Final Thesis

TELESCOPE DOME STRUCTURE.

ANALYSIS AND DESIGN

Gliwice, Poland, June, 2010

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1.-PROJECT OBJECTIVES

In this project, the objective is to design and calculate the dome for one telescope, whose external structure is about 10 meters of diameter. The requirements of design are, steel structure, this structure must be able to bear wind loads, thermal loads, gravity loads, shall be not considered mechanical parts in the design of the structure, like roller tracks of the connections between the upper and lower of the structure, motors, etcetera.

The project has to have the following contents:

- Review (overview)
- Preliminary Design
- Loads
- Modelling
- Calculations
- Drawings

2.-REVIEW

2.1.-TELESCOPES

A telescope is an instrument designed for the observation of remote objects by the collection of electromagnetic radiation. The first known practically functioning telescopes were invented in the Netherlands at the beginning of the 17th century. "Telescopes" can refer to a whole range of instruments operating in most regions of the electromagnetic spectrum.

The word "*telescope*" (from the Greek *tele* = 'far' and *skopein* = 'to look or see'; *teleskopos* = 'far-seeing') was coined in 1611 by the Greek mathematician Giovanni Demisiani for one of Galileo Galilei's instruments presented at a banquet at the Accademia dei Lincei In the *Starry Messenger* Galileo had used the term "perspicillum".[1]

Figure 2-1. Gran Telescopio Canarias (GTC), in Spain (source: GTC [2])**.**

[1] Telescopes: www.wikipedia.org

The first telescope developed was in 1609 by Galileo, he was the first man to turn his telescope toward the starts and see the craters of the moon. In 1611, Johannes Kepler switches from a concave eyepiece to a convex eyepiece. This not only allowed a larger field of view, but it allowed for the projection of images (such as the sun) onto a flat white screen. Although the images are inverted, Kepler demonstrates how a third convex lens turns the images right-side-up again. The use of a third lens also degrades the images, so this form of the telescope is not widely used. For terrestrial applications, particularly military applications, the Galilean form of the telescope is the most widely used.

After the technology of telescopes was developing increasingly with the passing years, with this, the telescopes have become an important field of technology[2]

2.1.1.-TYPES OF TELESCOPES

The name "telescope" covers a wide range of instruments and it is difficult to define. They all have the attribute of collecting electromagnetic radiation so it can be studied or analyzed in some manner. The most common type is the optical telescope; other types also exist and will be mentioned.

2.1.1.1.-Optical telescopes

There are three basic types of optical telescopes; Refractor, Newtonian reflector and Catadioptric. All of these telescopes are designed to collect light and bring it to a focus point so that it can be magnified by an "eyepiece", however each design does it in a different manner.

[2] An early history of the telescope: www.antiquetelescopes.org

Each of the designs has the potential to perform very well, and all have their own virtues, as well as faults.

Further on the most popular type of telescope will be described as well as it's advantages and disadvantages.

An optical telescope gathers and focuses light mainly from the visible part of the electromagnetic spectrum (although some work in the infrared and ultraviolet). In order for the image to be observed, photographed, studied, and sent to a computer, telescopes work by employing one or more curved optical elements—usually made from glass—lenses, or mirrors to gather light and other electromagnetic radiation to bring that light or radiation to a focal point.

a) The refracting telescope

The refractor, also known as the diopter, is a telescope that uses lenses to refract (bend) the light that accumulates. This refraction causes parallel light rays converge at a focal point at the opposite end, which can extend through an eyepiece. The large lens on the front is called the lens. The objective lens is usually composed of two or more separate lenses are bonded and / or arrangements that together form what is called the objective lens cell. The glassware can also vary which will help in the overall performance of the lens.

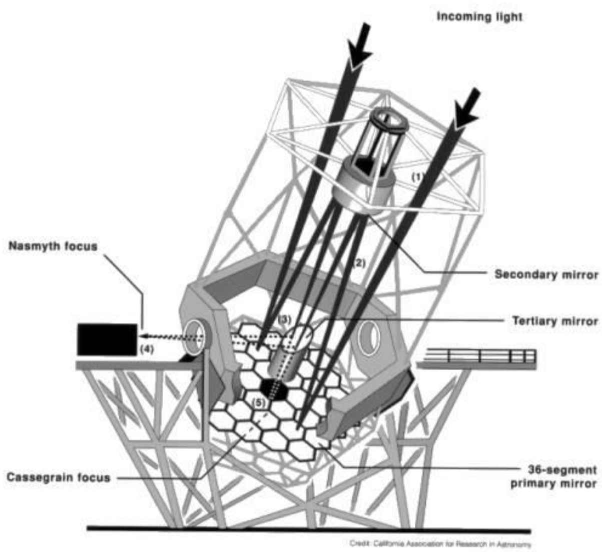

Figure 2-2. Schematic view of a Refracting Telescope (source: www.aoe.com.au [3]).

Some advantages can be achieved with this type: the labour of maintenance is quite easy and the use is quite easy comparing with other telescopes, it's reliable due to the simplicity of design, excellent for lunar, planetary or binary star viewing, objective lens is usually permanently mounted and aligned.

Also some disadvantages can be found, as for example; it is usually more expensive per inch of aperture tan Newtonians or Catadioptrics., heavier, longer and bulkier tan equivalent aperture Newtonians or Catadioptrics, less suited for observation of deep sky objects such as distant galaxies and nebulae because of it's impractical limitations.

b) Newtonian Reflector

The Newtonian Reflector, also known as catoptrics, is a telescope, which uses a spherical or concave parabolic primary mirror to collect, reflect, and focus the light onto a flat secondary mirror (diagonal). This secondary mirror in turn reflects the light out of an opening in the side of the tube and into an eyepiece for focus and magnification

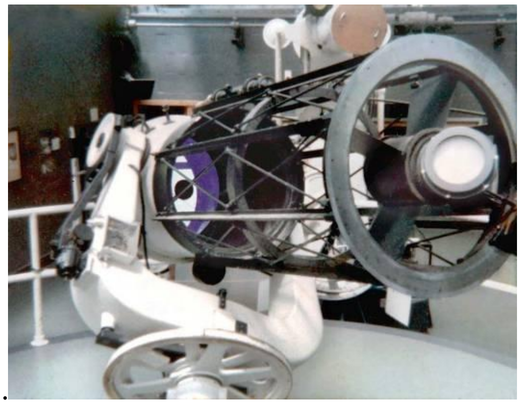

Figure 2-3. Inch convertible Newtonian/Cassegrain reflecting telescope on display at the Franklin Institute**.** (source: www.aoe.com.au [3])**.**

Some advantages can be as follows; this type gets the lowest cost per inch of aperture compared to refractors and catadioptrics, which is excellent for faint deep sky objects such as remote galaxies, nebulae and star clusters due to the generally fast focal ratios (f/4 to f/8). Reasonably good images can be achieved for lunar and planetary work. Newtonian refelctor has low optical aberrations and delivers very bright images.

As disadvantages, it requires regular alignment (collimation) of topics in order to perform at its best; it means high cost of maintenance. Badly aligned optics can make the image quality suffer quite dramatically. Primary mirrors may require re-coating (usually after years of service). It can be generally not suited for terrestrial applications.

c) The catadioptric telescope

Catadioptrics are telescopes that use a combination of mirrors and lenses to fold the light path and direct it for focus and magnification through a hole in the primary mirror. There are two popular designs, the Maksutov-Cassegrain and Schmidt-Cassegrain.

In Maksutov designs the light enters a thick meniscus correcting lens with a strong curvature. The light then strikes the primary mirror and is reflected back up to the seconday mirror that reflects the light out an opening in the rear of the instrument. The secondary mirror is usually smaller an aluminised spot on the back of the meniscus corrector.

In Schmidt designs the light enters a thin aspheric Schmidt correcting lens. The light then strikes the primary mirror and is reflected back up to the secondary mirror that reflects the light out an opening in the rear of the instrument. Schmidt's usually have shorter focal lengths thus making them more suitable for fainter deep sky objects.

The Maksutov secondary mirror is usually smaller tan the Schmidt's thus giving the Maksutov better resolution for planetary observing.

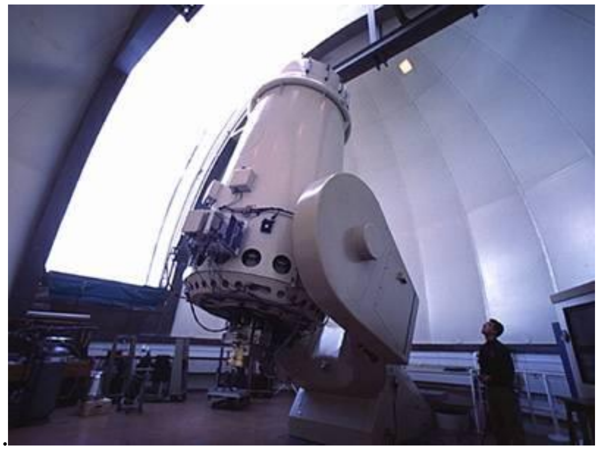

Figure 2-4. Mt Palomar 60" Schmidt Focus Telescope**.** (source: www.aoe.com.au [3])**.**

Figure 2-5. Schematic view of a Schmidt-Cassegrain**.** (source: www.aoe.com.au [3])**.**

*2.1.1.2.-**Radio Telescopes***

Radio telescopes are directional radio antennas used for radio astronomy. The dishes are sometimes constructed of a conductive wire mesh whose openings are smaller than the wavelength being observed. Multi-element Radio telescopes are constructed from pairs or larger groups of these dishes to synthesize large 'virtual' apertures that are similar in size to the separation between the telescopes; this process is known as aperture synthesis.

Aperture synthesis is now also being applied to optical telescopes using optical interferometers (arrays of optical telescopes) and aperture masking interferometry at single reflecting telescopes. Radio telescopes are also used to collect microwave radiation, which is used to collect radiation when any visible light is obstructed or faint, like that from quasars. Some radio telescopes are used by programs such as SETI and the Arecibo Observatory to search for exterrestrial life.

Figure 2-6. Westerbork Synthesis Radio Telescope. (source: www.aoe.com.au [3]**).**

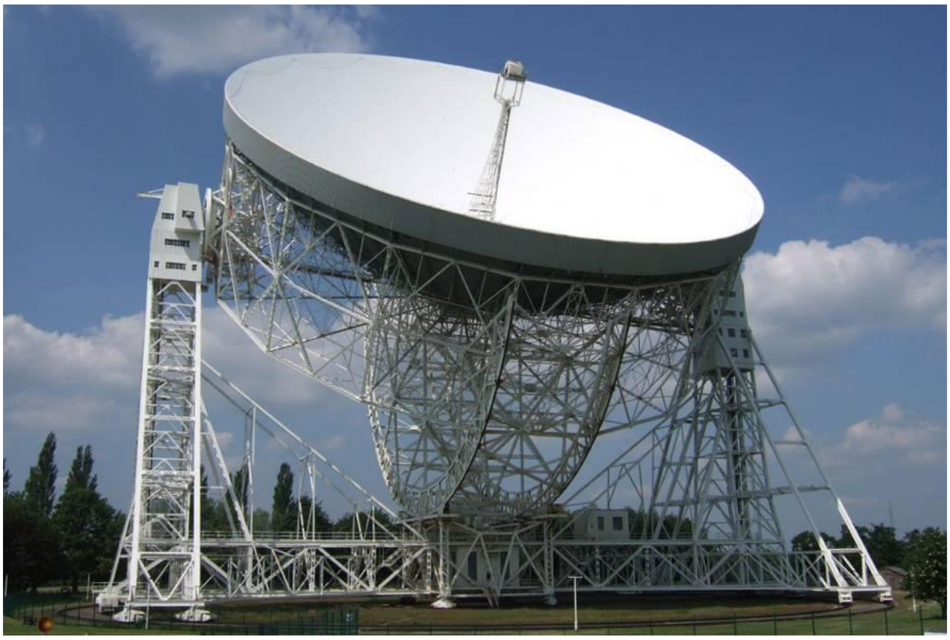

Figure 2-7. Yebes 40-m Telescope. (source: www.aoe.com.au [3]).

