the world such as sport stadiums, culture centers, aircraft hangers, leisure centers, radio telescopes, railway stations, shopping malls, auditoriums and gymnasiums. These paces mentioned generally kind of place that demand a wide area without column in between the structure. Therefore, an issues would arise upon the numerous design of structure which need an architect to design in particular type of building structure. The search for new structural forms to accommodate wide unobstructed areas will be main objective of engineers and architects. To avoid these issues, space structure shall be the key of the building structure that demand a free column in the large area.

In order to build these building structure, the skeletal space frame which are three-dimensional structures need to be capable in free column long span. The structures constructed from either individual elements or prefabricated modules possess a high strength to weight ratio and high inherent stiffness. Therefore, to provide complete freedom in large span areas while providing strong resistance, there are a structural solution called space structure.

Uncountable progress had done in the process of the development of the space structure. A huge amount of experimental and theoretical research programs was carried out. As a result, a great deal of useful information has been disseminated and fruitful results have been put into practice. With the appearance of new building techniques and construction materials, space structure currently provide the right answer and satisfy the requirements for large area without column, great structural potential and visual beauty.

1.3 OBJECTIVE

i. To study the formex Configuration Progressing on how to arrange the part of formex algebra called Formian the programming language of formex algebra.

ii. To analyse the several type of domes, by using the finite element software LUSAS programming analysis to evaluate the structural behaviours.

1.4 SCOPE OF STUDY

The space structure consist many form of configuration such as domes and barrel vaults. In this research will focusing on domes form of configuration. The analyses need to be perform for the type of domes using Formian the programming language of formex algebra to illustrate the composite transformations. The type of domes that will be analyse are ribbed dome, lamella dome and schwedler dome.

The scope of this research will covered the study about the basic concept of the Formex Configuration Processing on how to arrange the parts of formex algebra. Formex algebra itself as a mathematical system that provides simple tools mathematical system as stated by Noorshin H. and Disney P (2000). Therefore, it is required to study Formex Configuration Processing as convenient medium for configuration processing to illustrate the ribbed dome, lamella dome and schwedler dome.

To analyse these three type of domes, the same particular of the dome will be used, which is the span (S) is 40 meter, the rise (H) is 7 meter, the sweep angle (A) is 43 degree, the radius (R) is 30 meter and the central angle of the dome is twice the sweep angle equal to 86 degree. To compare the structural behavior of the dome in term of buckling. The types of buckling concerned here are the general buckling, the local buckling and the buckling of a member. In these analysis, the geometrical nonlinearity due to large displacements will be included.

Lastly, the research will include the study about type of connector or joint in term of prefabricated of space structure system which are called as nodular, modular and compositive. As for the nodular system, the main components are joint and elements such as ball ball joint system, socket joint system, plate joint system, slot joint system and shell joint system. Meanwhile, as for the modular system, consists of prefabricated basic units such as space deck system, unibat system and cubic system. As for compositive system do not has any particular joint components which has no specific ‘node piece’ or ‘unit’. In space structure system, each prefabricated space structure system had their relative advantages and disadvantages. The type of joint depends primarily on the connection techniques and also affected by the shape of the members, angle or wide flange. Therefore, as the prefabricated type connection of the joint, it is necessary need to be choose the most suitable for the particular structure.

1.5 SIGNIFICANT OF STUDY

The outcomes predicted from this research is to increase the achievement of development construction for residential, commercial or public purposes, by providing a column-free space with the most efficient domes. The efficiency of different type of domes, that is ribbed dome, schwedler dome and lamella dome will be compare through their structural behaviour. Besides that, the chosen of connector shall be most suitable and essential as the number of units and connections should be the minimized. In addition, the outcome from the research is to provide a research guide to the young engineer in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Space structure commonly involve three dimension of structural system. The space structure idealized is extend beyond a single plane, in term of the combination of configuration, external loads, internal forces and displacement. Meanwhile in single plane, the external loads and internal forces of plane structure contains the structure itself, both in its initial unloaded state and in its deformed loaded state. It is shows that the plane structure is completely contrast with space structure. As in practice, the space structure form is used to refer to the number of families of structures such as grids, tower, cable, net membrane system, and foldable assembly and tensegrity forms.

Space structures cover an enormous range of shapes and are constructed using different materials such as steel, aluminium, timber, concrete, fibre reinforced composite, glass, or a combination of these. As for this research, the material that were chose to apply in the analysis is mild steel. The introduction of steel, with its greatly improved properties of high strength, proved to be a fundamental influence in the development of various types of braced dome and their use for large spans.

Space structures may be divided into three categories that are lattice space structures, continuous space structures and biform space structure. Space structure forms are at the centre of attention in the present paper an overview of space structure form with emphasis on the geometric characteristics of lattice space structure. Lattice space structures describe as structure that consist of discrete, normally elongated element such as barrel vaults and domes. In particular, this research will overview the domes type of lattice space structures.

2.2 DOMES

Domes had the advantage of providing an easy and economic method of roofing large areas. Nowadays as we can see are used frequently by the designers who realize the advantages and the impressive beauty of this form of construction. Domes have been used in architecture since the earliest times. Braced steel dome structures have been widely used all over the world during last three decades. Some examples of braced steel domes in the world are shown in Figure 2.1 and Figure 2.2.

Figure 2.1: Nagoya Dome, Japan (Source: World Stadiums.com)

Figure 2.2: The Bloudel Conservatory, Queen Elizabeth Park, Vancouver/Canada
(Source: Venture Vancouver.com)

The curvature of any point is of the same sign in all direction in a dome is a typical example of a synclastic surface. The synclastic surfaces are also called surfaces of positive Gaussian curvature and are not developable, such as the domic surfaces cannot be flattened into a plane without stretching or shrinking it. This is become the reasons, domes cannot be built from members all of the same length.

Most domes built in practice have a surface which can be generated by the rotation of a plane curve around a vertical line. The rotating curve is called its meridian and the horizontal. Section are known as the parallels. Any curve can be used as a meridian, while a circle gives rise to a sphere, an ellipse to an ellipsoid of revolution and a parabola to a rotational paraboloid. The three afore-mentioned surface are all synclastic.

In an earlier study published by the Makowski in 1962, braced domes were classified into ten principal types, that are Ribbed domes, Schwedler domes, Lamella domes, Network domes, Plate-type domes, Zimmermann domes, Stiffly Jointed Framed domes, Kiewitt domes, Two-way and Three-way Grid domes and Geodesic domes. However, in this research would narrow down the analysis to three type of domes which are Ribbed domes, Schwedler domes and Lamella domes as shown in Figure 2.3, Figure 2.4 and Figure 2.5.

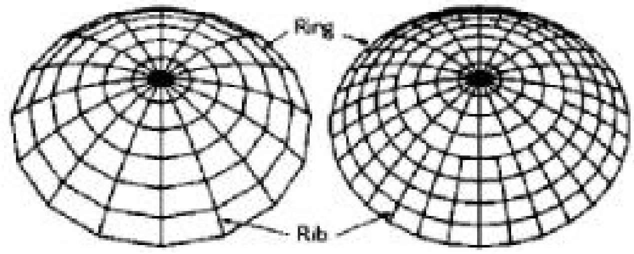


Figure 2.3: Ribbed Domes (Source: www.pages.drexel.edu)

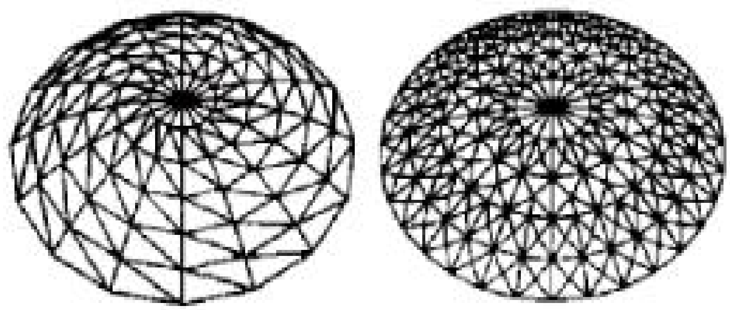


Figure 2.4: Schwedler Domes (Source: www.pages.drexel.edu)

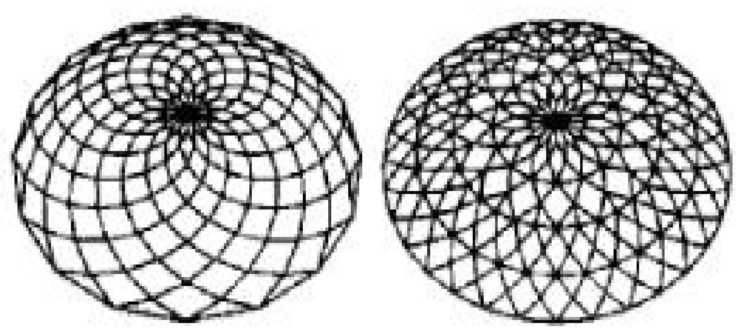


Figure 2.5: Lamella Domes (Source: www.pages.drexel.edu)

2.2.1 Ribbed Domes

Ribbed domes member commonly made up by solid ribs. The solid rib will interconnected to the crown and at the foundation will be stiffened by a tension ring. Ribbed domes which are now often used and are frequently constructed in prefabricated tubular arched rib units. They generally interconnect at the crown and a tension ring at the foundation stiffen the ribs. A ribbed dome will not be structurally stable unless it is designed as rigidly-jointed system, since it does not have diagonal elements structure.

Figure 2.6: Montan State College Dome (Source: www.glulam.co.uk)

2.2.2 Schwedler Domes

A schwedler dome made up of meridional ribs. The meridional rib connected to horizontal polygonal rings. To stiffen the resulting structure so that it will be able also to take unsymmetric loads, each trapezium formed by intersecting meridional ribs with horizontal rings is subdivided into two triangles by the introduction of a diagonal member as shown in Figure 2.7.

J.W. Schwedler, a German engineer, who introduced this type of dome in 1863, built numerous braced domes during his lifetime. The great popularity of Schwedler domes is due to the fact that, on the assumption of pin-connected joints, these structures can be regarded as statically determinate. In practice, the ribs are continuous members and the rings are rigidly jointed, in addition to axial forces, all the members are also under the action of bending and torsional moments.

Figure 2.7: Cinesphere - Ontario Place (Source: www.soto.on.ca)

2.2.3 Lamella Domes

The lamella dome made up of many similar units and the arrangement pattern is in a diamond. Each lamella unit has a length which is twice the length of the side of a diamond. To triangulate the diamond, the purlins were used in order to complete the stability that need by the surface of the dome. The lamella domes are renowned due to their exceptionally good behaviour under excessive wind loadings, as well as in fire and seismic disturbances.

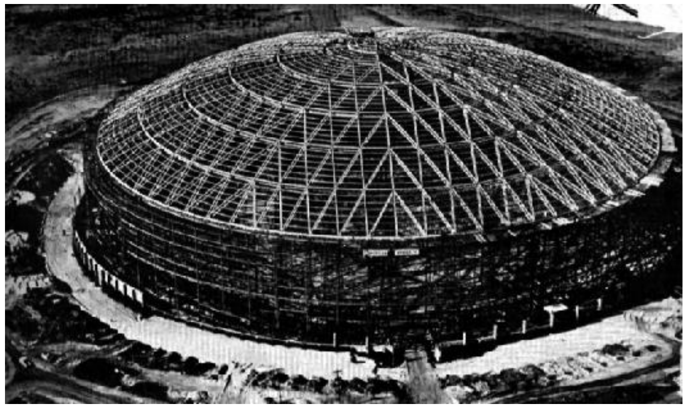


Figure 2.8: Stadium in Houston, Texas (Source: www.columbia.edu)

Figure 2.9: Astrodome (Steel Lamella Dome), Houston/USA (Source: www.columbia.edu)

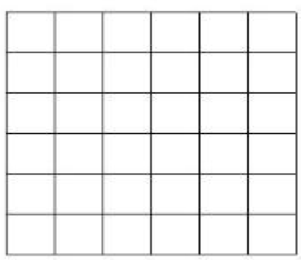
2.3 GRID

The element demanding one or more planar layers in structural system in order to consider as a grid. Commonly used grid are known as single layer grid, double layer grid and biform grid. As in this research would use the single layer grid which is also called as flat grid. A single layer grid consists of a planar arrangement of rigidly connected beam elements. The external loading system for a flat grid consists of forces perpendicular to the plane of the grid and moment whose axes lie in the plane of the grid (Bulendaa T., Knippers J.. 2001). The reason for classification of a flat grid as a space structure is that its external loads and displacements do not lie in the plane that contains its configuration.

There are many type of grid patterns that are frequently used in practice. The most basic type of grid pattern is two-way grid, while other type of grid pattern are normally derived by removal of some elements from the basic patterns. Therefore, as in this research will include those various type grid pattern, the pattern are two-way grid, three-way grid and four-way grid.

2.3.1 Two-way Grid

A number of basic grid pattern are illustrated in Figure 2.10 and 2.11, which is both are two-way grid pattern. The two-way grid pattern in Figure 2.10 is the simplest pattern for a flat grid also called as rectangular grid. It consists of two sets of interconnected beams that run parallel to the boundary lines. While Figure 2.11 shown a diagonal grid pattern that is consists of two parallel sets of interconnected beams that are disposed oblique with respect to the boundary lines.