*2.1.1.3.-**High energy particle telescopes***

X-ray telescopes use Wolter telescopes composed of ring-shaped 'glancing' mirrors made of heavy metals that are able to reflect the rays just a few degrees. The mirrors are usually a section of a rotated parabola and a hyperbola, or ellipse.

Gamma-ray telescopes refrain from focusing completely and use coded aperture masks: the patterns of the shadow the mask creates can be reconstructed to form an image.

X-ray and Gamma-ray telescopes are usually on Earth-orbiting satellites or high-flying balloons since the Earth's atmosphere is opaque to this part of the electromagnetic spectrum.

In other types of high energy particle telescopes there is no image-forming optical system. Cosmic-ray telescopes usually consist of an array of different detector types spread out over a large area. A Neutrino telescope consists of a large mass of water or ice, surrounded by an array of sensitive light detectors known as photomultiplier tubes.[34]

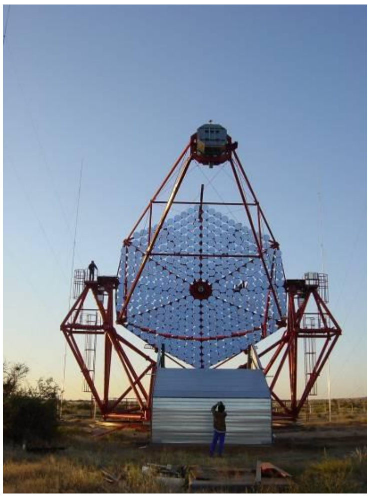

Figure 2-8.HESS Gamma-Ray Telescope (source: www.aoe.com.au [3])**.**

2.1.2.-TECHNOLOGY FOR TELESCOPES

Since its invention 400 years ago, the astronomical telescope has evolved from a small, manually pointed device for visual observations to a large, sophisticated, computer-controlled instrument with full digital output. Throughout this development, two properties have been particularly important: the light-collecting power, or diameter of the telescope's mirror (allowing for the detection of fainter and more distant objects), and the image sharpness, or angular resolution (allowing smaller and fainter objects to be seen).

3 Telescope Types and Designs: www.aoe.com.au

[4] Telescope Types : www.celestron.com

The European Southern Observatory (ESO), as a worldwide leader in astronomy, has developed several advanced technologies that have enabled the construction of ever larger telescope mirrors, while maintaining optical accuracy.

There is one innovative technique which has been developed by ESO, this is the technique of active optics, which is now in use in most modern medium-sized and large telescopes. It preserves optimal image quality by pairing a flexible mirror with actuators that actively adjust the mirror's shape during observations.

Due to distortions introduced by atmospheric turbulence, for a 4-metre telescope, atmospheric distortion degrades the resolution by more than an order of magnitude compared with what is theoretically possible, and the intensity of light at the centre of the star's image is lowered by a factor of 100 or more.

Combining the light collected by two or more telescopes in a technique known as interferometry can boost the resolution beyond what a single telescope can accomplish.

In addition to atmospheric turbulence, the telescopes themselves introduce errors into astronomical observations. For example manufacturing errors and irregularities in equipment can cause a big distortion in the image got. Over the years, engineers have made a series of improvements to minimise wear-and-tear errors caused by the mechanical movement of the telescope and heat damage.

To prevent these problems on resolution of the image which is analyzed, low expansion glass has also reduced mirror distortions when temperatures vary. To reduce the small, but noticeable, turbulence inside the telescope dome, heat loss from motors and electronic equipment is curtailed during the night, and the dome that shields the telescope from the wind is cooled during the day.

*2.1.2.1.-**Active optics***

Optical telescopes collect light from the cosmos using a primary mirror. Bigger primary mirrors allow astronomers to capture more light, and so the evolution of the telescope has often followed a “bigger is better”, more resolution, capacity, etc. mantra. In the past, mirrors over several metres in diameter had to be made extremely thick to prevent them from losing their shape as the telescope panned across the sky. Eventually such mirrors became prohibitively heavy and so a new way had to be found to ensure optical accuracy.

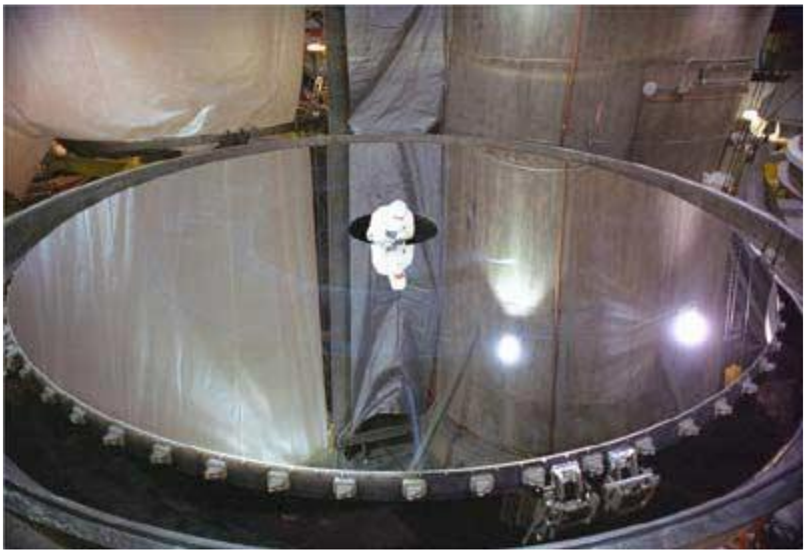

Figure 2-9. The primary mirror for Gemini North. Note the person in the center. The 8.1m primary is only 20 cm thick. Image: Gemini Observatory.(source: http://outreach.atnf.csiro.au/[5])

The problem is that the mirrors sag under their own weight as they point to different parts of the sky. To produce any worthwhile image the primary must be actively corrected by continuous computer control. By measuring a reference star within the field of view, corrections are sent to electromechanical actuators on the back of the primary. These push or pull on a section of the primary to change its shape. Active optic systems correct the primary shape about once per minute. The photo below shows the 150 actuators for one of the VLT primary mirrors. Each VLT primary is 8.2m diameter, 17cm thick and weighs 22 tonnes. [5]

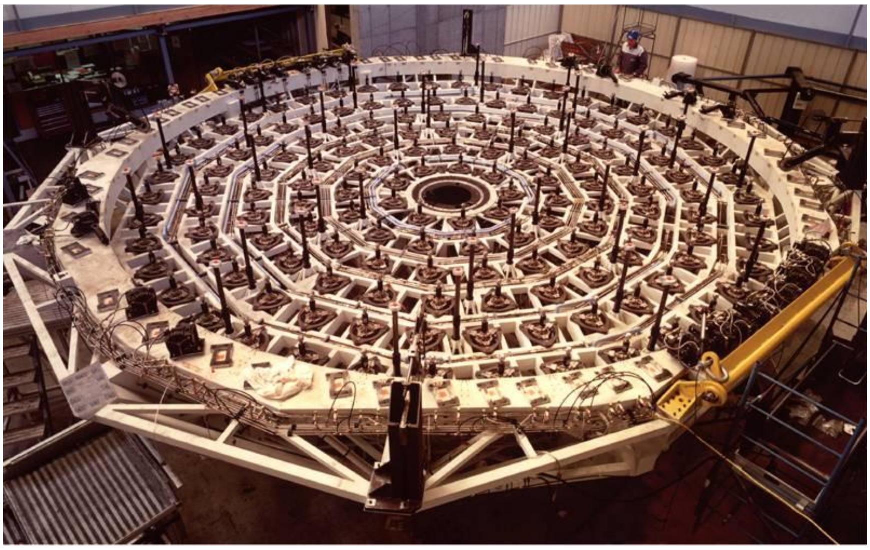

Figure 2-10. Active Mirrors Support In VLT M1 Cell. (source: www.eso.org [6]).

*2.1.2.2.-**Adaptative Optics***

Although active optics can ensure that a telescope's main mirror always retains a perfect shape, the turbulence of the Earth's atmosphere distorts images obtained at even the best sites in the world for astronomy, including Paranal in Chile, El Roque de los Muchachos in Spain.This turbulence causes the stars to twinkle in a way that delights poets but frustrates astronomers, since it blurs the finest details of the cosmos. Observing directly from space can avoid this atmospheric effect, but it means a high costs of operating space telescopes compared to using ground-based facilities limits the size and scope of the telescopes we can place off-Earth.

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[5] Active Optics: http://outreach.atnf.csiro.au/

Adaptive optics can be defined as, a sophisticated, deformable mirrors controlled by computers can correct in real-time for the distortion caused by the turbulence of the Earth's atmosphere, making the images obtained almost as sharp as those taken in space. Adaptive optics allows the corrected optical system to observe finer details of much fainter astronomical objects than is otherwise possible from the ground.

Adaptive optics requires a fairly bright reference star that is very close to the object under study. This star is used to measure the blurring caused by the local atmosphere so that the deformable mirror can correct for it. When the stars are not available in the night sky, an artificial stars can be used instead by shining a powerful laser beam into the Earth's upper atmosphere, when the light form the laser comes back, by analyzing this, several parameters are obtained, and thanks to them, the variable shape mirrors are moved to correct the distortion, and like this the image is more accurate.

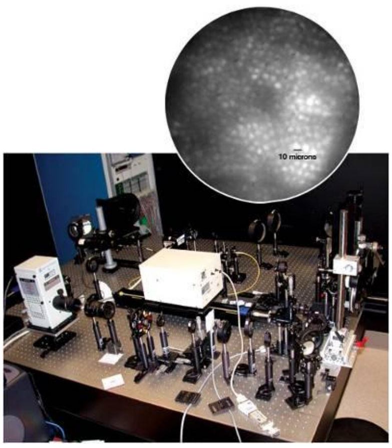

Figure 2-11.Laboratory for Adaptive Optics

*2.1.2.3.-**Interferemotry***

Lately the size of telescope mirrors is increasing, but this is not an easy task, so astronomers have come up with a new technology to see even finer details: interferometry. This observational technique combines the light received by two or more telescopes and allows them to act as a single unit with a mirror diameter equivalent to the distance between the telescopes.

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A complex system of mirrors brings the light from the different telescopes to the astronomical instruments where it is combined and processed. This feat demands stunning technical powers, the light paths must be kept equal to within 1/1000 mm over distances of a few hundred metres. [6]

Figure 2-12.VLT at Paranal. (source: www.eso.org [6]).

[6] Technology for Telescopes : www.eso.org

2.1.3.-PARTS OF THE STRUCTURE OF A TELESCOPE

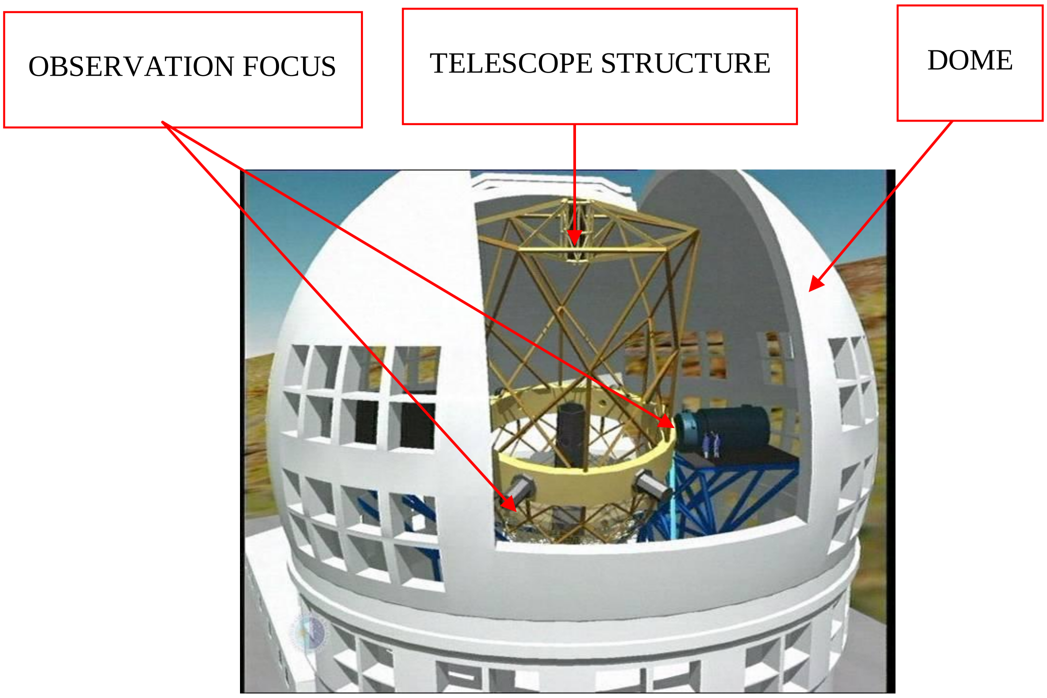


Figure 2-13. Parts of the structure of a telescope**.** (source: www.gtc.iac.es)

*2.1.3.1.-**Telescope Structure***

When the size of the telescope increases the design of the structure that supports all elements becomes to be more and more difficult, due to the accurate movement needed, taking into count, specially, the weight of all elements involved. For a reasonable range of design choices, the modal performance and the ability to resist disturbances such as wind shake naturally decrease with increasing structure size. Wind acting on the structure and optics will perturb the alignment of the optics and telescope pointing. These disturbances will be resisted by the telescope structure and drives.

The best of the current generation of large telescopes have lowest vibration modes around 8 Hz. This gets down to a range of frequencies where wind disturbance has increasingly significant power and where attenuation and correction of disturbances with the telescope structure and drives becomes less effective.

Costs of the telescope structure and mechanisms will generally scale with the mass of the telescope. Minimizing these costs is essential for a telescope 2.5-4 times the size of the current generation of large telescopes and requires an exceptionally efficient structure in terms of stiffness to weight. The choice of materials, use of standard and commercially available components, fabrication techniques and the means for transporting the telescope parts to the site are all factors in the cost that have been considered in the conceptual design.

The big mass of the telescope structure also cause problems for thermal conditions in the dome. Heat released as the structure cools during the night will contribute to blurring of the images (dome seeing). The heat would be flushed from the enclosure with wind-driven ventilation through the enclosure doors and vent openings. Minimizing the telescope and enclosure mass will reduce the ventilation requirements and wind loading on the telescope.[7]

[7] Telescope Structures: www.gmto.org

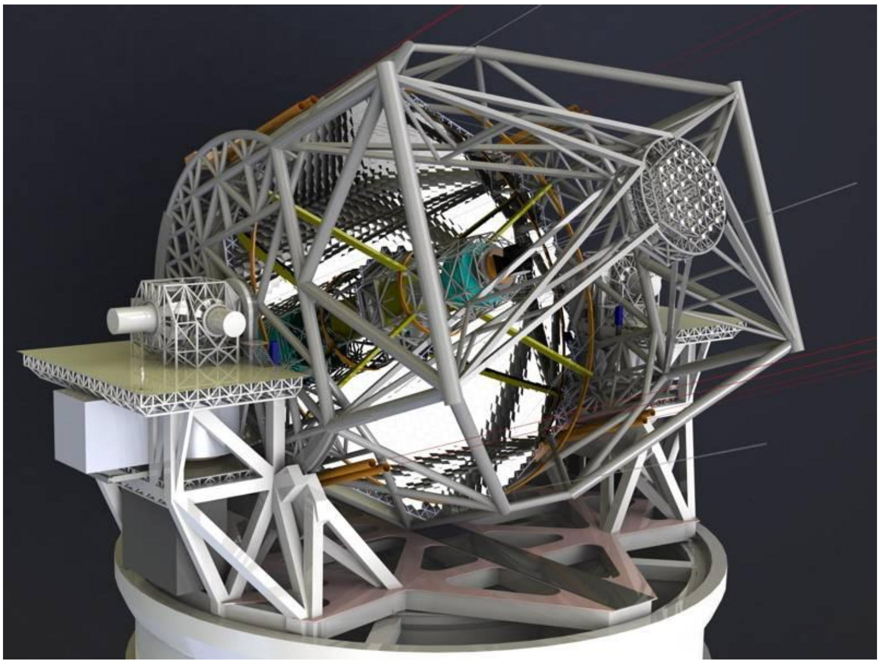


Figure 2-14.E-ELT: Telescope design (source: www.eso.org [6]).

*2.1.3.2.-**Observation Focus***

At this point the telescope is mounted and instruments observed. From a structural point of view are quite important because in them is where we get the information of the observed light, therefore are points of high structural rigidity.

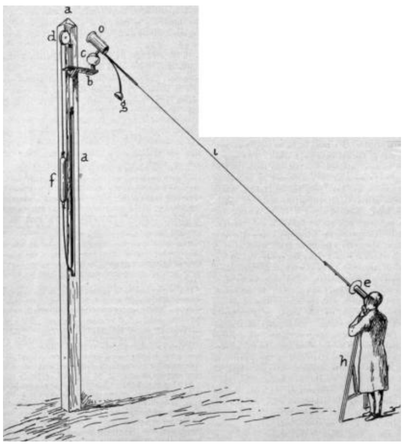


Figure 2-15. Observation Focus.

*2.1.3.3.-**Dome***

This structure protects and isolates the telescope structure from the external environment, when the telescope is not used.

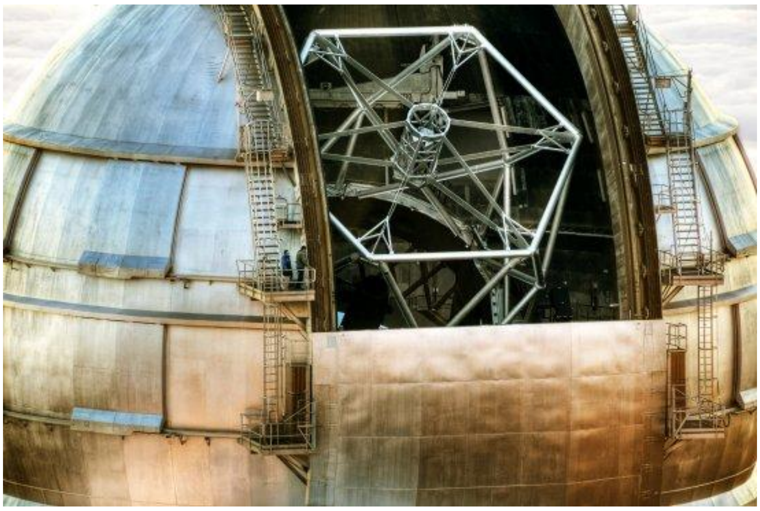


Figure 2-16. Dome GTC (source: www.gtc.iac.es)

2.2.-TELESCOPE DOME

2.2.1.-INTRODUCTION

Dome can be defined as the structure protecting the telescope (important investment) against external factors.

A standard astronomical dome is a major source of bad vision, as the dome is heated during the day and at night the warm air is kept inside of the dome. It can only go out through the slit, which the telescope is observing through. For this reason it is important to make a good design for thermal conditions, due that influences in the observation time.

Figure 2-17. View of GTC dome (source: www.gtc.iac.es)

Aim of the dome:

- The protection of the telescope against rain, snow, dust and wind, with which it avoids image degradation and telescope damage.
- Elimination of temperature gradients that can cause distortion in the image analyzed.
- The instruments of observation must be protected.

- Lately modern telescopes require amenities, control rooms, computers, machine/electronics shops, aluminizing chamber, etc., they must be protected

- This Structure must be given freedom of movement, work and testing space around telescope.[8]

2.2.2.-REVIEW

The classical design

The classical design consists of in a semi-spherical structure, when the shutters opens laterally. To sum up, the main issues are:

- Rotating circular dome with shutters opening laterally.
- The dome structures is strong.
- It allow the use windscreens.
- Complete free range of motion with minimum volume-enables performing test with dome closed.
- It is used in small telescopes.
- It can be cumbersome to build, especially for big telescopes.

[8] Gran Telescopio Canaria, 1998, Selection Telescope Dome.

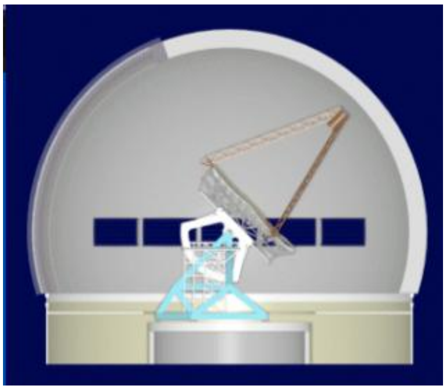


Figure 2-18. Dome classical design.(source: [9])

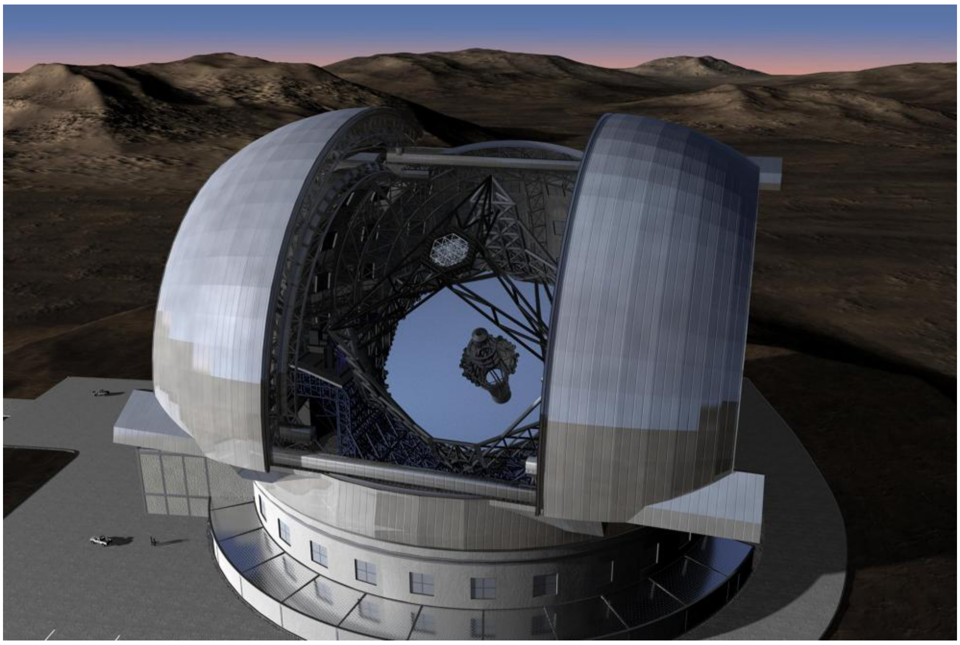


Figure 2-19. Model of the E-ELT within its enclosure (source: [9])

Changes in classical design

With the passing of the years some changes have been introduced, to adjust a better the smooth running of telescopes, however it depends of the kind and size of each telescope, and in each case the best solution must be studied.

Some important changes are:

1. **Shutters slides over top.**

   - Mechanically more difficult, but it gives greater freedom in slit opening.
   - Side panels can provide ventilation.
   - Good wind protection from rounded edges, but the protrusions has to be analyzed for each particular case.

Figure 2-20. The under construction PS1 telescope, part of the Pan-STARRS asteroid early-warning system (source:www.asteroidshield.com).

2. The use of girders

- The girders behave well for distributed loads, no advantage for concentrated loads.
- Large slit reduces strength of dome.
- If not clear, how the girders shake the wind, so it must be studied and simulated to know how the behaviour of the wind close to the obervation area.