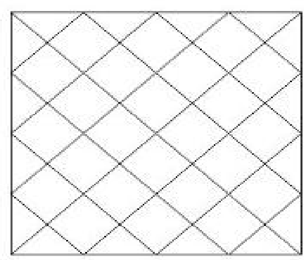
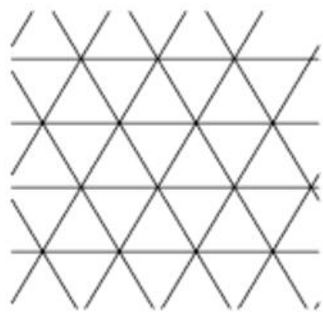


Figure 2.10: Rectangular grid **Figure 2.11:** Diagonal grid

(Source: www.fgg.uni-lj.si)

2.3.2 Three-way Grid

Figure 2.12 and Figure 2.13 show some basic three-way grid pattern. The grid pattern in these figure is obtained from a derived by removal or by adding of some elements from the basic pattern of two-way grid. It will produce three axes in the plane of grid which will consist three parallel sets of interconnected beams. Mostly the three-way grid pattern will create triangle shape in the structural system. These grids are formed of a series of struts each of which constitutes one side of one of the substantially equilateral triangles defined by the lines of the grid.



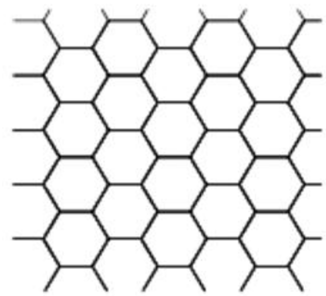


Figure 2.12: Triangular grid **Figure 2.13:** Hexagonal grid
(Source: www.fgg.uni-lj.si)

2.3.3 Four-way Grid

Reference is now made to the modified from previous basic grid that illustrated in Figure 2.13. These figure represents a shape of triangular in the grid similar to previous, three-way grid. However, instead of three axes that exist, the axes increase to four axes as the name of pattern itself. The planes of the equilateral triangles formed by the grid pattern in these figure is obtained from a derived by removal or by adding of some elements from the basic pattern of three-way grid. It will produce four parallel sets of interconnected beams from the combination of superposition rectangular and diagonal.

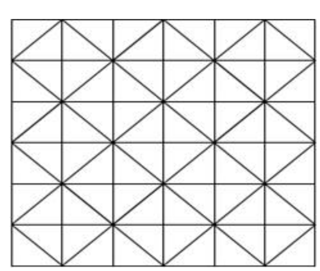


Figure 2.14: Combination rectangular and triangle grid (Source: www.fgg.uni-lj.si)

2.4 DOMES DESIGN ANALYSIS

Structural loads or actions are forces, deformations, or accelerations applied to a structure or its components. Loads cause stresses, deformations, and displacements in structures. Assessment of their effects is carried out by the methods of structural analysis, referring to the Kardysz M., Rebielak J., Tarczewski R

Excess load or overloading may cause structural failure, and hence such possibility should be either considered in the design or strictly controlled. The practical design of any large dome requires at least three different loading systems should be fully analysed that are wind load, dead load and fabric cover load. However in this research have not considering the wind load and the analysis just include the dead load and the fabric cover load.

2.4.1 Wind Load

Dragone (1979) states that his results are valid only for particular models and the particular wind profiles used in his work. They cannot be used directly to estimate the actual pressure distribution on a real structure, but have been used to illustrate the complex pattern of wind forces which apply to a domic surface. Dragone confirms that the wind pressure distribution on hemispherical domes has been found to have a small amount of positive pressure at the front of the dome and a large region of negative pressure at the back of the structure.

Nowadays the determination of wind distribution of domic surfaces is still based on some very approximate assumption. There are state in previous research (Montes P., Fernandez, A.. 2001) ,that the intensity of wind distribution varies greatly, depending mainly on rise-to-span ratio and that the adjacent buildings have an important influence upon the distribution. Since the rise-to-span ratio of those three type of domes that would be analyse is small, therefore the wind load have been ignored.

2.4.2 Dead Load

Dead loads are also known as permanent or static loads which are unmovable loads and fixed in behaviour. The dead load includes loads that are relatively constant over time. There are several items that can be mark as dead load and those are self-weight of the structure, slab, bricks, mechanical equipment or any building properties.

The constant type mild steel is used as material properties for all three type of domes. Hence, the dead load of this material properties of mild steel, including frame elements to be used for girts is taken as 100 N/m^2.

2.4.3 Fabric Cover Load

There are few assumption need to be made during analysis structure in order to complete the analysis. Therefore, by referring previously research by M. Kardysz, the fabric cover load have been taken as 66 x 1.1 N/m^2 = 72.6 N/m^2.

2.5 DOME BEHAVIOUR

The way a braced dome works depends on the configuration of the members. Braced domes which are fully triangulated will have a high stiffness in all directions in the surface of the dome. These configurations are also kinematically stable when idealized as a space truss (Montes, P.,and Fernandez A). Accordingly, the forces in a fully triangulated dome will be principally axial and will have direction and magnitude similar to those in a shell dome. As recall from the figures of domes built in Turkey, they are all single-layer triangulated truss type which is assumed as pin-connected joints structures due to the instability of mechanism concern.

Dome with a single layer must be triangulated as shown in Figure 2.14.(a) in order to be stable. A dome which is not fully triangulated is kinematically unstable when idealized as a truss and may also have widely different stiffnesses in different directions in the surface of the dome. The dome shown in Figure 2.14.(b) can only support loads by developing bending moments in the members and joints. The dome shown in Figure 2.14.(c) will require continuous joints or structural cladding to give the dome stability and to resist non-axisymmetric loading.

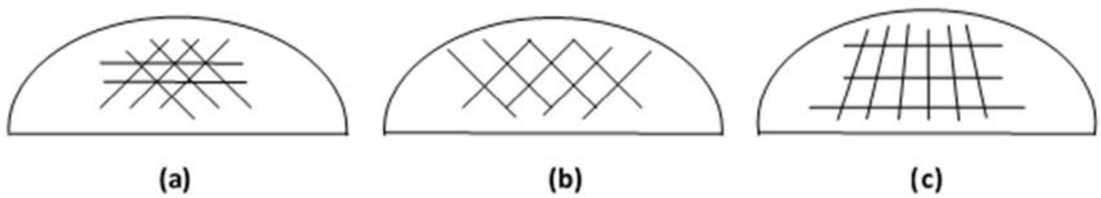


Figure 2.15: Single-layer grid dome

Source: AVUZ SARAÇ 2005

General buckling, local buckling and individual member buckling are the types of instability that must be checked in the design. An important point that should be kept in mind is that one should be careful in using single layer domes unless the jointing system provides sufficient rigidity for the connections and that the elements are designed for resisting bending and shear in addition to the axial forces. Otherwise, the structures will be susceptible to snap-through buckling.

Critical buckling load is the maximum load which a member can support before it becomes unstable (Wang N.A 1993). Buckling is a form of failure which is often thought to be anathema within the plastic theorems and plastic design. Buckling and its analysis can be divided into two parts as linear (eigenvalue) buckling analysis and non-linear buckling analysis. As in this will covered the non-linear buckling analysis.

2.5.1 Non-Linear Buckling Analysis

Non-linear buckling analysis is usually the more accurate approach and is recommended for design or evaluation of actual structure. This technique employs a non-linear static analysis with gradually increasing loads to seek the load level at which your structure becomes unstable. To summarize, one major characteristic of non-linear buckling, as opposed to eigenvalue buckling, is that non-linear buckling phenomenon includes a region of instability in the post-buckling region, whereas eigenvalue buckling only involves linear, pre-buckling behaviour up to the bifurcation (critical loading) point (Yamada S., Takeuchi A., Tada Y., Tsutsumi K 2001) . This behaviour is shown graphically in Figure 2.15.

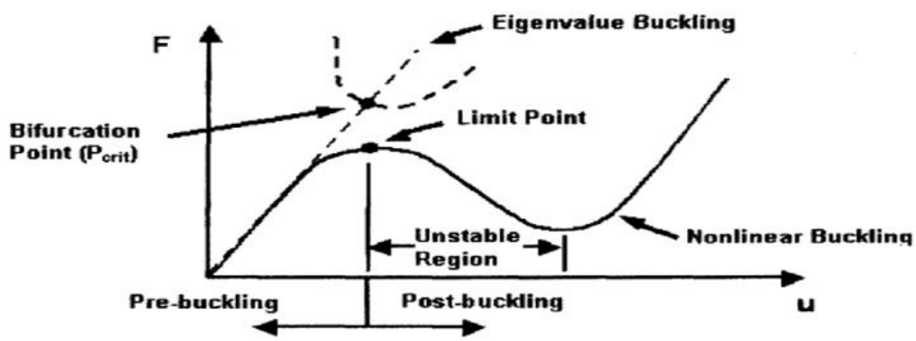


Fig.2.16: Non-linear vs. eigenvalue buckling behaviour

Source: AVUZ SARAÇ 2005

2.5.1.1 Factor Influencing The Buckling Load

Several instability modes can occur in the behaviour of reticulated shells which must be taken be taken into account in determining the limit bearing capacity (Ueki T. 1991 and Ueki T. 1990) There are:

i. Member instability occurs when an individual member buckles and other members are not affected as shows in Figure 18. Due to the large number of members in a dome, it is difficult to predict the one in the most dangerous situation. The main problem is define the proper sizing of a bar in the reticulated shell.

ii. Node instability occurs when all connected member in a node undergo suc axial strain that they cannot resist the node external load as shows in Figure 19. It must be mentioned that this buckling type is the most studied case, because almost all new non-linear programs have been tested using a cell characteristic for this instability type.

iii. Torsional instability of node occur when the size of joint is large and the bending rigidly in surface plan is weaker, refer Figure 20. This instability mode is characteristic for metal reticulated shells using insertion joints with vertical gussets. Two modes of torsional buckling as in Figure 20 are possible.

2.5.2 Stress Analysis

Stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on (Amaratunga M.. 1986). When external forces are applied to object made of elastic materials, they produce changes in shape and size of the object. Stress is the internal force associated with a strain, as state by J. R. Rice (1970) and the theoretically calculation can be expressed as:

$\sigma = Fn / A$

where
σ = normal stress (Pa, N/m2)
Fn = normal component force (N)
A = area (m^2)

2.5.3 Strain Analysis

Strain is defined as the amount of deformation an object experiences compared to its original size and shape. Strain that changes the length of a line without changing its direction. Can be either compressional or tensional. The ratio of extension to original length is called strain it has no units as it is a ratio of two lengths measured in meter (Zhu Y. 2006) and can be expressed as:

$\varepsilon = \Delta L/L$

where

ε = m/m

ΔL =extension measured in metres

L = original length measured in metres

2.6 SPACE STRUCTURE SYSTEM

There are three type of prefabricated of space structure system which are called as nodular, modular and compositive system (Gaul L. 2004). Each of those had their own characteristic, connecting mechanism, manufacturing methods, appearance and applications. The materials of these prefabricated space structure system are normally steel or timber.

2.6.1 Nodular System

As for the nodular system, the main components are joint and elements where these are connected together by bolting, welding or other method (GAR Parker 2000). There are five types of connection have been proved to be most popular and versatile of all the space structures connection systems.

2.6.1.1 Ball Joint System

The components of a ball joint system consist of ball joint, members and connection mechanism. Each of the system consists of a ball joint, a tubular member and a bolted connection between the ball joint and the member. So far many prefabricated ball joint systems have been developed in the world. Most have bolted connections that were used in all over the world are KK-system, TM-truss, Uzaykon Space Frame System, KRUPP MONTAL system, ORBA HUB, Zublin Space Frame System, Unitruss and many more.

2.6.1.2 Socket Joint System

In this system, the joints have one or two openings for the insertion of the bolts and the bolts go from the joint into the end of members. Commonly this joint system have a profile that is like a hollow sphere which is partly cut. The following are famous used prefabricated socket joint system, which are NN Space Truss System, Spherobat, Tuball and Akam System.

2.6.1.3 Plate Joint System

The components of a plate joint system consist of plate joints, members and fasteners such as bolts and nuts. There is a big difference between ball joint or socket joint system and plate joint system. These systems with respect to the transmitting mechanism of the axial forces in the members. The bolt in the ball system transmits the member force directly, while the plate system transmits the axial force of the member by shear force. The following are the example of fabricate plate joint system, Unistut Space-Frame System, Power-Strut, KE-truss, Octabube, Tridimatec system and a lot more.

2.6.1.4 Slot Joint System

A joint in this kind of system is a cylindrical piece that has slots around its periphery. These slots receive the ends of the members which have the male forms fitting to the slots of the joint. Each end of a member can be inserted into the appropriate slot. The member is connected to the joint without bolt, riveting or welding. The Triodetic system as an example of slot joint system.

2.6.1.5 Shell Joint System

The members can be connected in any position on the ball joint, although there is a limit depending on the size of the ball and the members. Therefore, this system can be applied to the multi-layer grid structures with any configuration. These prefabricated space structure system consists of joints and members such as Nodus system, Oktaplatte system and SDC system.

2.6.2 Modular System

Meanwhile, as for the modular system, consists of prefabricated basic units, which are assembled together on site (GAR Parker 2000). The difference between nodular systems and modular system is that the basic components of nodular system consist of nodes and members, while in modular system, all of the component parts or some of them are units that consist of two or more interconnected parts.

2.6.2.1 Space Deck System

The Space Deck unit is an inverted square pyramid and can be applied to double-layer square-on- grids only. A unit consists of four top chord angles, four diagonals and a forged boss. These are welded together as a pyramidal unit in factory, using special jigs to ensure accuracy. The units are connected by tie bars and bolts. The bolts are used for connecting together the top chord members.

2.6.2.2 Unibat System

The system consists of pyramidal units, bottom chord members and bolts. The unit is an inverted square pyramid which a unit consists of four top chord members, four web members, four corner pieces and an apex piece. The corner pieces and apex pieces are forged. The top chords and web members are welded to the corner pieces and the apex piece to form a pyramidal unit in the factory.

2.6.2.3 Cubic System

This system is suitable for structures that require full flexibility for the accommodation of service for office buildings and particular facilities. A square hollow section member is used for the vertical post and I-section members form the chords of the unit. Each end of the post is covered with a plate to which the flanges of the chord members are welded. The other flanges of the I-sections are also welded to the post walls with collar plates.