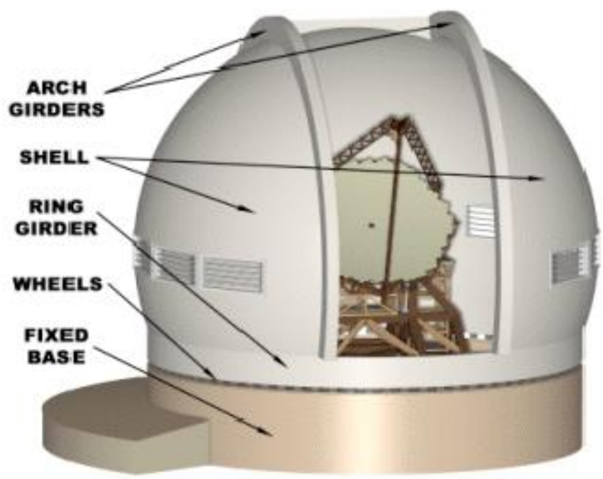


Figure 2-21. Example of a dome with garders. (source: [9])

Other types of domes

There are more kinds of domes for telescopes, where each seems the best solution for each case. The choice of the dome depends of the requirements, the most important of them usually are, size and kind of telescope, thermal conditions of operations for the telescope and the ratio of view of observation, this influences, how the telescope is going to operate. Some of these changes will be showed, however could be found more types.

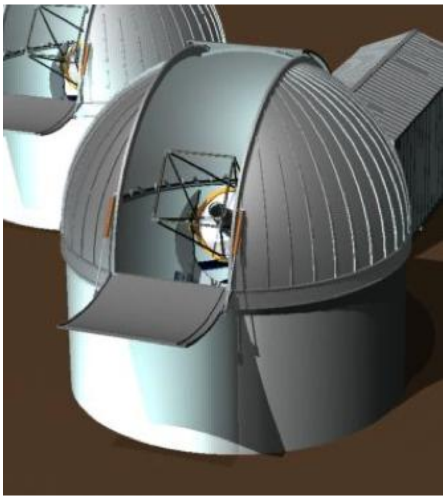


Figure 2-22. Example of a simply dome. (source: [9])

The Thirty Meter Telescope (TMT) project is designing the first of the next generation of giant optical/infrared telescopes. Planned for first light in the next decade, TMT will image the first galaxies, the birth of stars and advance the search for exosolar planets. With a diameter of 30 meters, TMT will collect 9 times more light than the current largest terrestrial telescopes (the Keck telescopes on Mauna Kea)

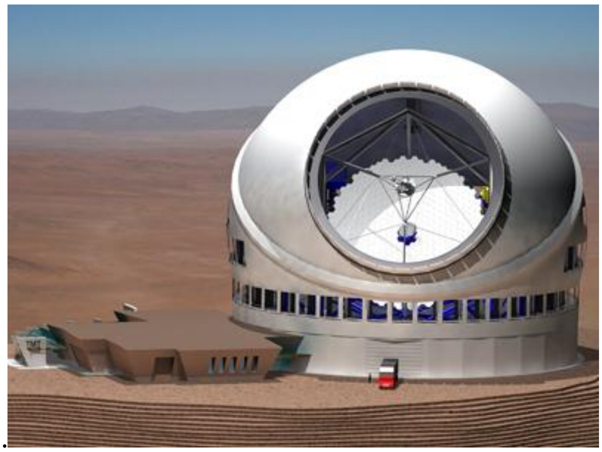


Figure 2-23. The Thirty Meter Telescope. (source: [9])

The Discovery Channel Telescope (DCT) dome houses and protects the telescope from the natural environment. When observing, the dome will follow the telescope movement and shield the telescope from wind and stray light. When not observing, the dome shutter and ventilation doors will be closed to protect the telescope from high winds, dust, and precipitation. During the day, the dome will be closed to insulate the telescope and observing space. During observing, the telescope shutter and ventilation doors will be open to allow maximum flushing of air through the facility.

Figure 2-24. The Discovery Channel Telescope (DCT) dome**.** (source: [9])

At Paranal Obervatory can be found some littles telescopes, The Very Large Telescope Interferometer (VLTI). VLTI uses multiple telescopes to synthesize a single larger telescope. The dome is like petals of flowers, this type of dome allows an easy opening, also a simply design. [9]

[9]Desroches L., 2003, Telescope Domes.

Figure 2-25. Four little telescopes at Paranal Observatory, Chile. (source: [9])

2.2.3.-GUIDELINES FOR DESIGN

Two main technical requirements are to be accomplished when designing an enclosure for a telescope, a *complete protection* of the telescope itself and its instrumentation, and a minimal *seeing affectation*. These two aspects are in fact the need from which every project has to take over and develop. But even in the case one could accomplish the above requirements as close be achieved this “other requirements-fabrication”, operation and maintenance cost, structural behaviour, etc, can be in fact the responsible of the final selection adopted since the two initially presented are in a very close level for the most commonly selected dome and building alternatives, especially the cylindrical and spherical alternatives for the telescope dome.

As it has been already identified not all the requirements are equally weighted and also not all of them are equally attainable, but once a list of requisites have been set up the important matter is to know each alternative is able to meet them and evaluate from study a final recommendation on the design solution.

Innovative design of enclosures are being studied for the generation of large telescopes which are currently being developed, essentially in order to keep cost from increasing unacceptably with the size of the telescopes. These studies and the generally positive experience with MM-type buildings, largely open to the wind during observation times, are confirming the trend toward a radical change of philosophy in the concept for telescopes enclosures, which recognises that in many cases the open air environment is more favourable to optimum telescopes operation tan the nominally stable and controlled environment inside a classical dome.

For dome selection, there are several parameters that should be taken in consideration, although a large number of parameters for the comparison of the alternatives would lead to a higher precision, a good accuracy with a limited number of parameters can be reached if these have been carefully selected with an additional economy of time and efforts.

The possible parameters to decide which alternative gives the best solution can be classified as follows.

*2.2.3.1.-**Cost***

- The design and manufacture for the structure and of its principal components (shutter, windows, wind protectors, etc.).
- The integration, test and assembly costs should be made at the site or not.

- Cost associated with the different dome types with regard to operation and maintenance during the life-cycle of the installation (a special mention shall be made for the air volumes that would have to renovate on each typology - related to the air conditioning power consumption).

*2.2.3.2.-**Time***

- The time needed to manufacture the structure and of its principal components.
- The time needed to make test and assembly of the structure and of its principal components at the site or not (if not time of transportation).

*2.2.3.3.-**Manufacture***

- Viability of manufacture by the national and/or local industry of the dome structure, main components and mechanisms.
- Suitability of installation and control of a natural ventilation system for each typology

*2.2.3.4.-**Structural Behaviour***

- Structural strength of the rotating structure and the shutter assembly due to their geometry and to the stress distribution on them.
- Feasibility for natural ventilation windows embodiment on the dome structure without affecting its strength. Suitability for dimension and location variations of these apertures.

- Vibrations induced by air flow onto the dome structure due to its aero dynamical behaviour.
- Stability in withstanding severe wind conditions as well as possible seismic tremors.

2.2.3.5.-*Supportability*

- Ease of access for the operation and maintenance of the telescope optics, telescope mechanisms and driving systems, instrumentation and the dome itself.
- Feasibility for instrument changes at the focal stations.
- Feasibility of the dome to install on it manipulation systems as cranes, elevators, platforms, etc.
- Dome movement by an easy and well trusted mechanism guarantying the established dynamic requirements, in terms of velocity, acceleration, stop margin and non-transmission of vibrations to the telescope.
- Suitability for telescope assembly.

2.2.3.6.-*Protection against adverse weather conditions*

- Risk of snow and ice falling into the telescope chamber when opening the shutter in winter –related to the dome shutter opening.
- Comparison of the snow, ice and wind loads that could be produced on each of the dome types.

- Comparison of water and dust proofing efficiency for each typology.

*2.2.3.7.-**Operation***

- Air flushing capability for the natural ventilation system offered by each typology.
- The up-lift effect on each typology. (Up-lift refers to the part of the air flow that rises over an obstacle rather than going around it. The raising of the turbulent conditions of the surface layer up to higher heights can lead to an affectation of the telescope image quality). [10]

[10] Gran Telescopio Canaria, 1998, Selection Telescope Dome

3.-DOME DESIGN

In this project a spherical dome will be designed and calculated, because maybe is the most common structure used as a protection structure for a telescope and its instruments involved. This kind of dome can be used to protect several types of telescopes, as Refracting telescopes, Newtonian Telescopes and Catadioptric telescopes, with the most popular designs, Maksutov-Cassegrain and Schmidt-Cassegrain. Obviously, the size of the telescope must be suitable for the size of the dome.

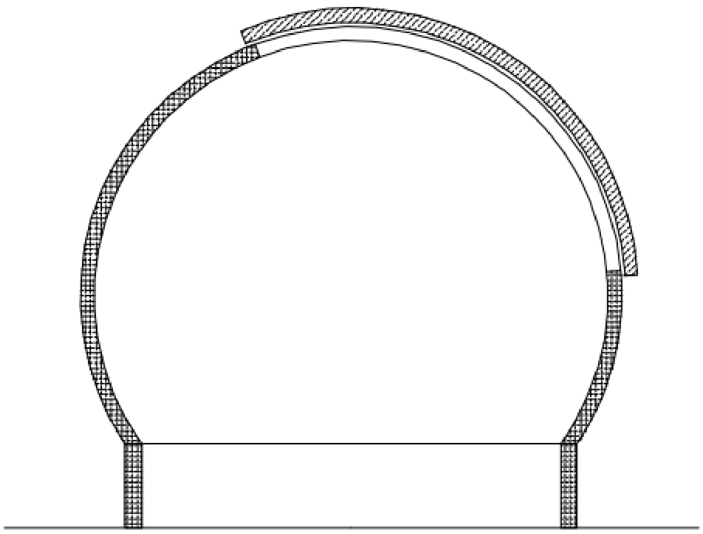


Figure 3-1. Spherical dome (cross section).

The dome selection process depends strongly of the dome performance related to its shutter concept. For the spherical shape, the shutter concept has a direct consequence on the telescope chamber volume, diameter of the dome supporting ring, etc. Therefore, several alternatives can be set up related to its shutter geometry:

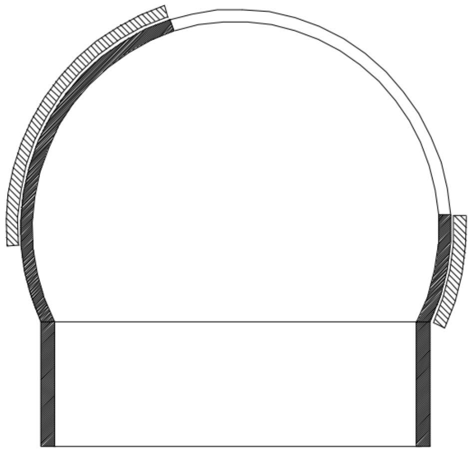


Figure 3-2. Double door shutter (traditional arrangement) (option 1).

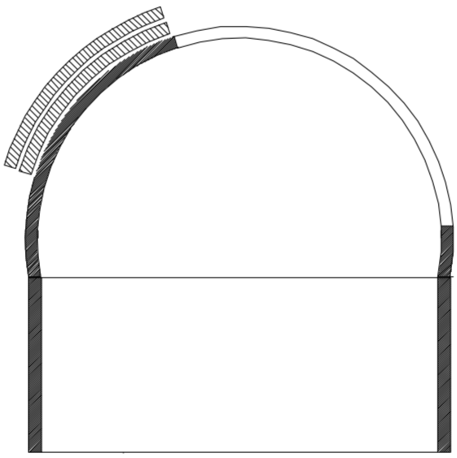


Figure 3-3. Double door shutter (telescopic arrangement) (option 2).

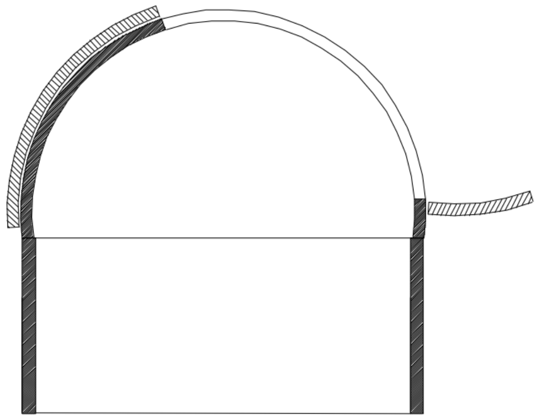


Figure 3-4. Sliding and foldable shutter arrangement (option 3).