2.6.3 Compositive System

As for compositive system do not has any particular joint components which has no specific ‘node piece’ or ‘unit’ (GAR Parker 2000). The term compositive usually refer to the system called Harley systems.

2.6.3.1 Series 80

The components of this system consist of chord members, web members and fasteners of the bolts, nuts and washers. Both top and bottom chord members are continuous through the joints. This system can be applied to cover flat areas with multilayer two-way grids.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will discuss about the method that are used to illustrate the model, analysis and design the structure. Finite element method is use to analyse the structure of all the dome and its behaviour upon the loading applied. This research will illustrated these five dome with the same specification of particular size of the dome, which is the span (S) is 40 meter, the rise (H) is 7 meter, the sweep angle (A) is 43 degree, the radius (R) is 30 meter and the central angle is 86 degree. Only difference between the domes is the grid pattern that will be illustrate.

For modelling the dome in this research will use the interactive programming language called 'Formian' which is provide a suitable medium for formex configuration processing. Formian is the basic concept of the Formex Configuration Processing programming on how to arrange the parts of formex algebra. The total summation that include in this research are five domes which are one of Ribbed dome, two of Schwedler domes and other two of Lamella domes. The modelling need to be perform use the Formian to form the configuration and to illustrate the composite transformations of these domes.

In order to compare the structural behavior of the dome in term of buckling, the finite element software LUSAS programming analysis will be use. To analysis the structure, need to decide the properties of the structure of domes. Besides that, basically the information about the structure have been taken from the previous research, such as the load. The finite element software LUSAS programming analysis will analyse the structure and come out with the result.

3.2 FLOW CHART OF PROJECT METHODOLOGY

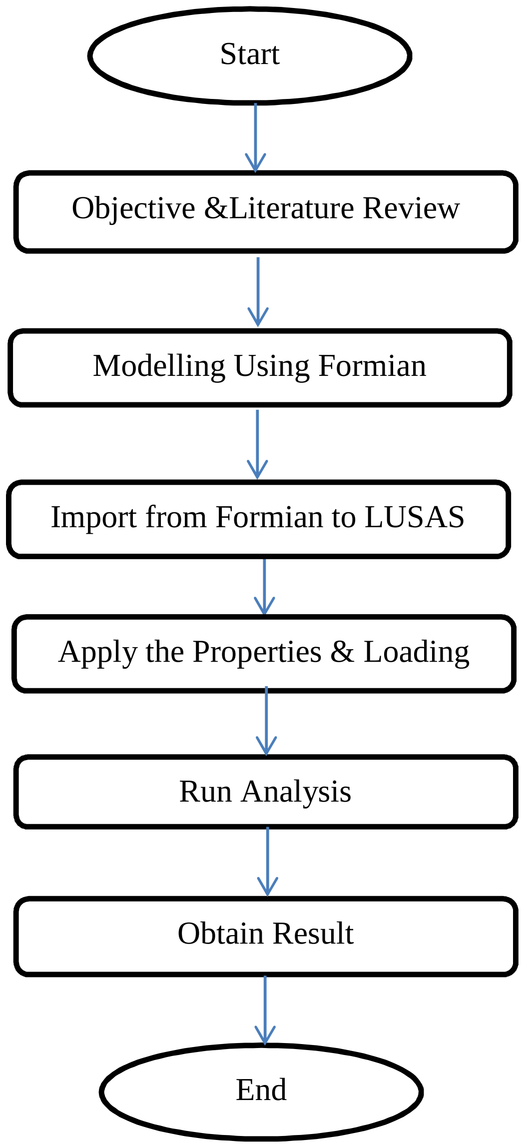


Figure 3.1: Project Flow Chart

Figure 3.1 shows a project methodology which involved numbers of steps that have been taken in order to complete this study. The first part was set the objective and literature review. In order to analysis the structure, first of all need to do some studies from previous research to decide the properties of the structure of domes. As example the material properties and geometric properties. Hence, basically the information about the structure of the domes have been taken from the previous research, such as self-weight load or dead load and fabric load.

After selection of the dome had decide to be illustrated, the modelling using the Formian programming as shows in Figure 3.2 is the second step. In order to illustrate the formex configuration, it is a need to overview of the basic aspects of this programming language. All of the five domes would have the same number of ring and the rib around the domes. The different is the context of a structural configuration, such as the basic formex composition of the signet, the cantle and the formex itself.

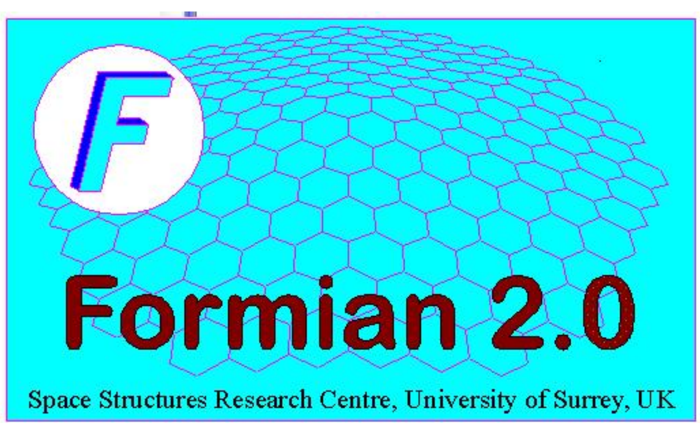


Figure 3.2: Formian Programming Software

Third step is to import the model to the LUSAS software as shows in Figure 3.3, after done with the illustrate from the Formian programming. Next step is to apply the properties and assign the loading to the model that imported. Include the material properties, geometric properties, self-weight load or dead load, fabric load and others. Followed by the step of run the analysis to determine the buckling, stress and strain. Lastly, by obtaining the result, the maximum buckling, stress and strain at which particular element will be detected. Therefore from the result the conclusion of the research can be made.

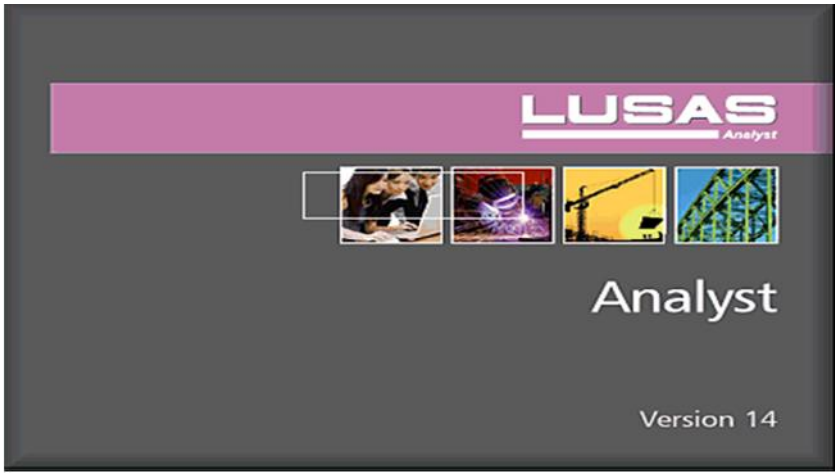


Figure 3.3: Lusas Analysis Software

3.3 FORMIAN PROGRAMMING

Formex algebra is a mathematical system that provides a convenient medium for configuration processing. The concepts are general and can be used in many fields. In particular, the ideas may be employed for generation of information about various aspects of structural systems such as element connectivity, nodal coordinates, loading detail, joint numbers and support arrangements. The information generated may be used for various purposes, such as graphic visualization or input data for structural. Therefore, in this case the information need to complete to illustrate a structure of the domes. Figure below show all of five model that done illustrate by using the Formian programming.

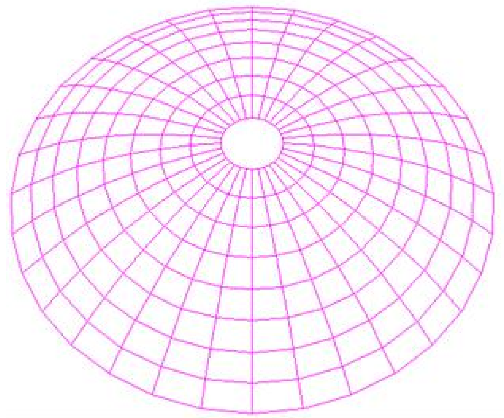


Figure 3.4: Ribbed Dome

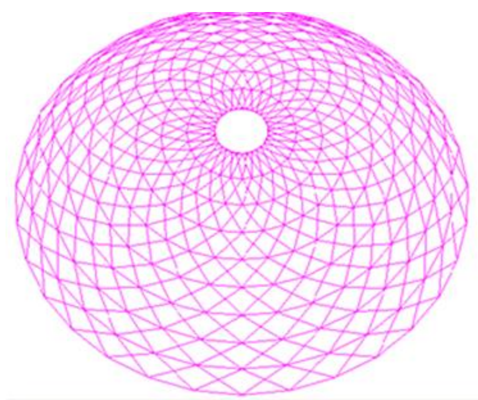


Figure 3.5: Lamella Dome 1

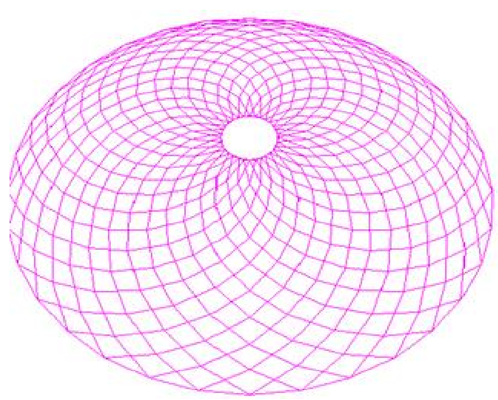


Figure 3.6: Lamella Dome 2

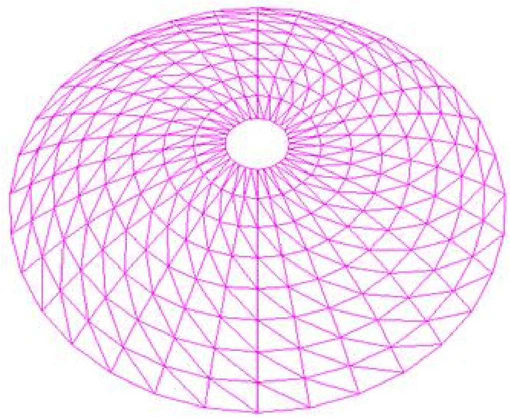


Figure 3.7: Schewdler Dome 1

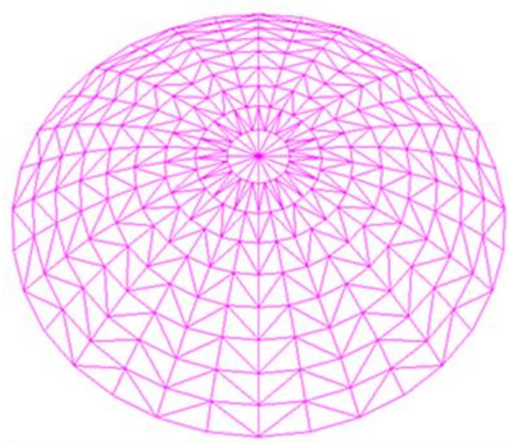


Figure 3.8: Schwedler Dome 2

3.3.1 Modelling Using Formian

The Figure 3.9 shows the Formian screen with two schemes in the editor on the left side and a formex plot in the drawpad on the left side. An arrangement of the form which is referred as an ‘editory display’, by inserting the contents of the element in the editory display, the illustrated formex will be shows in drawpad.

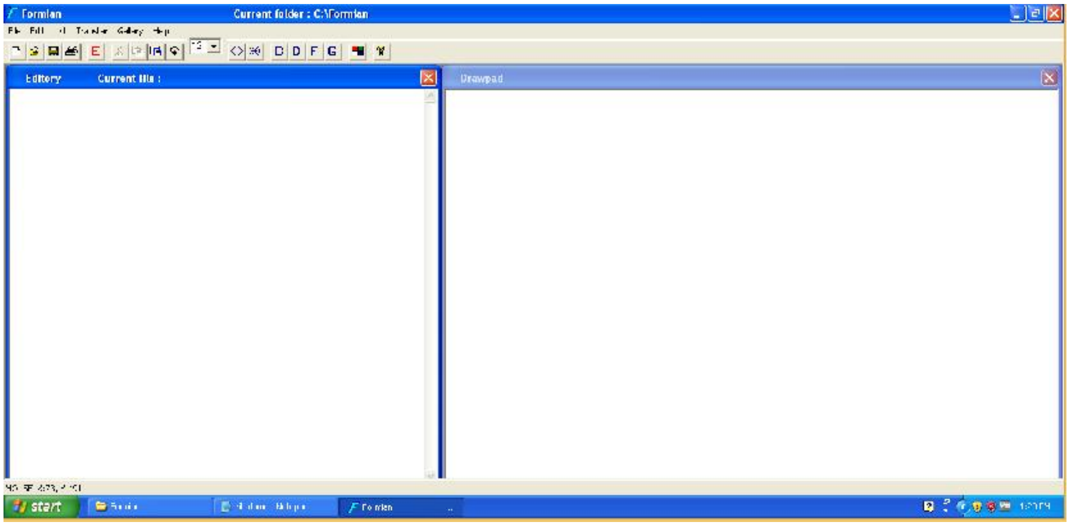


Figure 3.9: Formian Screen

3.3.2 Define The Element

As state before, all of the five domes would have the same specification of particular size of the dome, which is the span (S) is 40 meter, the rise (H) is 7 meter, the sweep angle (A) is 43 degree, the radius (R) is 30 meter and the central angle is 86 degree. Besides the domes had the same number of ring, (N) and the rib,(M) around the domes. The different is the context of a structural configuration, such as the basic formex composition of the signet, the cantle and the formex itself. The formex formulation in the scheme of Figure 3.10 is generic version of the formulation. As example, a generic scheme of dome with a pattern of elements as shown in Figure 3.10 is referred to as a 'Ribbed dome'.

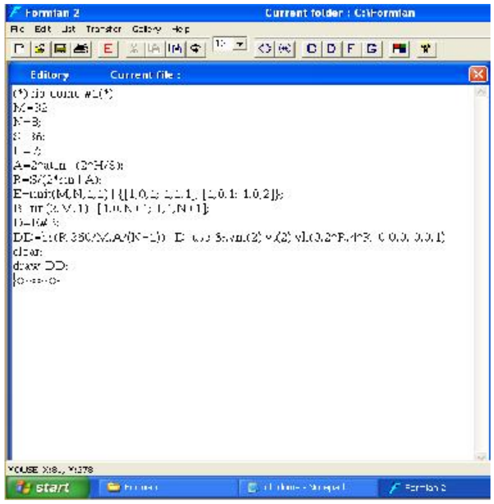


Figure 3.10: Processing of a Ribbed Dome

3.3.3 Formian Scheme

By inserting the generic Formian scheme for the formulation of the every each of the domes, the drawpad will illustrate different type of the dome. The formex formulation in the scheme is based on a formex that contains the description of the grid in term of the x-y coordinate system. After insert the formian scheme, select the scheme by highlight all the input, then run the program by clicking the button ‘E’ at the tool bar and the model will come out at the drawpad as shown in Figure 3.11, 3.12 and 3.13.

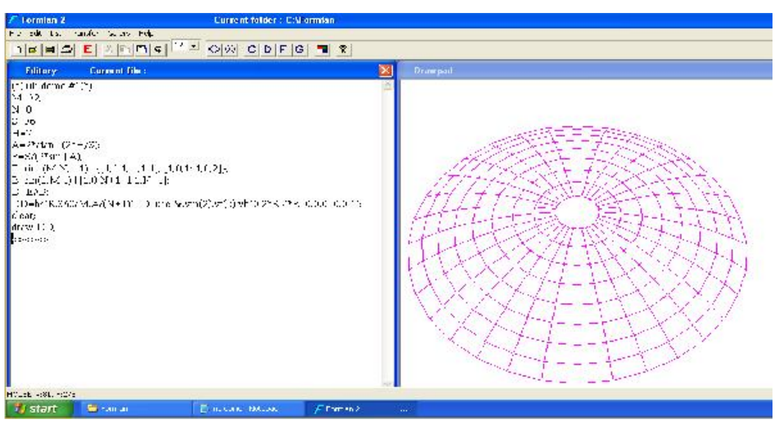


Figure 3.11: Formulation of a Ribbed Dome

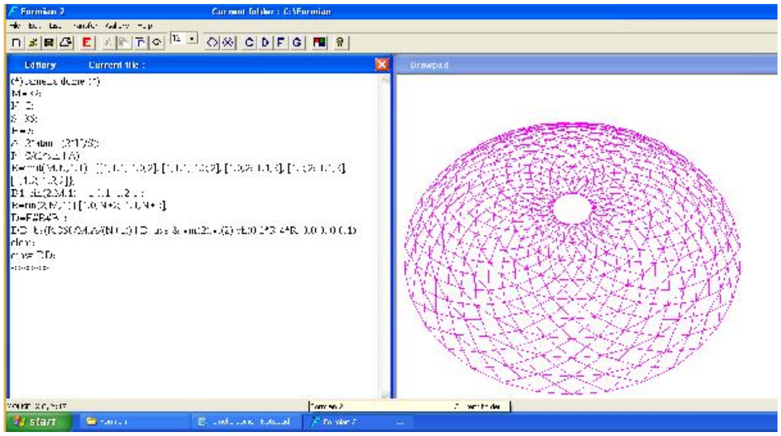


Figure 3.12: Formulation of a Lamella Dome

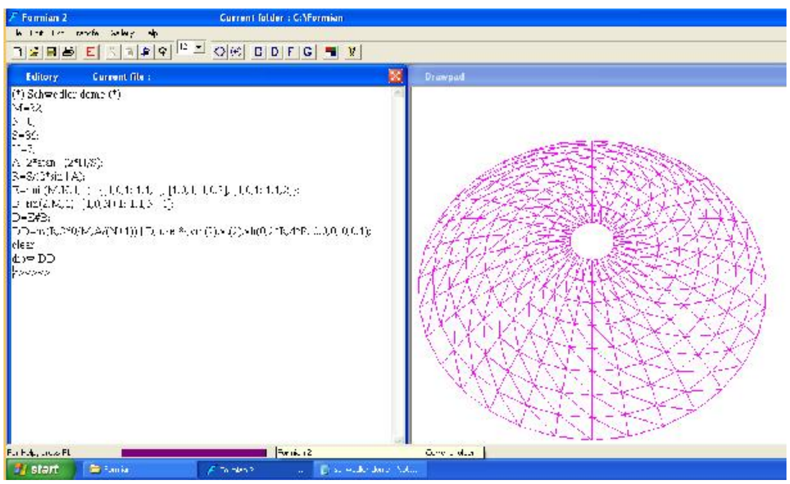


Figure 3.13: Formulation of a Schwedler Dome

3.4 LUSAS SOFTWARE

LUSAS is software for analyzing and designing a structure. This software is equipped with various design codes worldwide. In this software, there is a finite element analysis method that can be done to analyze the structure. The finite element method is a numerical procedure for solving many problems in engineering analysis. This method has become so important to solve problems in engineering such as structural analysis, continuum mechanics and fluid flow.

3.4 1 Import File

In order to analyse the completed modelling domes, first need to import the model to the LUSAS software from the Formian programming. Open the file tab in the tool bar, then choose Import tab as in Figure 3.14(a). The Import window will pop-up as shown in Figure 3.14(b), select the file that were save from the Formian and select the Import button to display the selected domes in the LUSAS.

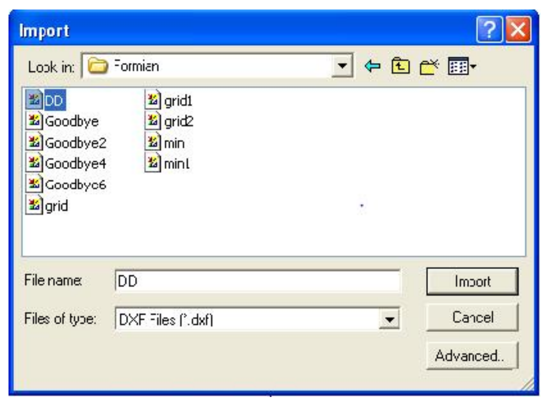


Figure 3.14(a): First step in import file **Figure 3.14(b):** Second step in import file

3.4.2 Analyse the dome

The template used in this research is default template from the LUSAS software which is Y-template. Y-direction template use because the research is to study the 3D static analysis on the y-direction. The first step on creating a new project is to set up the unit used for the analysis as shown in Figure 3.15 below. The unit for LUSAS is consistent which mean it is fixed to the equation F=ma.

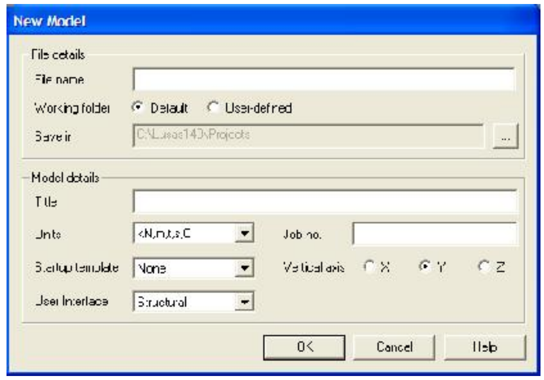
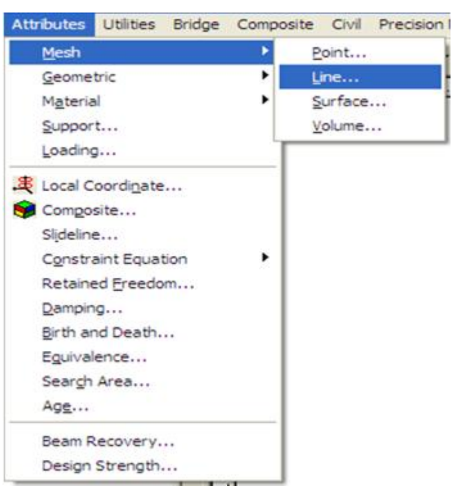


Figure 3.15: Create a project step

Next step is to specify the mesh attributes for all the line created shown as the Figure 3.16(a). The selected a mesh need to be similar for all the model for element, select attributes tab, choose mesh and followed by line. Line mesh window will pop-up shown as the Figure 3.16(b). For the all five domes, three dimensional of Bar with four divisions are used and the interpolation order is linear. For the cable stays the structural element type used is one divisions two dimensional bar element with also linear interpolation order.



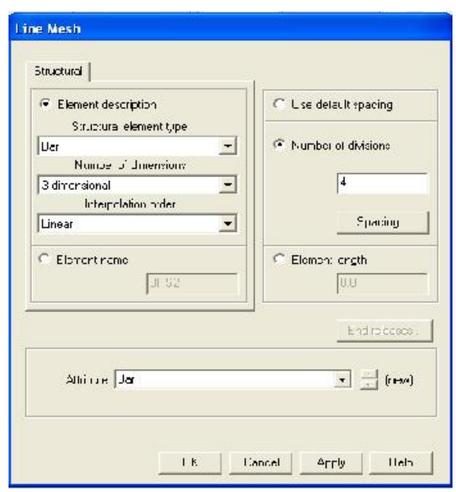


Figure 3.16(a): First step in selection of mesh attributes

Figure 3.16(b): Second step in selection of mesh attributes

All the element must be mesh first before the geometric section is assigned. To create a new geometric section, select utilities, choose section property calculator and followed by select the standard section tab as shows in Figure 3.17(a). A standard section property calculator will pop up, which the geometric section will be create with the user own dimension. For this case, as decide before 12mm diameter circular solid section is used as shown in Figure 3.17(b).Next to assign the geometric section, select attribute tab, then choose geometric and select section library as shown in Figure 3.17(c). As the new window pop up, select the user section for library, select the local for type and select CSS=0.012m for name.

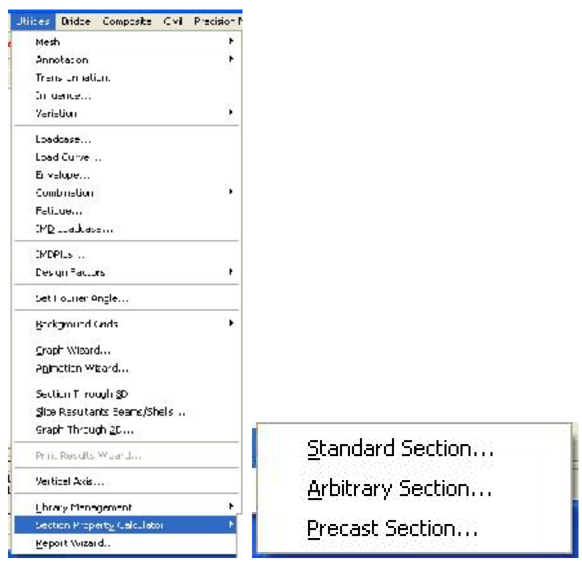


Figure 3.17(a): First step in selection of geometric section

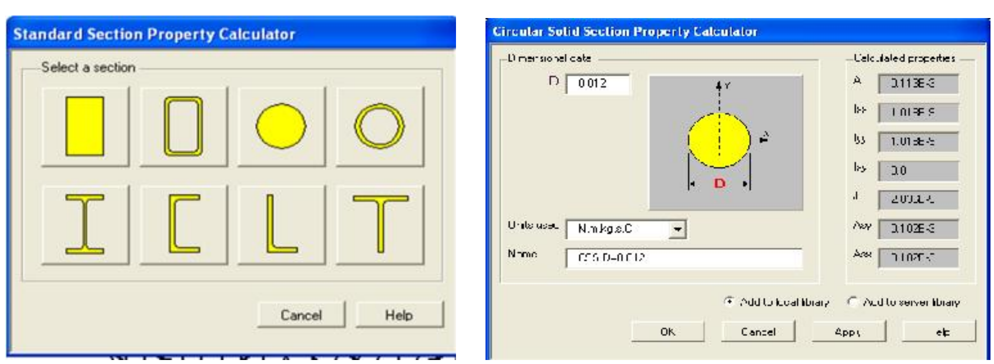


Figure 3.17(b): Second step in selection of geometric section

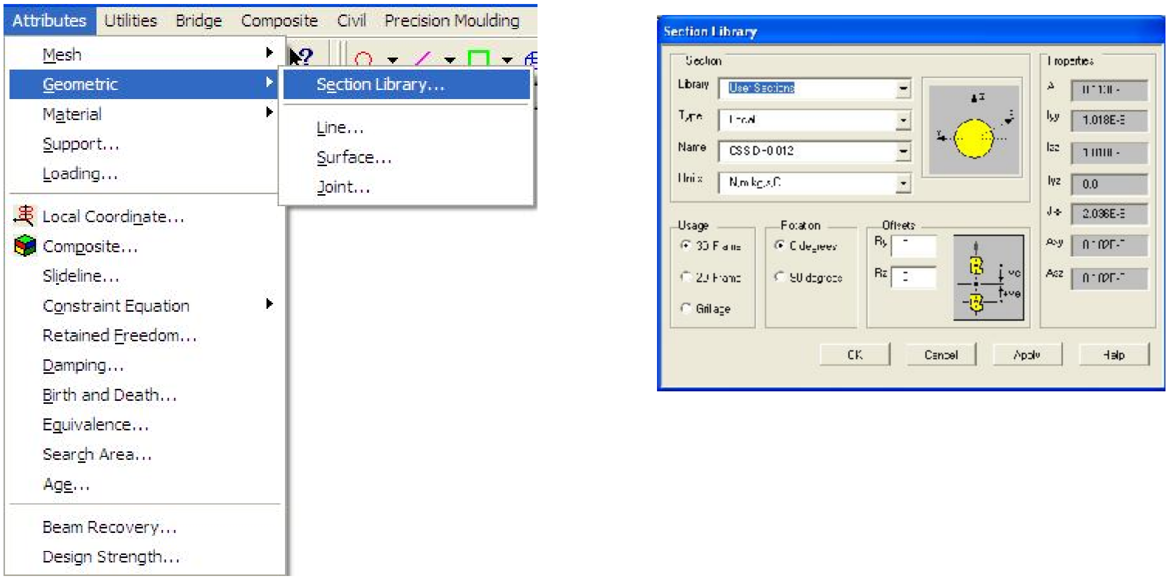


Figure 3.17(c): Third step in selection of geometric section

After that, material attributes is specify for all whole bridge elements. Material used in this project is ungraded mild steel with density of kN/m^2 shown in Figure 3.18. Next, supports are assigned to the model. Select attributes, and choose support to determine the support as shown in Figure 3.19 below. Pinned supports are used on this research for all the joint of the member. All translation on x, y, and z are considered fixed.