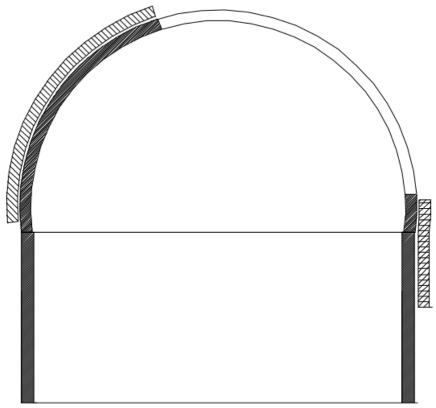


Figure 3-5. Sliding and flexible shutter arrangement(option 4).

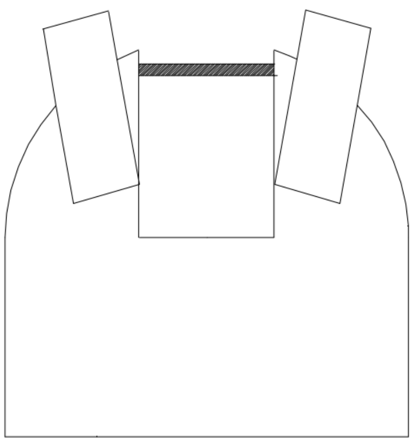


Figure 3-6. Laterally opening V doors arrangement (option 5).

For the aforementioned shutter alternatives the discussion could be summarised as follows:

1. For the spherical dome with a double cylindrical sliding shutter, a larger dome surface is required to allocate the shutter, and therefore, higher weight of the dome -and higher stresses at the rotating elements- and higher insulation and structure cost as compared to other alternatives. Furthermore, it implies a smaller carousel ring diameter -lesser dome structure stability. On the other hand the shutters have an easy and trusting driving and guiding, and their structures can be light and strong with a good tightness. Each door has a simple driving mechanism and guide-rails, it can form a single part, and it is robust, light and with sealed closure surfaces.

2. For the spherical dome with a cylindrical sliding shutter and a foldable small one, the spherical dome with two laterally opening V door or the spherical dome with a cylindrical shutter and a flexible adjustable one, the advantage obtained would be a smaller dome surface and a larger carousel supporting ring diameter also allowing observing at altitudes close to the horizon. The disadvantage would come from the non standard shutter arrangement which could not attain the desired reliability or specifications within the budget.

3. Finally, for the telescopic double door arrangement, the advantages would be those enumerated above but with the possibility to attain the desired reliability in the design of the shutter and its mechanism at an affordable cost.

The Design chosen for the shutter is the type called “sliding and flexible shutter arrangement”, it is the option 4, due to the objectives of the project, is the most common, and this is enough to get an idea how this structure behaves against wind load, thermal changes and its own weight. [11]

[11] Gran Telescopio Canaria, 1998, Selection Telescope Dome.

3.1.-Schematic design

The structure consist of a half-sphere with 5000 mm of diameter, which can be divided into 5 substructures connected one to another,

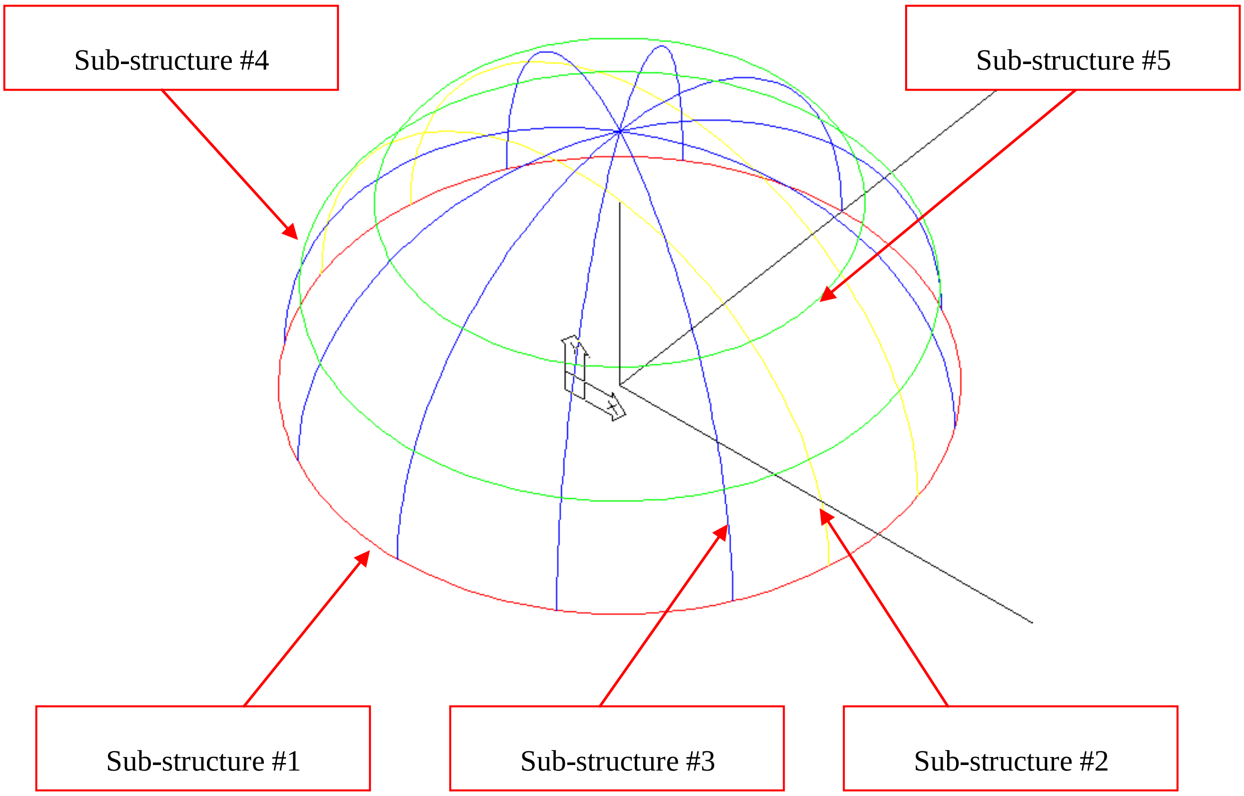


Figure 3-7. Schematic design of the dome.

- **Sub-structure #1:** is the main structure, it consists of a ring of 5000 mm in diameter, upon which is supported the whole structure of the dome. The dome can rotate in the x-z plane thanks to this structure, where there can be attached the a track with a bearing system to allow the rotation of the structure.

- **Sub-structure #2:** this structure is adjoint to the sub-structure #1 by welding joints, on this structure there will be placed the door shutter, going further with the mechanical design, 2 track guidelines to move the door along the structure. This structure consists of half of a ring of 2449.49 mm in diameter. There are 2 structures of this type, placed on the main structure within 1000 mm of width (equal to the size of the door shutter).

- **Sub-structure #3:** this structure supports or reinforces the substructure #2, and this binds substructure #1 and #2. Those 3 structures are held by welding joints. This structure is a half of a ring of 5000 mm in diameter. There are 5 structures of this types, placed at an 30º orientation of each other (see drawings for further details)

- **Sub-structure #4:** this structure keeps the sub-structure #3 in the one position and is used to place a steel sheet (to cover the dome), this sub-structures are joint by welding joints. It consists in a ring of 4693.31 mm in diameter.

- **Sub-structure # 5:** this structure keeps the sub-structure #3 in the one position and is used to place the steel sheet (to cover the dome), this sub-structures are joint by welding joints. It is made of in a ring of 3592.10 mm in diameter.

This is a preliminary design; other structures can be design if it is required. The sheet are no shown in this schematic design, Further on, the structure will be shown in 3-D with all elements and profiles used.

3.2.- 3-D design

The structure introduced previously has been designed in 3-D CAD, Pro-engineer wildfire 3.0, and the result is shown in the following pictures.

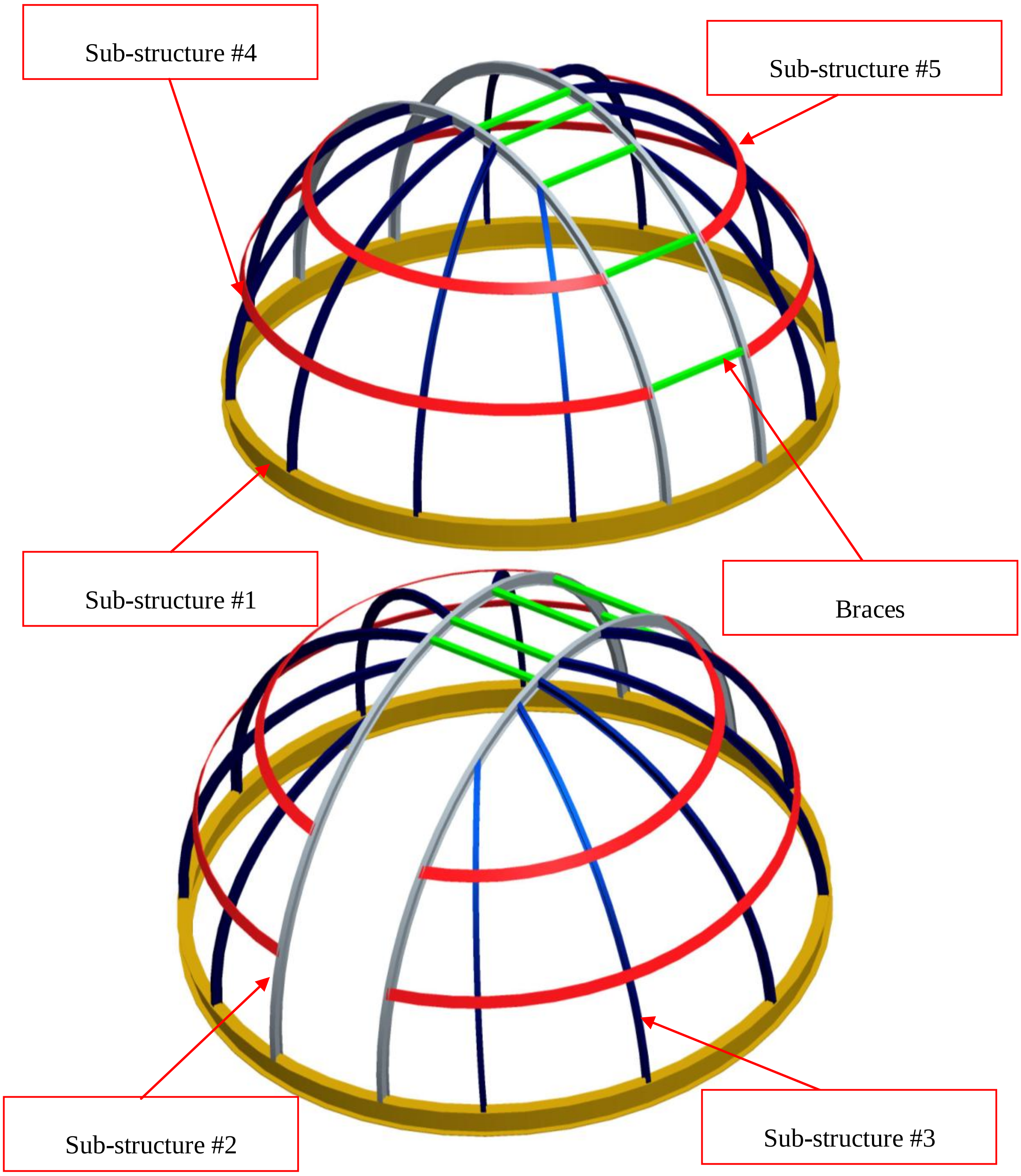


Figure 3-8. 3-D design of the dome.

The profiles used for each group of structures as shown:

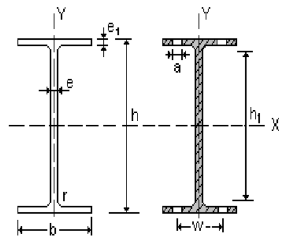
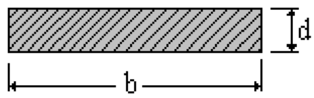
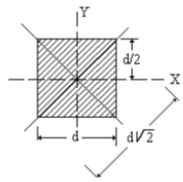
Sub-structure	Profile	Cross section
1	IPE 240	
2	IPE 100	
3	IPE 80	
4	Rectangle 100x20	
5	Rectangle 100x20	
Braces	Square 50	

Table 3-1. Profiles used in the dome.