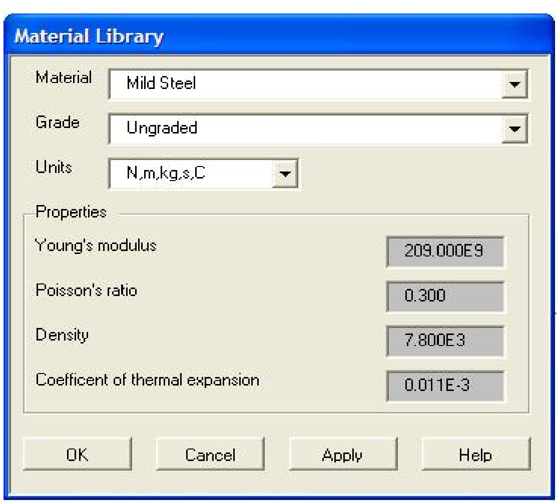


Figure 3.18: Selection of structure material

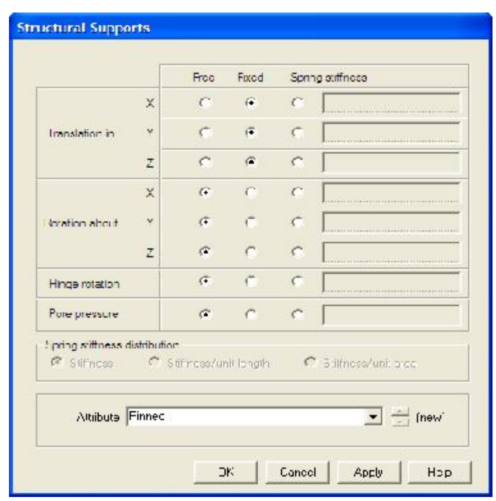


Figure 3.19: Selection of structure support

And lastly, loading attributes need to be specified. To applied load, select attribute, and choose load shown in Figure 3.20. Body force load is applied to the element of the models. This research loading are taken from previous studies, where the dead load and the fabric cover load are considered. Dead load applied is 100N/m and the fabric cover load applied is 72.6 N/m^2 for each element. After the load is applied the models is solve.

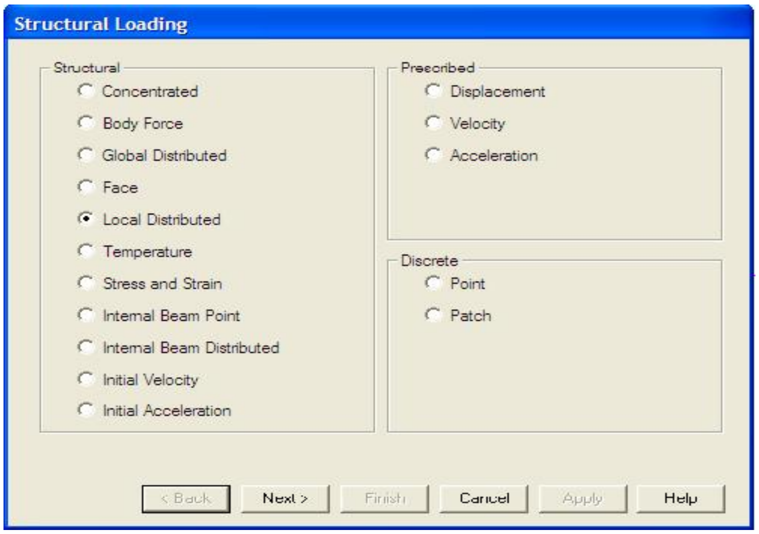


Figure 3.20: Specify the loading for the structure

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will show the result of the research and the discussion about the result obtained. The results for the all five domes structure analysis which were modelling from Formian and import to be analyse into LUSAS software will be discuss in term of their behaviours. The behaviour of these structure analysis were included the buckling, stress and strain.

All the data and result will be analyzing to check whether the research that had been carried out will achieve the objective and expected outcome. All the result will be recorded and compared in the table and graph form. In order to achieve the objectives, all of the five domes are modelled with the same specification of the dome in term of the span, rise, sweep angle, radius and central angle.

The structural behaviour result of each dome will be state in term of maximum buckling, maximum stress and maximum strain. From the result, it will be concluded which dome had the highest and the lowest structural behaviours.

4.2 RESULT

4.2.1 Ribbed Dome Analysis

Table 4.1 shows the maximum buckling, maximum stress and maximum strain of Ribbed dome for two-way grid with the rectangular shape.

Table 4.1: Maximum buckling, maximum stress and maximum strain of Ribbed Dome

Analysis	**Result**
Maximum Buckling	0.00314 m
Maximum Stress	9.0994 kN/m^2
Maximum Strain	0.3811 m⁄m

From the analysis, with this type of configuration pattern grid of dome, the maximum buckling of the bar element is 0.00314m which occurs at the center of the dome. This is happen due to principal in factor influencing the buckling load. The node instability occurs when all connected members in a node undergo such axial strains that they cannot resist the node external load. The maximum stress of the dome is 9.0994 kN/m^2 and the maximum strain is 0.3811 m/m where appoint at red region that shows in Appendix A.

4.2.2 Lamella Dome 1 Analysis

Table 4.2 shows the maximum buckling, maximum stress and maximum strain of Lamella Dome 1 for three-way grid with the triangular shape.

Table 4.2: Maximum buckling, maximum stress and maximum strain of Lamella Dome 1

Analysis	**Result**
Maximum Buckling	0.000 022 4 m
Maximum Stress	0.2198 kN/m^2
Maximum Strain	0.0935m⁄m

From the analysis, with this type of configuration pattern grid of dome, the maximum buckling of the bar element is 0.000 022 4m which occurs at the fourth ring from the center of the dome. In this case, the maximum buckling value is too small which is consider as stable structure. The maximum stress of the dome is 0.2198 kN/m^2 and the maximum strain is 0.0935 m/m where appoint at red region that shows in Appendix B.

4.2.3 Lamella Dome 2 Analysis

Table 4.3 shows the maximum buckling, maximum stress and maximum strain of Lamella Dome 2 for two-way grid with the diagonal shape.

Table 4.3: Maximum buckling, maximum stress and maximum strain of Lamella Dome 2

Analysis	**Result**
Maximum Buckling	0.000 000 2 m
Maximum Stress	0.5231 kN/m^2
Maximum Strain	0.0176 m⁄m

From the analysis, with this type of configuration pattern grid of dome, the maximum buckling of the bar element is 0.000 000 2m which occurs at the center of the dome. In this case, the maximum buckling value is too small which is consider as stable structure. The maximum stress of the dome is 0.5231 kN/m^2 and the maximum strain is 0.0176 m/m where appoint at red region that shows in Appendix C.

4.2.4 Schwedler Dome 1 Analysis

Table 4.4 shows the maximum buckling, maximum stress and maximum strain of Schwedler Dome 1 for three-way grid with the triangular shape.

Table 4.4: Maximum buckling, maximum stress and maximum strain of Schwedler Dome 1

Analysis	**Result**
Maximum Buckling	0.000 000 1 m
Maximum Stress	0.0194 kN/m^2
Maximum Strain	0.0820 m⁄m

From the analysis, with this type of configuration pattern grid of dome, the maximum buckling of the bar element is 0.000 000 1m which occurs at the center of the dome. In this case, the maximum buckling value is too small which is consider as stable structure. The maximum stress of the dome is 0.0194 kN/m^2 and the maximum strain is 0.0820 m/m where appoint at red region that shows in Appendix D.

4.2.5 Schwedler Dome 2 Analysis

Table 4.5 shows the maximum buckling, maximum stress and maximum strain of Schwedler Dome 2 for four-way grid with the combination of superposition rectangular and diagonal shape.

Table 4.5: Maximum buckling, maximum stress and maximum strain of Schwedler Dome 2

Analysis	**Result**
Maximum Buckling	0.0696 m
Maximum Stress	13.204 kN/m^2
Maximum Strain	0.5026 m⁄m

From the analysis, with this type of configuration pattern grid of dome, the maximum buckling of the bar element is 0.0696 m which occurs at the center of the dome. This is happen due to principal in factor influencing the buckling load which is similar with the Ribbed dome case. The node instability occurs when all connected members in a node undergo such axial strains that they cannot resist the node external load. The maximum stress of the dome is 13.204 kN/m^2 and the maximum strain is 0.5026 m/m where appoint at red region that shows in Appendix E.

4.3 ANALYSIS

4.3.1 Maximum Buckling Analysis

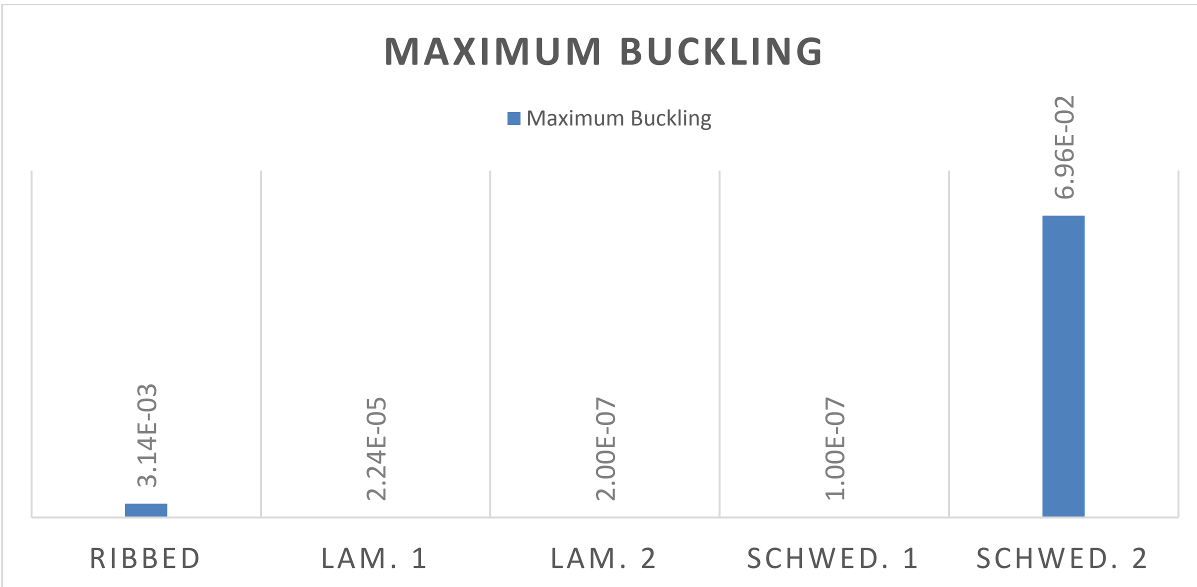


Figure 4.1: Maximum buckling of Ribbed dome, Lamella dome 1, Lamella dome 2, Schwedler dome 1 and Schwedler dome 2

Based on Figure 4.1, the maximum buckling for Ribbed dome and Schwedler dome 2 had higher value with a bigger gap with other domes, which is respectively 0.003 14m and 0.069 6m. The maximum buckling happen at center of the dome for the both type of grid pattern domes. The lower buckling value shows that the structure is stable. In the other hand, the lowest value of maximum buckling among of the domes is the Schwedler dome 1 with 0.000 000 1m.