3.2.1.-Sub-structure # 1

As it has been described before, this structure is a ring of 5000 mm in diameter, divided into 2 structures, 2 half rings of 5000 mm in diameter, adjoined by welding joints. The profile used isIPE240, which dimensions can be later found in this document as an annex. The total weight of this structure is 232,43 kg per each half-ring, it gives a total weight of 464.86 kg.

This sub-structure is adjoined with sub-structures #2 and #3, by welding joints, see pictures bellow for more details.

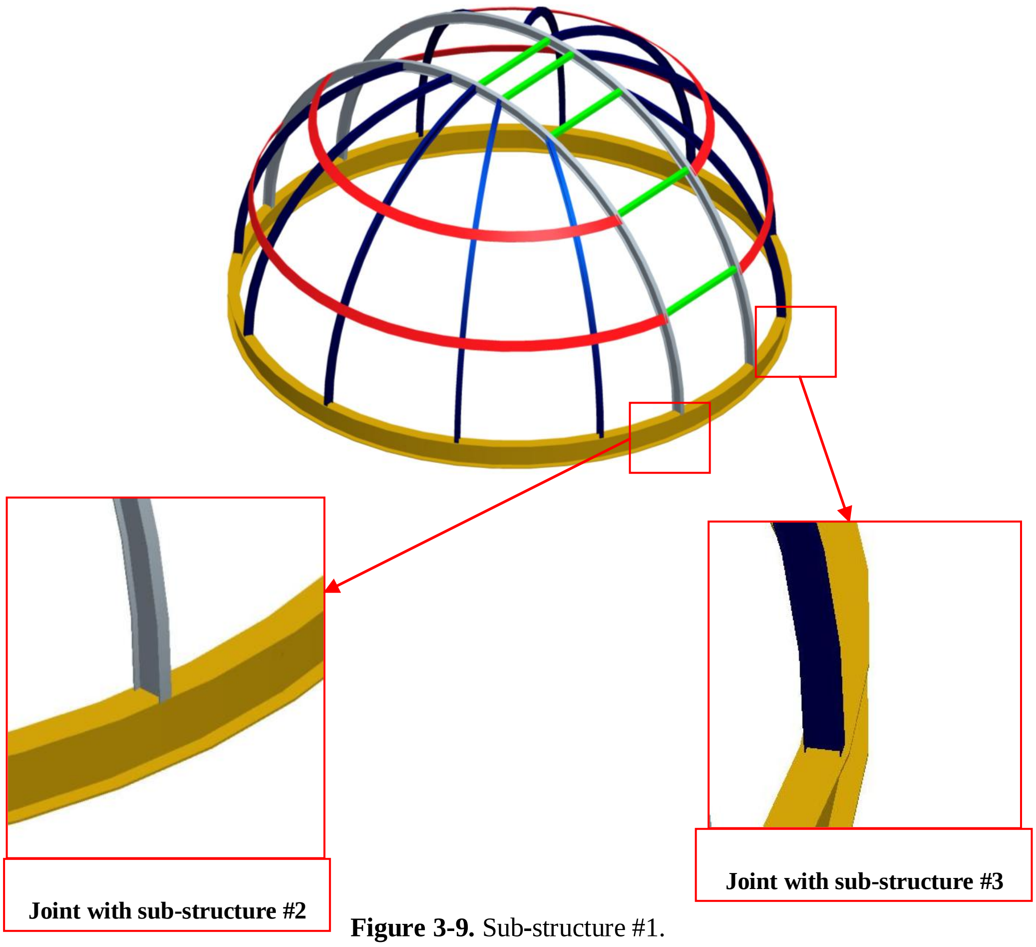


Figure 3-9. Sub-structure #1.

3.2.2.-Sub-structure #2

These profiles are attached to the sub-structure #1, and on them will be placed the door shutter. Here are two profiles IPE 100, which consist of half -ring of 2449.49 mm in diameter, located on the main structure by 1000 mm of separation between both, parallel to each other on the middle of the sub-structure #1.

The weight of each profile is 51.76 kg, making a total weight of 103.52 kg for the whole sub-structure #2.

This sub-structure is connected with all the other substructures of the dome, in the picture below such joints are shown. All joints are by welded, (not visible in the 3-D model).

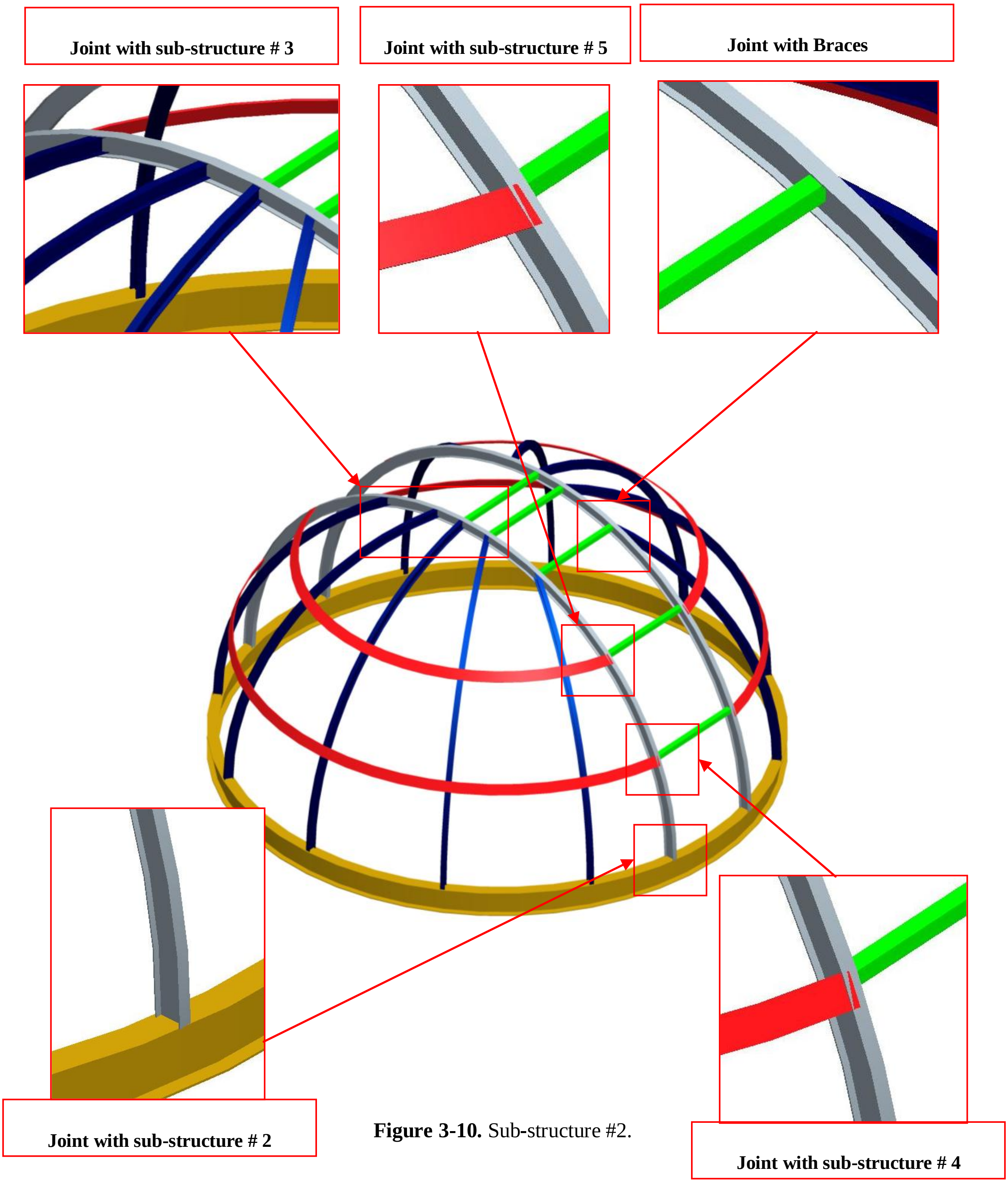


Figure 3-10. Sub-structure #2.

3.2.3.-Sub-structure # 3

This structure connects the sub-structure #2 with the sub-structure #1, as well as keeping the position of sub-structure #2, with regard to the main structure of the dome. Also on top of it are placed the sheets steel that cover the dome (not represented in the 3-D model).

This substructure consists of IPE 80 profiles, with several shapes and lengths (for further details see the drawings), but in general it is a profile curved with 5000 mm in diameter. In total there are 10 profiles for this sub-structure conveniently located on sub-structure #1 and #2.

The weight for this sub-structure is approximately 187.24 kg.

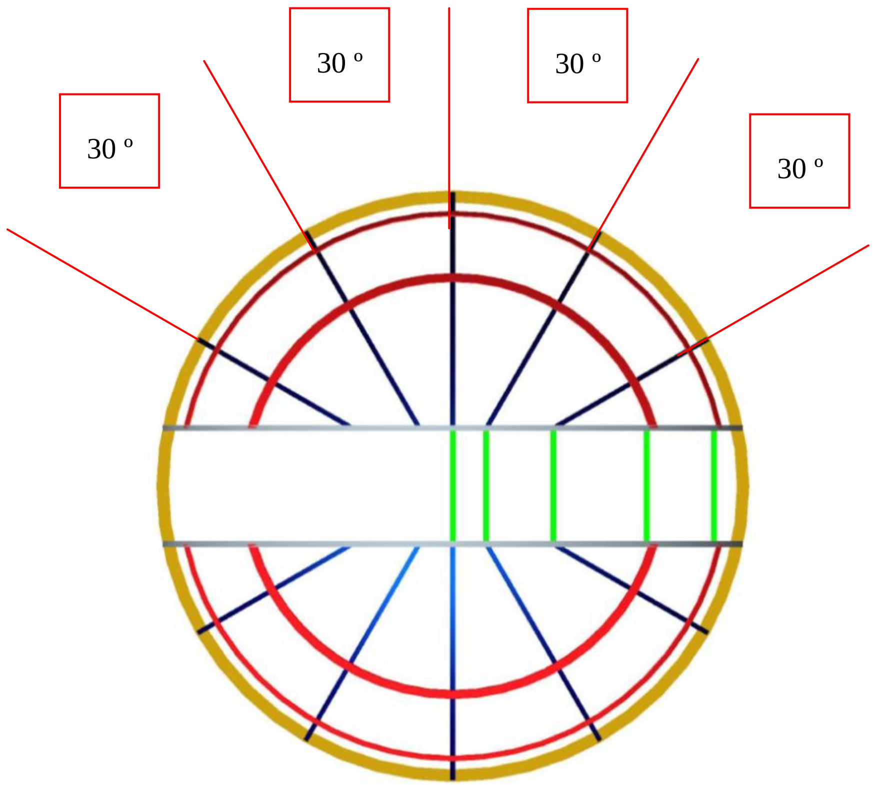


Figure 3-11. Sub-structure #3, orientation.

This sub-structure is adjoined with other sub-structures as the following:

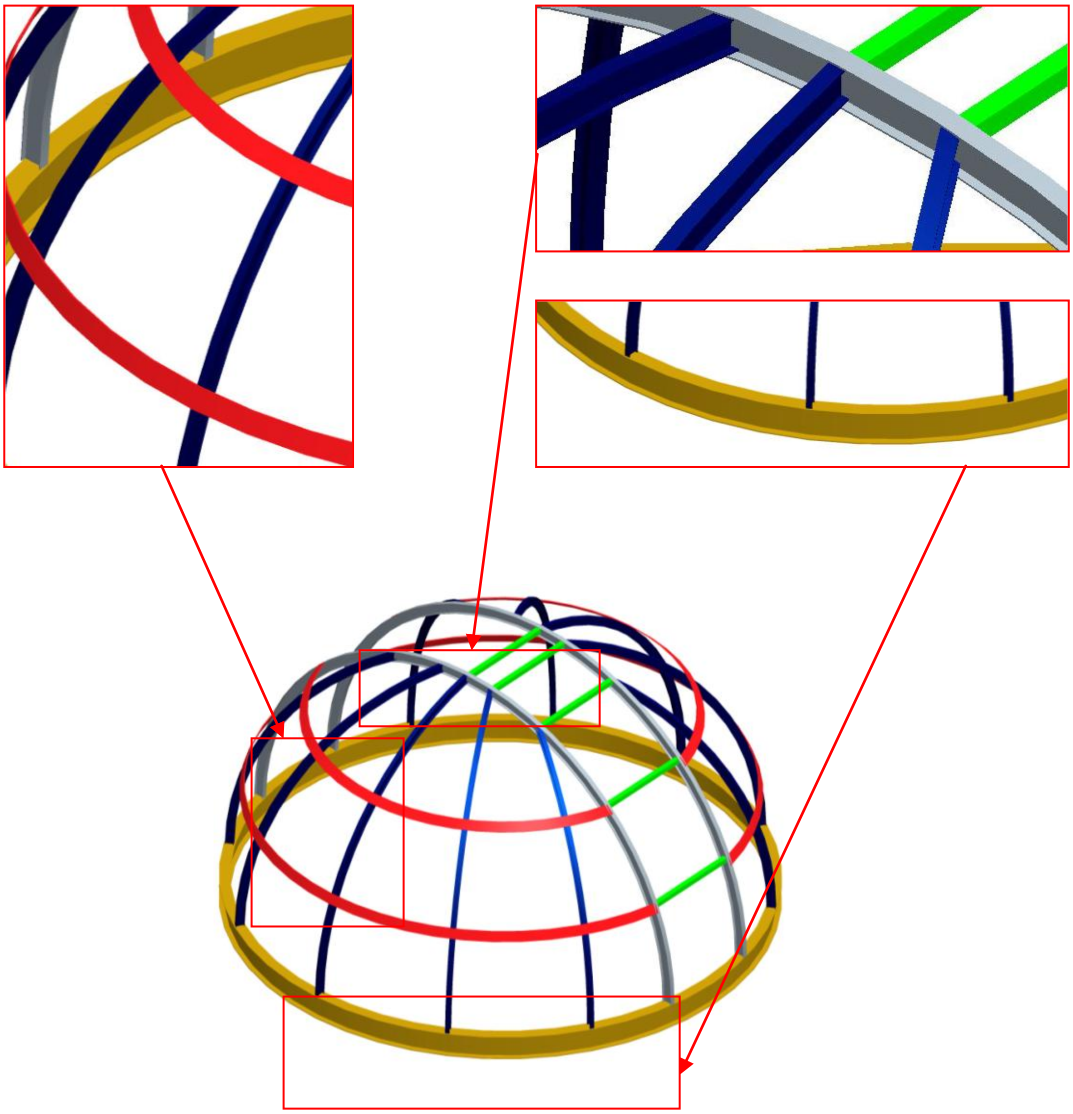


Figure 3-12. Sub-structure #3.

3.2.4.-Sub-structure # 4 and # 5

They are profiles in rectangular shape of 100x20 mm^2, located on the sub-structure # 3, and also adjoined to the sub-structure # 2, all joint by welding joints. Both sub-structures consist of rectangular profiles curved into two different diameters, 4693.21 mm and

3592.10 mm for sub-structure # 4 and # 5 respectively. Both sub-structures weigh of 115.6 kg and 88.48 kg, for sub-structure # 4 and # 5 respectively, giving a total of 204.8 kg. (For further details about geometry, see the drawings).

*3.2.4.1.-**Braces***

These Braces have been designed in the 3-D model to give more capacity to the dome but mainly to keep the sub-structure #2 in the correct position (1000 mm of separation). In the final model, in this part there will be a mechanism that manoeuvres the door shutter, In a case like this, it can have its own sub-structure (not objective in this project), but of most importance these Braces have been placed to give more accuracy to the calculations. Obviously in the final calculation, the structure of the mechanism and these Braces has to be equivalent.

Braces have been designed with a square shaped profile 50x50 mm^2, in total there are 5 segments of 997 mm of length, located on the sub-structure #2. They give a weight of 117.6 kg for the whole structure.

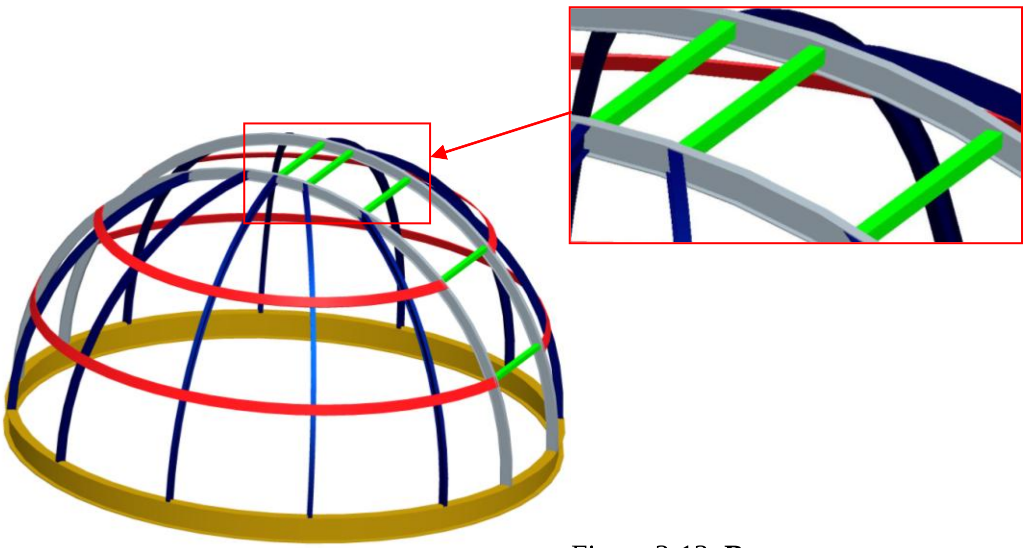


Figure 3-13. **Braces**.

*3.2.4.2.-**Data***

Sub-structure	Profile	Total length(m) *
1	IPE 240	15.71
2	IPE 100	7.69
3	IPE 80	78.54
4 and 5	Rectangle 100x20	26.03
Reinforcement	Square 50	4.99

Table 3-2. Data lengths profiles used in the dome design.

*: *total length is the minimal length of profiles needed for each sub-structure, as for they need to be cut conveniently to get the final profile to be used in the structure of the dome.*

The total weight of the whole structure, made of stainless steel (see material properties in 3.3.3.-,and only profiles and taking in account the Braces) is 989.84 kg. To this weight has to be added the weight of the sheet steel that covers the dome. In the calculations this weight is taken into account.

3.3.-Modelling in ANSYS

To make the calculations in ANSYS (software of calculation by finite element method), the structure has been created in ANSYS as lines (for profiles) and areas (for sheet steel). To draw the structure in 3-D a further process has been followed.

The units used in the calculations are mm for length, kg for mass, N for force, MPa for pressure.

3.3.1.-Modelling of the structure

Based on the 3-D model of the structure and the computer modelling of ANSYS the structure has been divided into points, lines and areas, the points drawn on ANSYS have been named as shown on the following pictures.

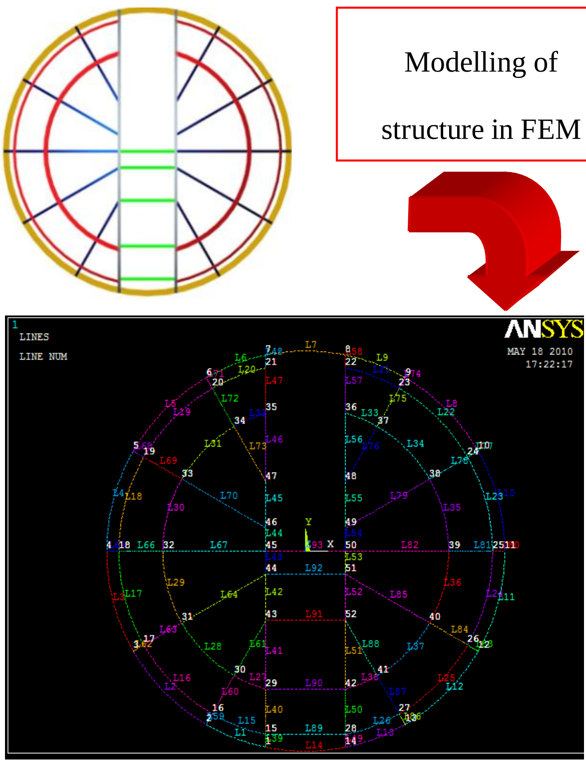


Figure 3-14. Modelling of the structure.

The points are measured in mm, and the coordinate system is located in the centre of the sub-structure #1.

Point	X	Y	Z
1	-500.00	-2449.49	0.00
2	2500.00	0.00	0.00
3	2500.00	0.00	0.00
4	2500.00	0.00	0.00
5	2500.00	0.00	0.00
6	2500.00	0.00	0.00
7	-500.00	2449.49	0.00
8	500.00	2449.49	0.00
9	2500.00	0.00	0.00
10	2500.00	0.00	0.00
11	2500.00	0.00	0.00
12	2500.00	0.00	0.00
13	2500.00	0.00	0.00
14	500.00	-2449.49	0.00
15	-500.00	-2292.77	972.02
16	2346.66	0.00	972.02
17	2346.66	0.00	972.02
18	2346.66	0.00	972.02
19	2346.66	0.00	972.02
20	2346.66	0.00	972.02
21	-500.00	2292.77	972.02
22	500.00	2292.77	972.02
23	2346.66	0.00	972.02
24	2346.66	0.00	972.02
25	2346.66	0.00	972.02
26	2346.66	0.00	972.02
27	2346.66	0.00	972.02
28	500.00	-2292.77	972.02
29	-500.00	-1725.05	1796.50
30	1796.05	0.00	1796.50
31	1796.05	0.00	1796.50
32	1796.05	0.00	1796.50
33	1796.05	0.00	1796.50
34	1796.05	0.00	1796.50
35	-500.00	1725.05	1796.50
36	500.00	1725.05	1796.50
37	1796.05	0.00	1796.50
38	1796.05	0.00	1796.50
39	1796.05	0.00	1796.50
40	1796.05	0.00	1796.50
41	1796.05	0.00	1796.50
42	500.00	-1725.05	1796.50
43	-500.00	-866.03	2291.29
44	-500.00	-288.68	2432.42
45	-500.00	0.00	2449.49
46	-500.00	288.68	2432.42
47	-500.00	866.03	2291.29
48	500.00	866.03	2291.29
49	500.00	288.68	2432.42
50	500.00	0.00	2449.49
51	500.00	-288.68	2432.42
52	500.00	-866.03	2291.29
53	-500.00	-2263.04	937.38
54	-500.00	-1732.06	1723.06
55	-500.00	-937.38	2263.04
56	500.00	-937.38	2263.04
57	500.00	-1732.06	1723.06
58	500.00	-2263.04	937.38
59	0.00	0.00	0.00

Table 3-3. Points to model the structure in ANSYS.

The lines of the structure that symbolize the beams between each point of joint in the structure were drawn as follow.