4.3.2 Maximum Stress Analysis

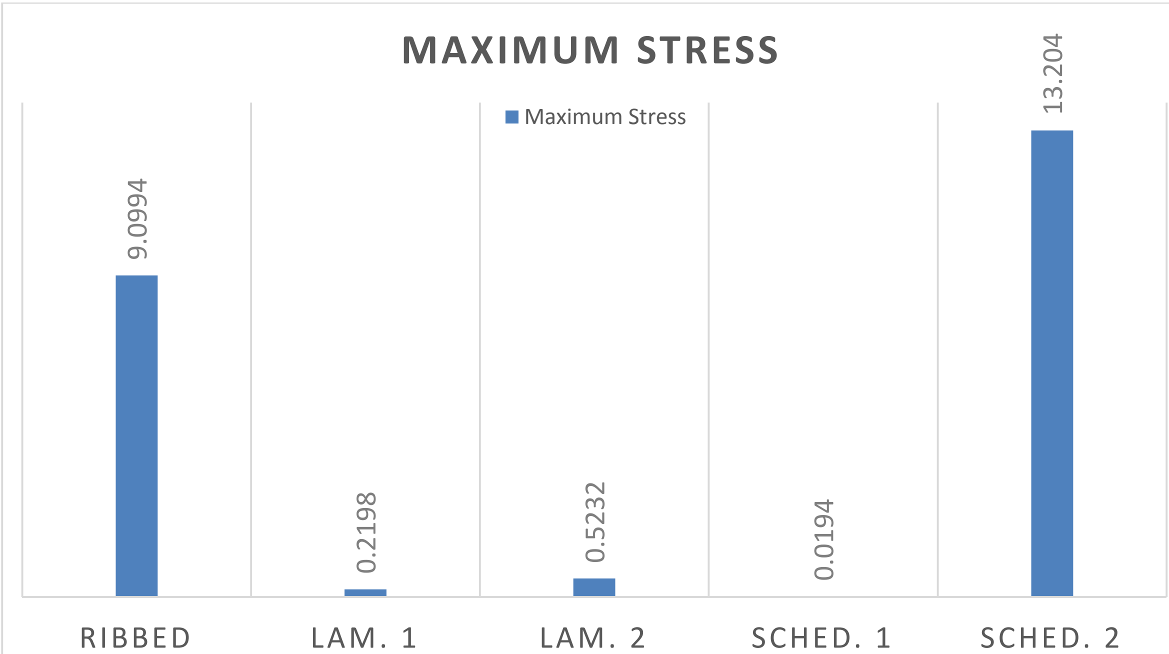


Figure 4.2: Maximum stress of Ribbed dome, Lamella dome 1, Lamella dome 2, Schwedler dome 1 and Schwedler dome 2

Based on Figure 4.2, the maximum stress for Ribbed dome and Schwedler dome 2 had higher value with a bigger gap with other domes, which is respectively 9.0994 kN/m^2 and 13.204 kN/m^2. The maximum stress happen at red region for the both type of grid pattern domes as shown in the appendix. In the other hand, the lowest value of maximum strain among of the domes is the Schwedler dome 1 with 0.019 4m/m.

4.3.3 Maximum Strain Analysis

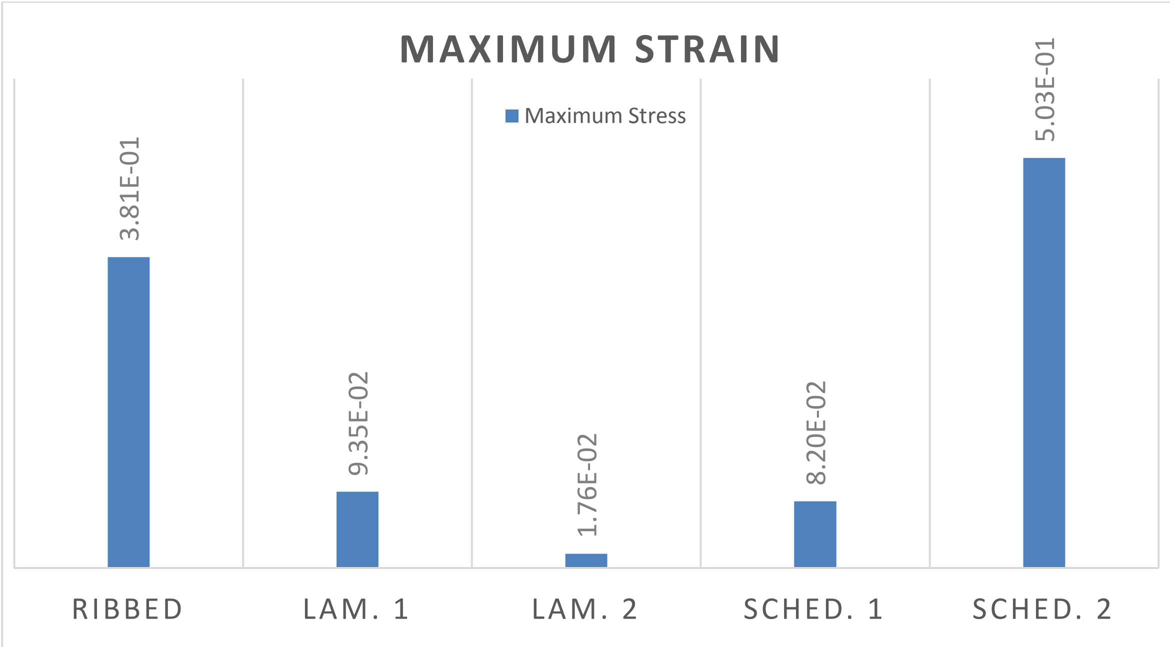


Figure 4.3: Maximum strain of Ribbed dome, Lamella dome 1, Lamella dome 2, Schwedler dome 1 and Schwedler dome 2

Based on Figure 4.3, the maximum strain for Ribbed dome and Schwedler dome 2 had higher value with a bigger gap with other domes, which is respectively 0.381m/m and 0.503m/m. The maximum strain happen at red region for the both type of grid pattern domes as shown in the appendix. In the other hand, the lowest value of maximum strain among of the domes is the Lamella dome 2 with 0.017 6m/m.

4.4 RESULT COMPARISON

Table 4.6 shows the maximum buckling, maximum stress and maximum strain comparison of all the five in term of their structural behaviour including the buckling, stress and strain.

Table 4.6: Maximum buckling, maximum stress and maximum strain comparison.

	Maximum Buckling (m)	**Maximum Stress (kN/m^2)**	**Maximum Strain (m/m)**
Ribbed Dome	0.003 14	9.0994	0.3811
Lamella Dome 1	0.000 022 4	0.2198	0.0935
Lamella Dome 2	0.000 000 2	0.5231	0.0176
Schwedler Dome 1	0.000 000 1	0.0194	0.0820
Schwedler Dome 2	0.069.6	13.204	0.5026

According to the table 4.6, the dome that had the highest structural behaviour in term of maximum buckling, maximum stress and maximum strain is Schwedler dome 2, with value from the result is respectively 0.069.6m, 13.204 kN/m^2, and 0.5026m/m. While the lowest structural behaviour in term of maximum buckling and maximum stress is Schwedler dome 1, with value from the result is respectively 0.000 000 1m and 0.0194 kN/m^2. For lowest structure behavious of maximum strain is Lamella dome 2, with value from the result is 0.0176m/m.

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1 INTRODUCTION

This chapter will finalized all the analysis that made into a conclusion base on the objectives of the research. Other than that, some possible recommendations for future research in the related topic. The conclusion made will indicate either the objectives are fulfilling the requirement or otherwise.

5.2 CONCLUSION BASED ON OBJECTIVES

The entire research were performed based on the objective that had determined as the guideline. From this research, the conclusion will be made based on the objectives whether the objective is achieved or not.

5.2.1 Objective 1: To study the Formex Configuration Progressing on how to arrange the part of formex algebra called Formian the programming language of formex algebra.

In order to illustrate all the model which are five different pattern grid of domes, it is necessary to study the formex Configuration Progressing on how to arrange the part of formex algebra called Formian. The basic studied of the Formex Configuration Progressing, had been used to illustrate the configuration as a dome model to be analyse. Therefore, the first objective had successfully achieved.

5.2.2 Objective 2: To analyse the several type of space structure which is domes, by using the finite element software LUSAS programming analysis to evaluate the structural behaviours.

Based on the several type dome model that already illustrated by using Formian software, the analysis were carried on by using the finite element software LUSAS to evaluate the structural behaviours. The space structure behaviours that were covered in this research are non-linear buckling, stress and strain. At the end of the analysis, the result of these structure behaviours were obtained as expected for all of the five different grid pattern of domes and the second objective had achieved as well.

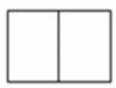
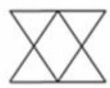
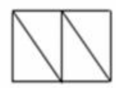
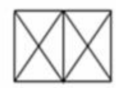
5.3 CONCLUSION BASED ON ANALYSIS

From analysis that had been done, the different grid pattern of domes gives the big different on the maximum buckling, maximum stress and maximum strain. These were showed that there is an effect when the various shape had been used for every each of the domes. The different type of single-layer shape grid pattern of dome were used in this analysis. According to the basic of theory, the simplest triangle shape will gives the most efficiency of structure behaviours which are maximum buckling, maximum stress and maximum strain.

As shown in Table 5.1, the Lamella dome 1, Lamella dome 2 and Schwedler dome 1 had lowest result of structure behaviour, as these are in simple triangle shape While Schwedler dome 2 had the highest structure behaviour in term of the maximum buckling, maximum stress and maximum strain among all these domes, as the dome had four-way grid pattern in combination of superposition rectangular and diagonal. Lastly, as for Ribbed dome, the structure behaviours shows that it had high value of maximum buckling, maximum stress and maximum strain, as the dome are not in simple triangle shape.

As conclusion, the different grid patterns do indeed have their own characteristic of structural behaviours. In designing a grid pattern of configuration, there are no inherent 'good' or 'bad' grid patterns and the suitability of a pattern for each particular case. Therefore, there are necessity to consider with regard to the shape and size of the boundary, support positions, loading characteristics and material to be used.

Table 5.1: Comparison in shape of grid pattern

	Ribbed Dome	Lamella Dome 1	Lamella Dome 2	Schwedler Dome 1	Schwedler Dome 2
Type Of Single-layer Grid	Two-way grid (rectangular)	three-way grid (triangle)	Two-way grid (diagonal)	three-way grid (triangle)	Four-way grid (combination of superposition rectangular and diagonal)
Shape					
Stress	High	Low	Low	Low	Very High
Strain	High	Low	Low	Low	Very High
Buckling	High	Low	Low	Low	Very High

5.4 RECOMMENDATIONS

There are some limitation while running this study where the main limitation is not enough information regarding the wind profile in particularly rise-to-span ratios and in simulated different surface condition. There are some suggestions for future study to ensure a better analysis and more effective result can be obtained from the analysis of the domes structure. The recommendation are as listed below.

i. Wind load consideration

Wind pressure distribution on hemispherical domes has been found to have a small amount of positive pressure at the front and a large region of negative pressure at the back of structure. From the previsions study states that it is valid only for particular models and the particular wind profile, which is the influence of wind load grow as the span-to-rise ratio increase. For more accurate result it is would be better perform the analysis by consider the wind load or up lift load.

ii. Various rise-to-span ratio

The comparison of the various rise-to-span ratio show different behaviour of the buckling in the structure. Basically, the dead weight of domes is a function of the structure material used. It is depends mainly on the span, rise-to-span ratio, type of bracing, boundary conditions and intensity of external loading applied. Therefore, more detail result will be obtain by compare the result between the ratios.

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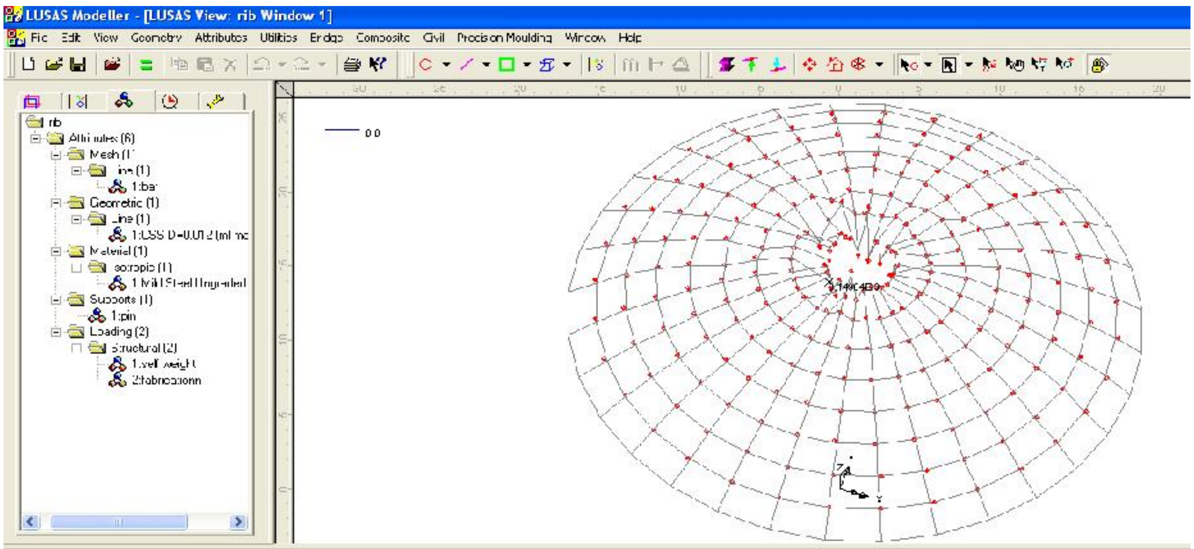
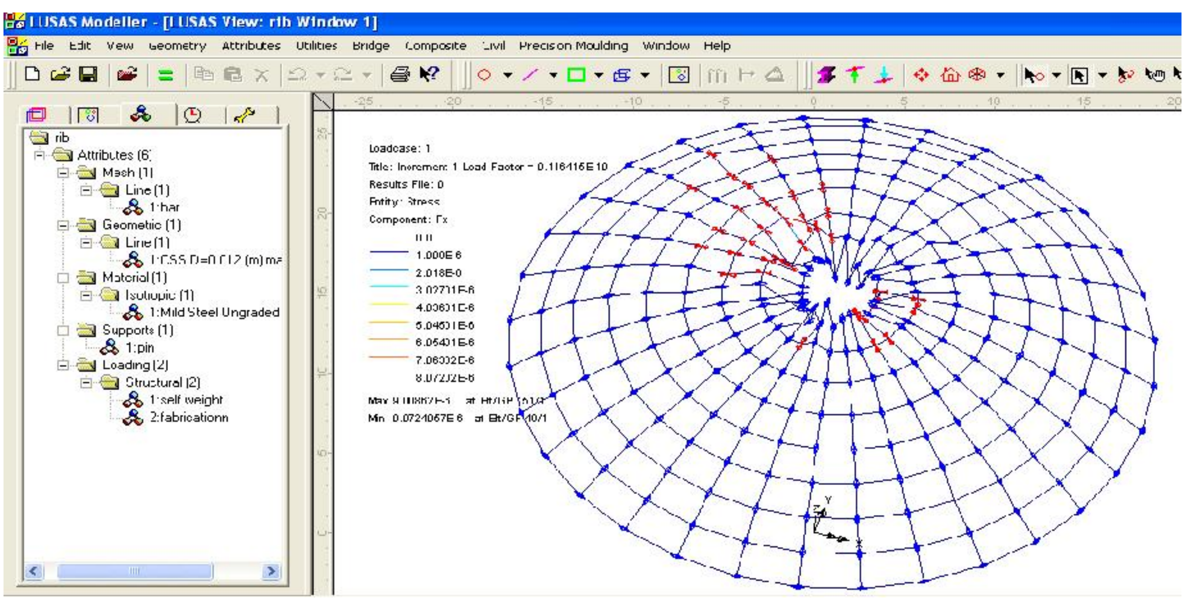
APPENDIX A

RIBBED DOME

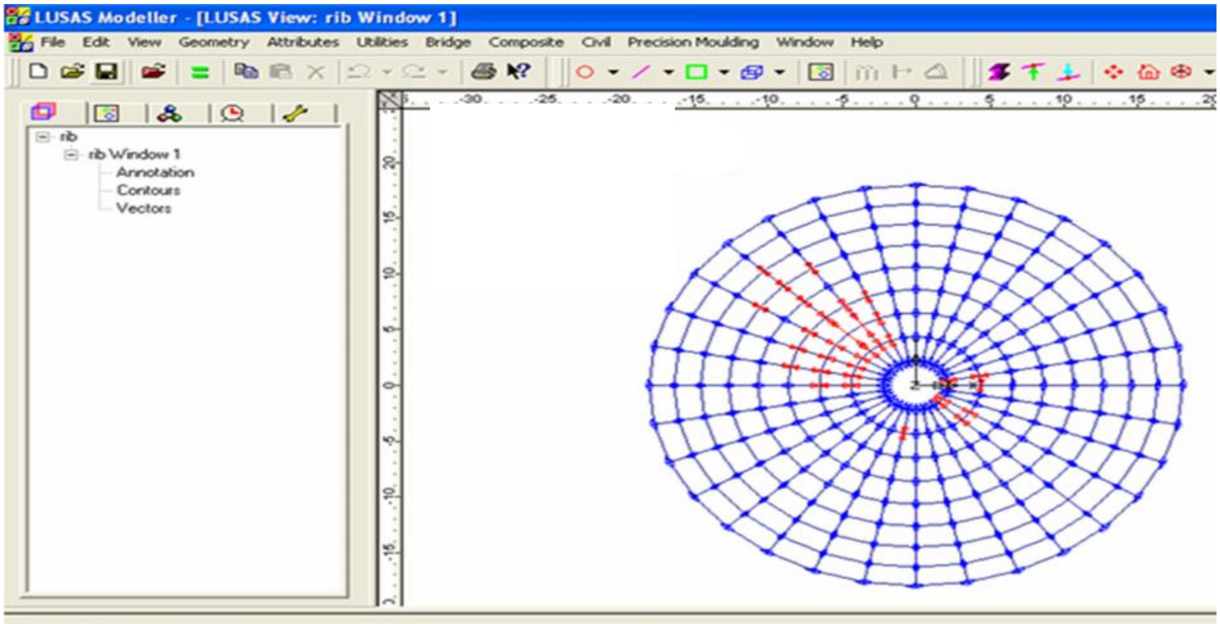
Buckling Analysis



Stress Analysis



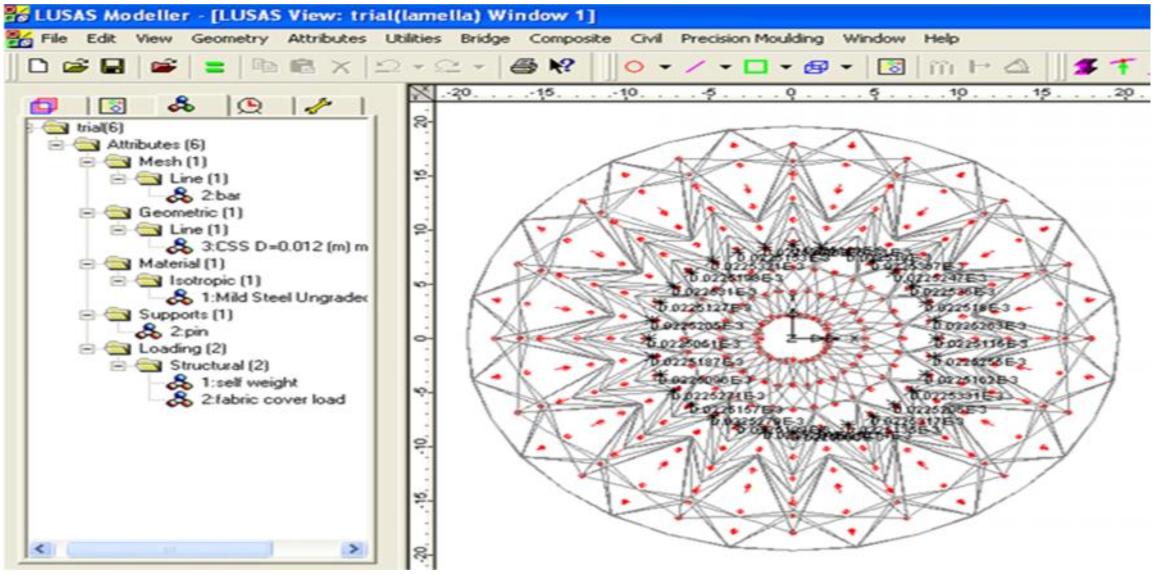
Strain Analysis



APPENDIX B

LAMELLA DOME 1

Buckling Analysis



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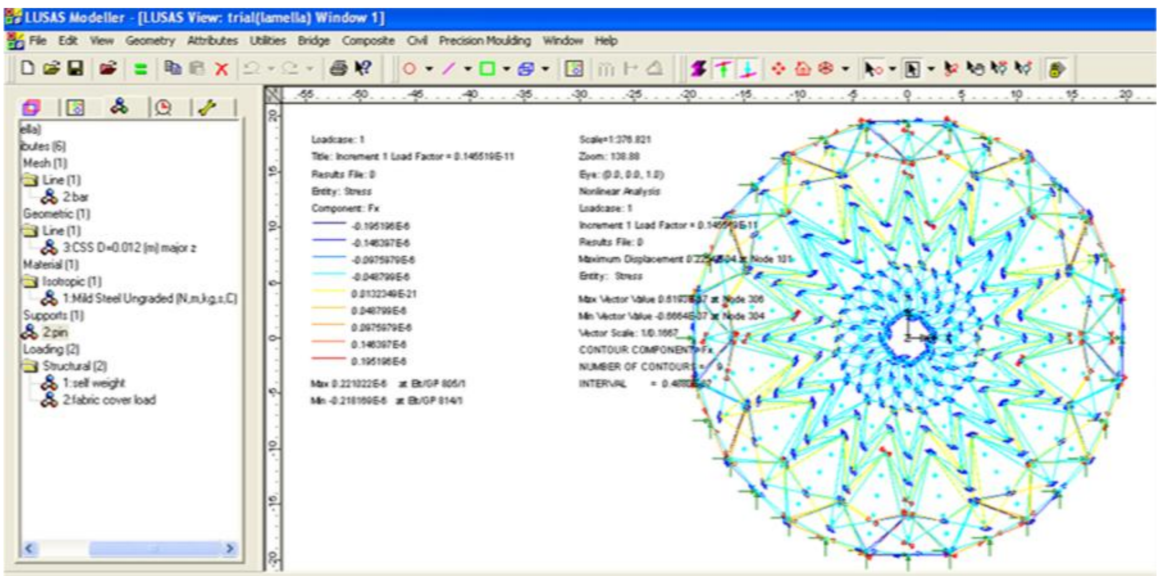

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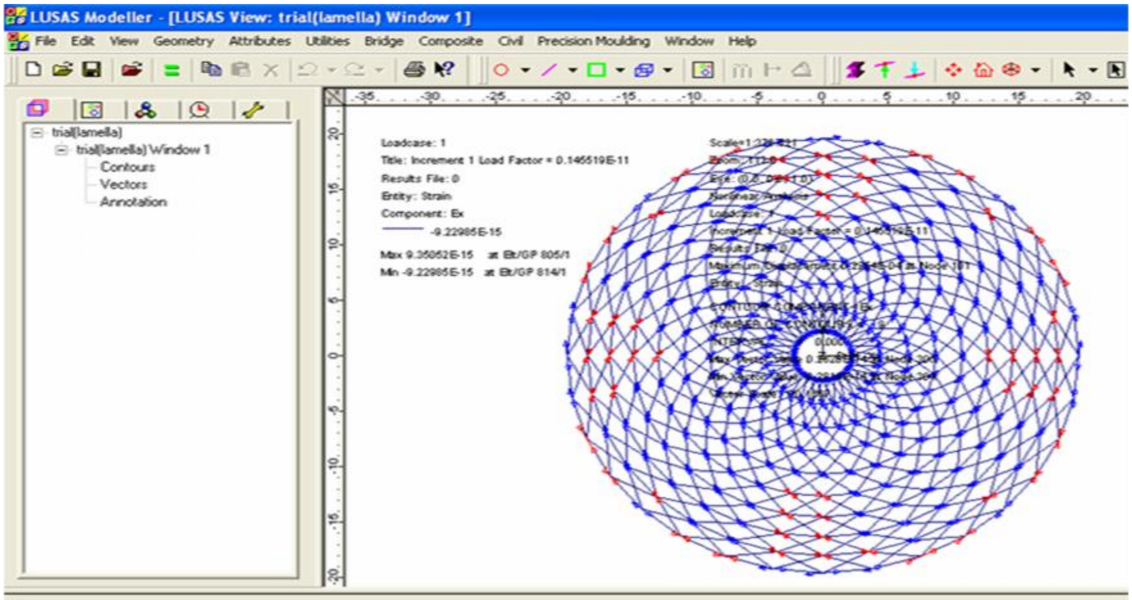
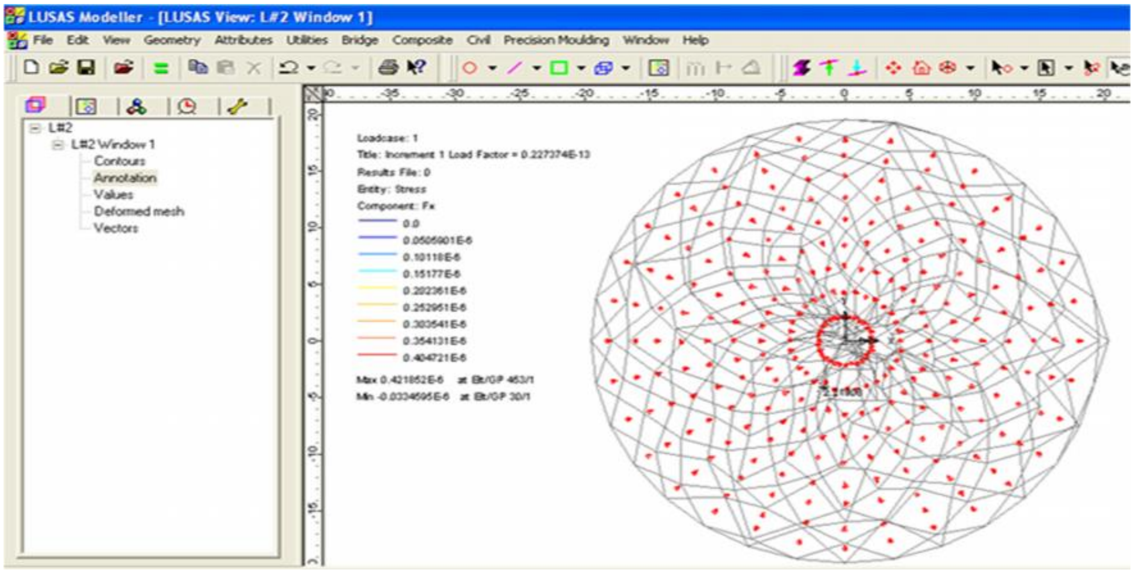


APPENDIX C

LAMELLA DOME 2

Buckling Analysis



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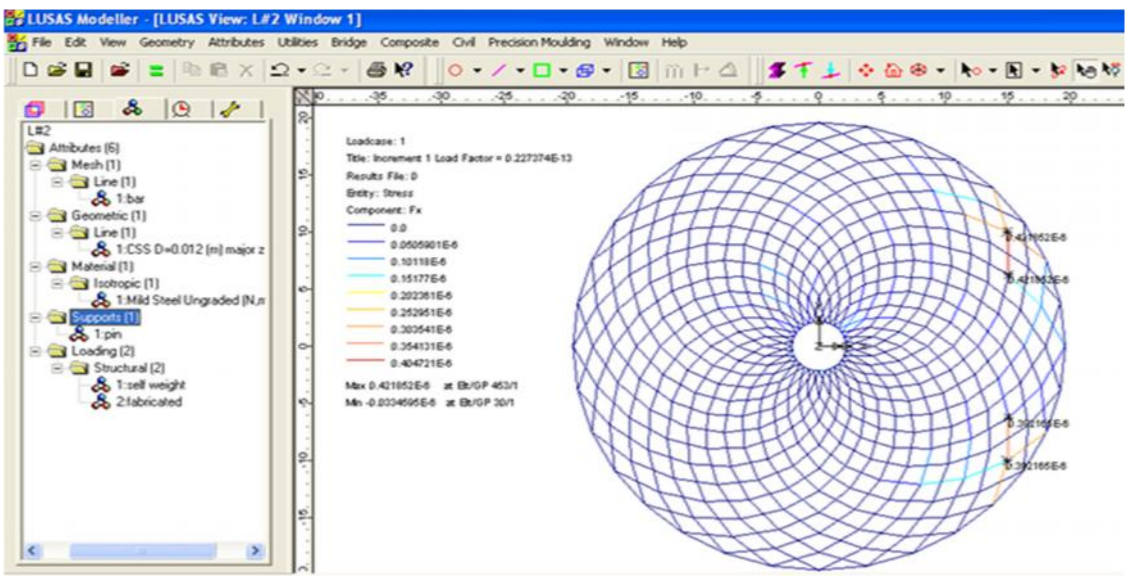

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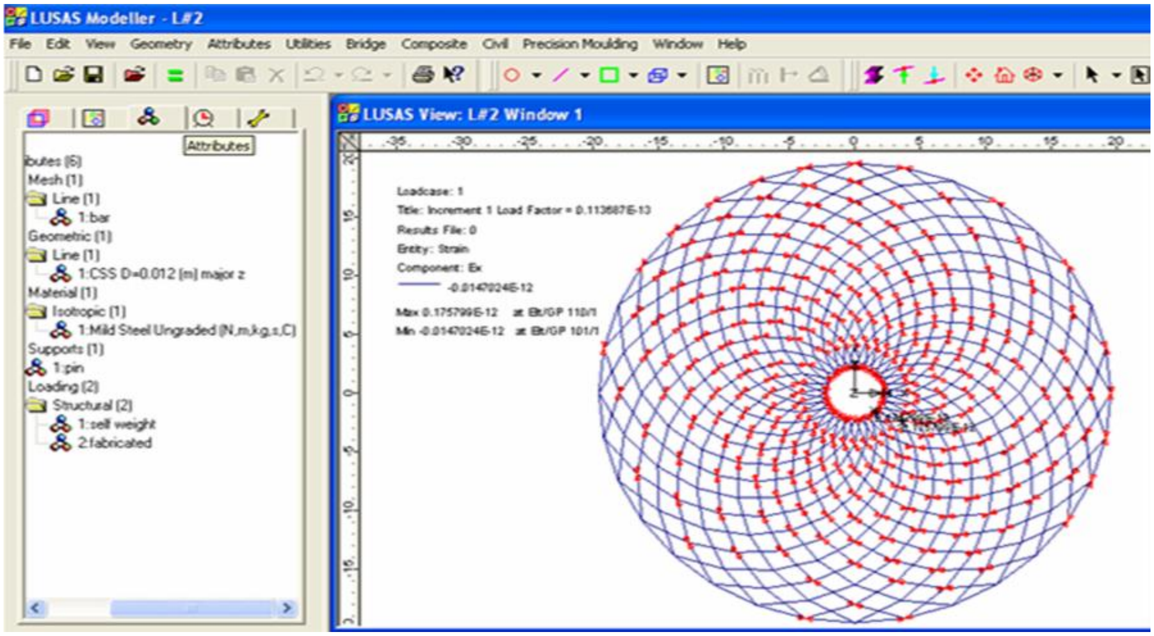
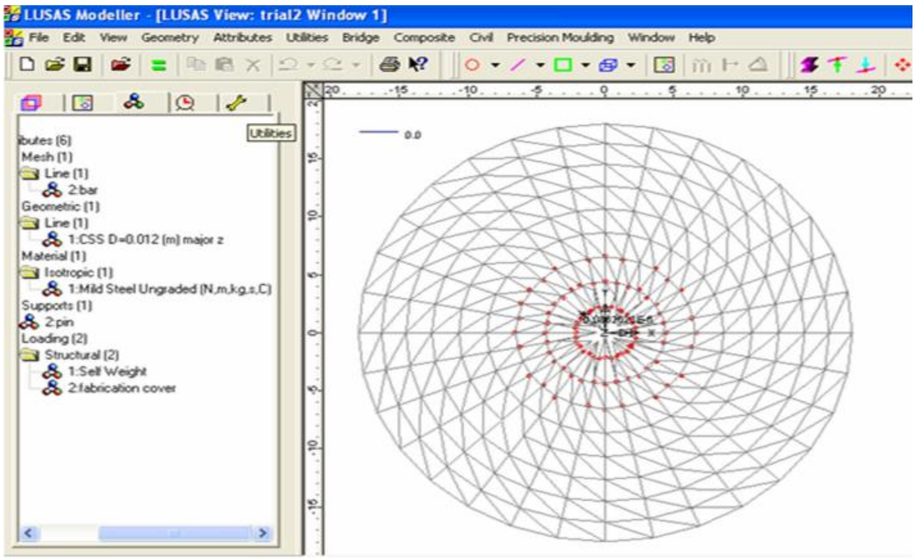


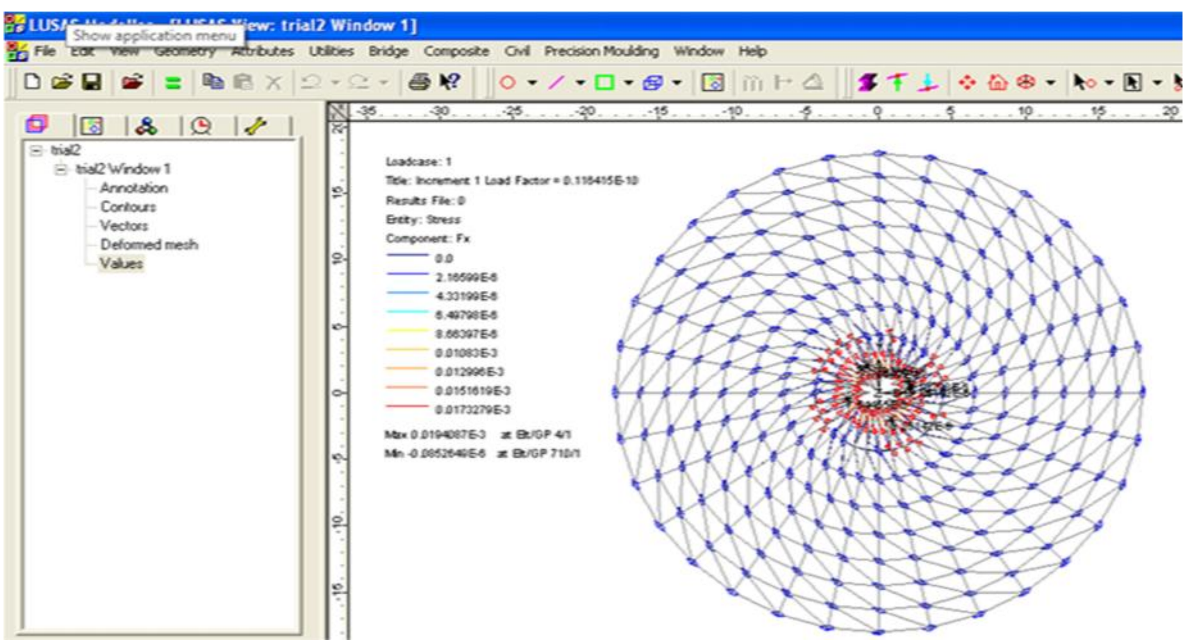
APPENDIX D

SCHWEDLER DOME 1

Buckling Analysis



Stress Analysis



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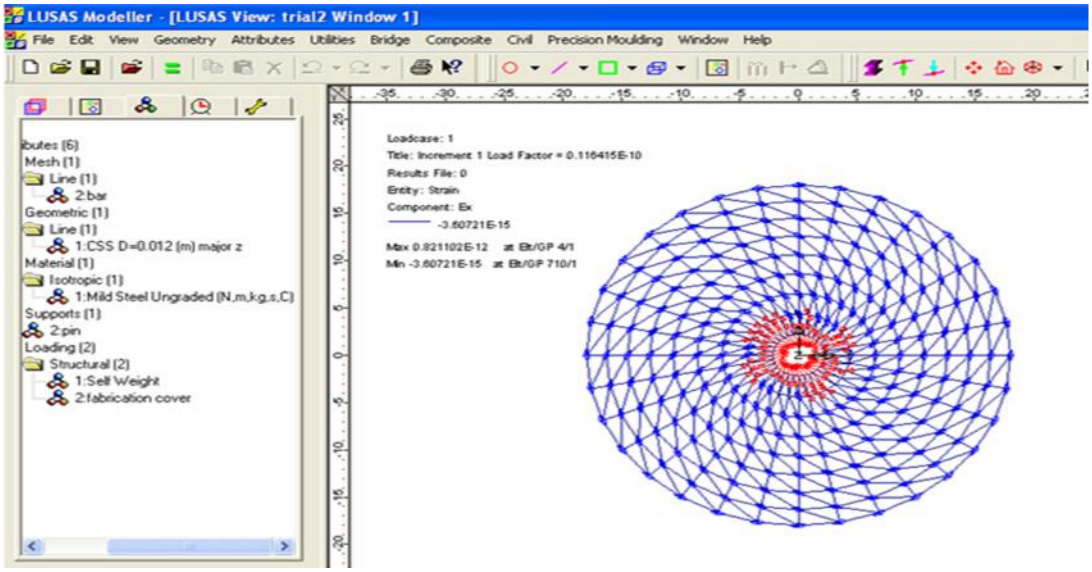
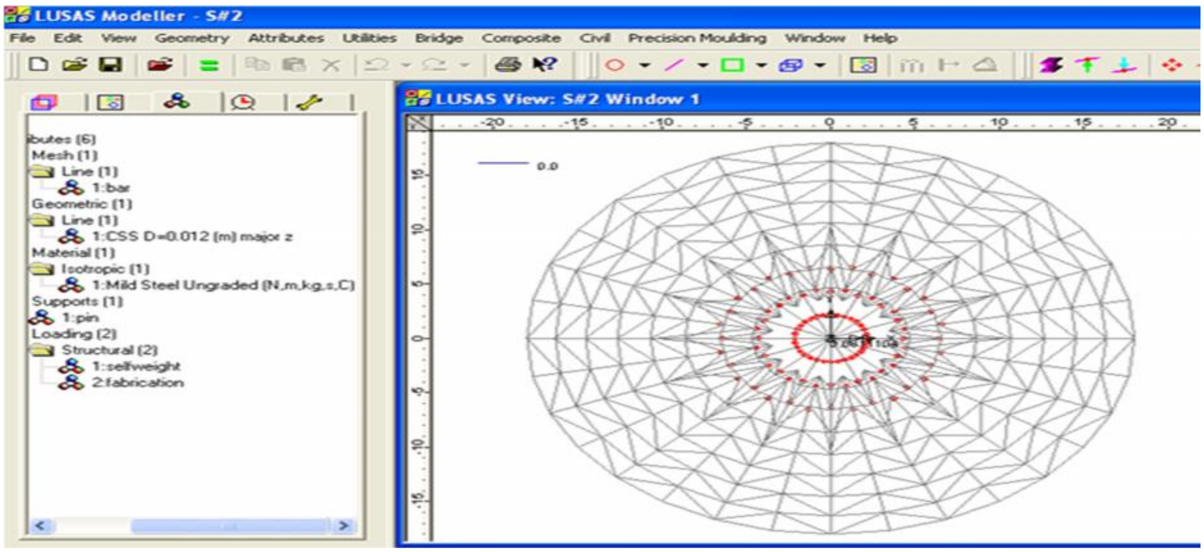


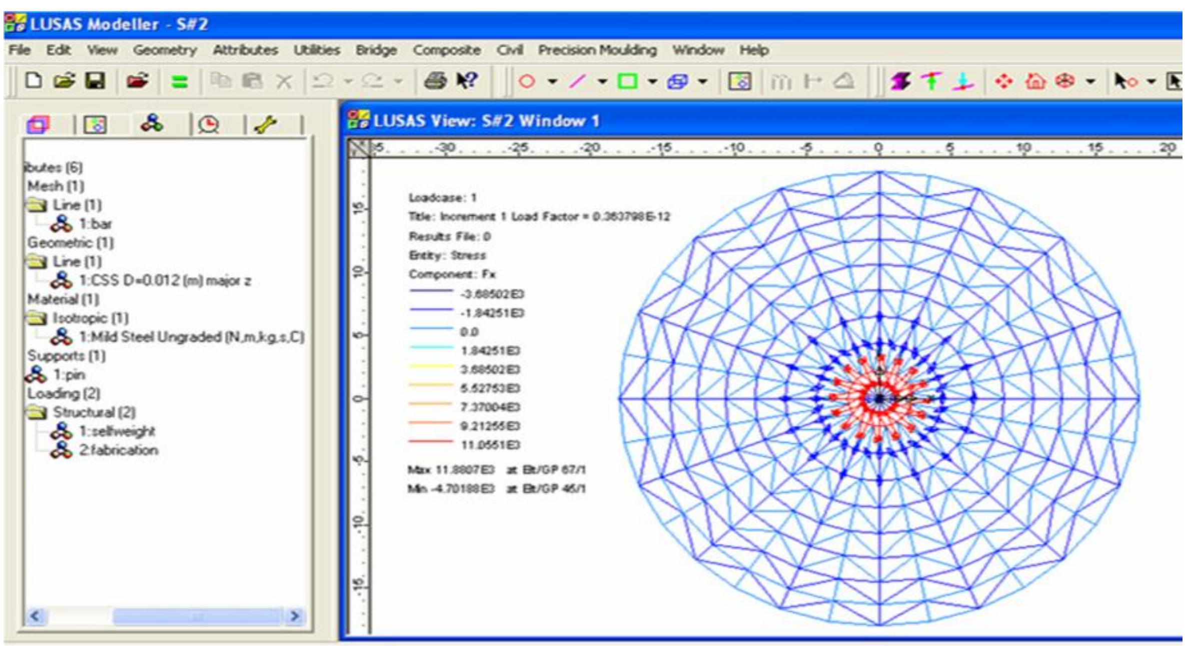
APPENDIX F

SCHWEDLER DOME 2

Buckling Analysis



Stress Analysis



Strain Analysis