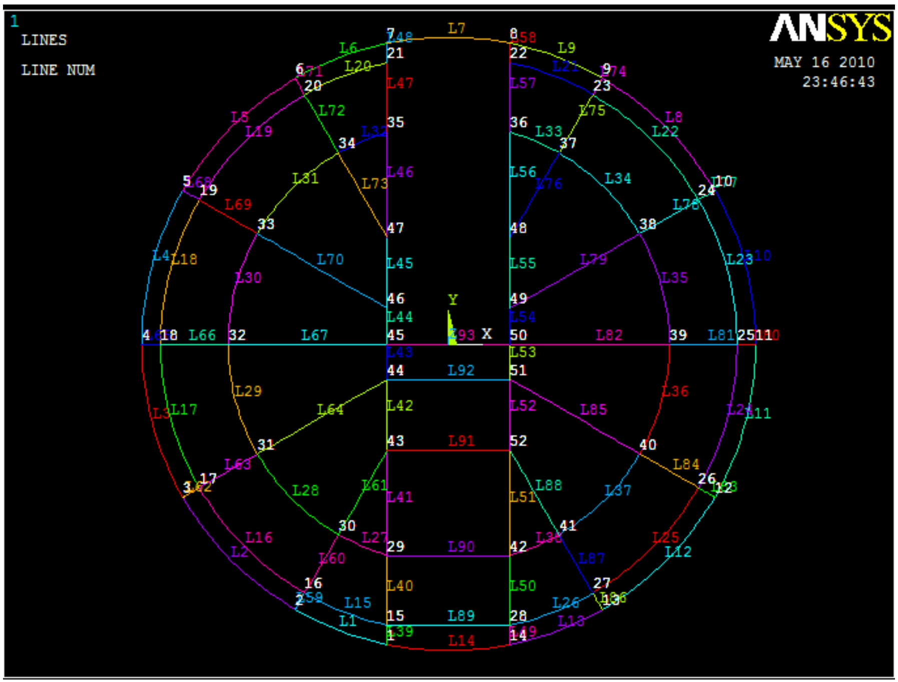


Figure 3-15. Lines (beams, 2-D view) modelling structure in ANSYS.

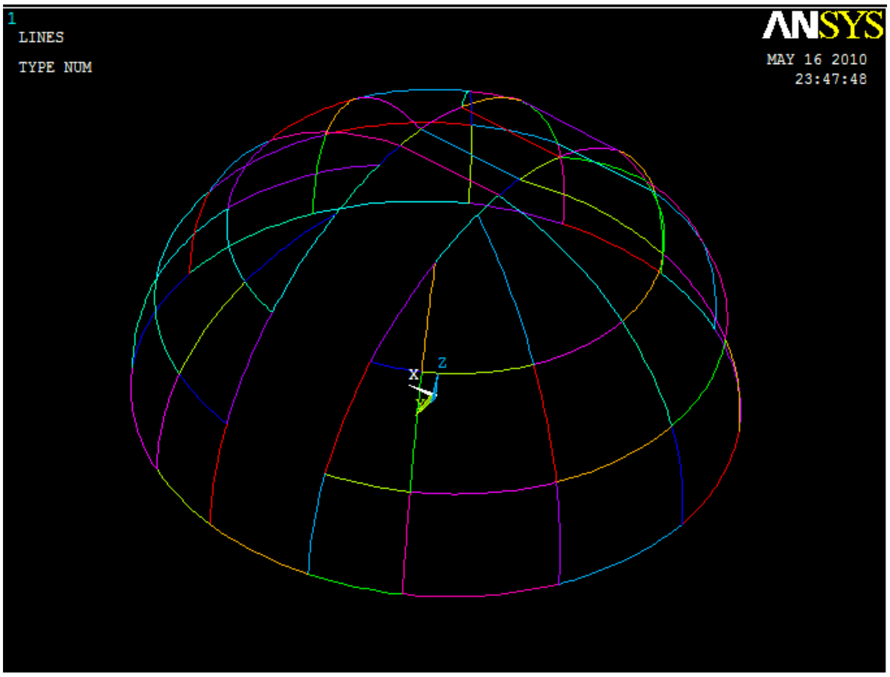


Figure 3-16. Lines (beams 3-D view) modelling structure in ANSYS**.**

To model the sheet steel on top of the dome, areas with shell properties have been used, and created exactly in that part of the structure where the sheet to cover the dome will be placed, the model looks as on the next picture:

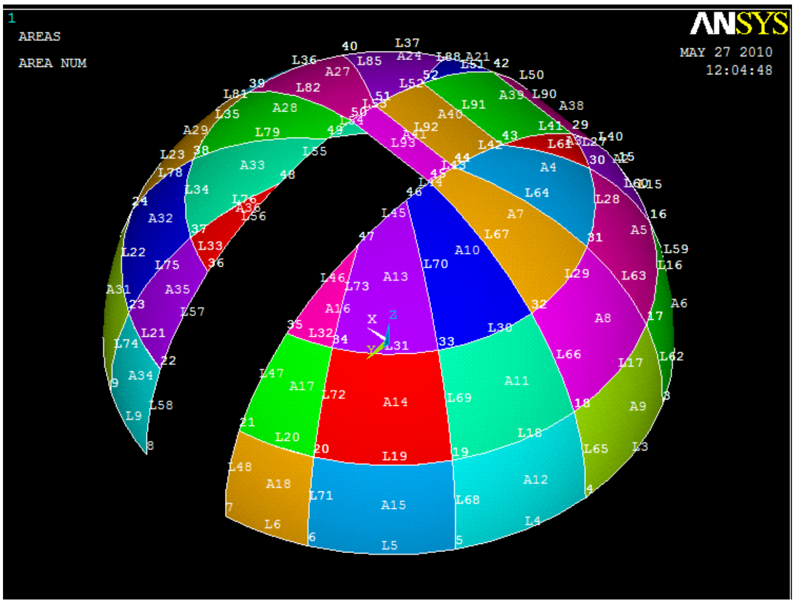


Figure 3-17. Areas (sheets, 3-D view) modelling structure in ANSYS

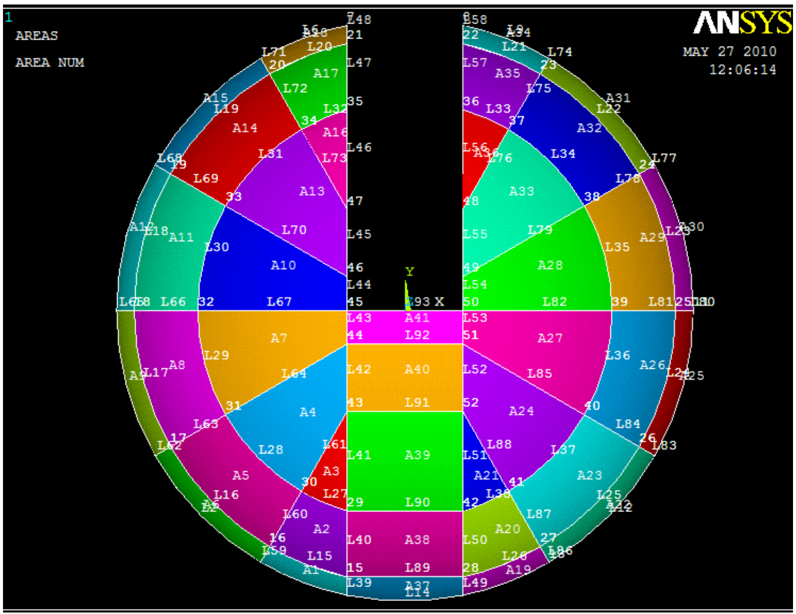


Figure 3-18. Areas (sheets, 2-D view) modelling structure in ANSYS.

3.3.2.-Elements for calculations

To model the beams in ANSYS, the element BEAM4 has been chosen; due to its characteristics it provides the best options for the required calculations

BEAM4 Element Description

BEAM4 is an uniaxial element with tension, compression, torsion, and bending capabilities. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses. See BEAM4 in the Theory Reference for ANSYS and ANSYS Workbench for more details about this element.

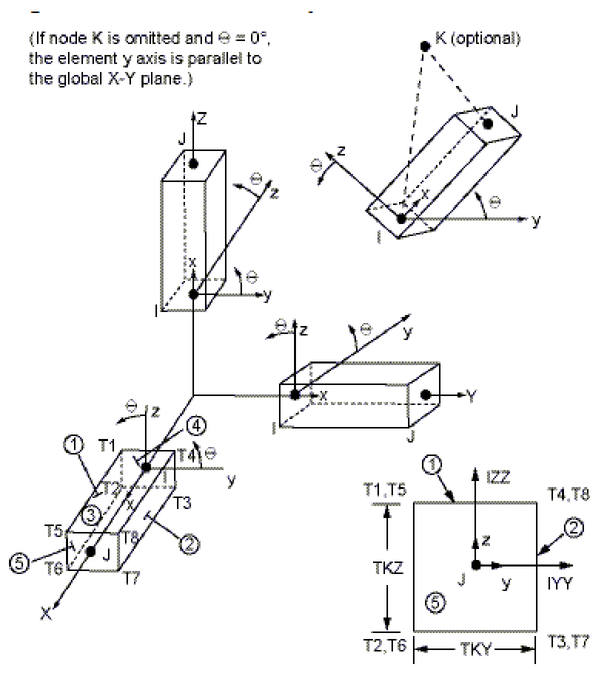


Figure 3-19.BEAM4, element description.

BEAM4 Input Summary

Nodes

I, J, K (K orientation node is optional)

Degrees of Freedom

UX, UY, UZ, ROTX, ROTY, ROTZ

Real Constants

No.	Name	Description
1	AREA	Cross-sectional area
2	IZZ	Area moment of inertia
3	IYY	Area moment of inertia
4	TKZ	Thickness along Z axis
5	TKY	Thickness along Y axis
6	THETA	Orientation about X axis
7	ISTRN	Initial strain
8	IXX	Torsional moment of inertia
9	SHEARZ	Shear deflection constant Z [1]
10	SHEARY	Shear deflection constant Y [2]
11	SPIN	Rotational frequency (required if KEYOPT(7) = 1)
12	ADDMAS	Added mass/unit length

Table 3-4.BEAM4, element description.

Material Properties

EX, ALPX (or CTEX *or* THSX), DENS, GXY, DAMP

Pressures

face 1 (I-J) (-Z normal direction)

face 2 (I-J) (-Y normal direction)

face 3 (I-J) (+X tangential direction)

face 4 (I) (+X axial direction)

face 5 (J) (-X axial direction)

(use negative value for opposite loading)

Body Loads

Temperatures --

T1, T2, T3, T4, T5, T6, T7, T8

For each kind of profile, a real constant with the cross section data has to be created, in total, for beam elements 6 real constants have been defined, with the different area properties.

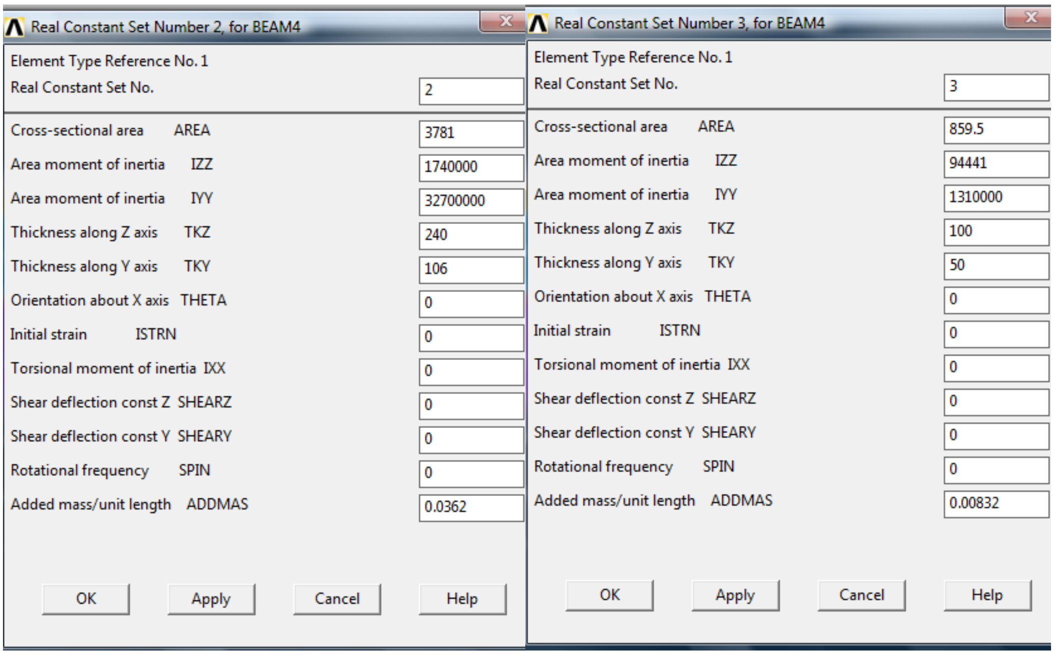


Figure 3-20.BEAM4 elements, real constants 2 and 3.

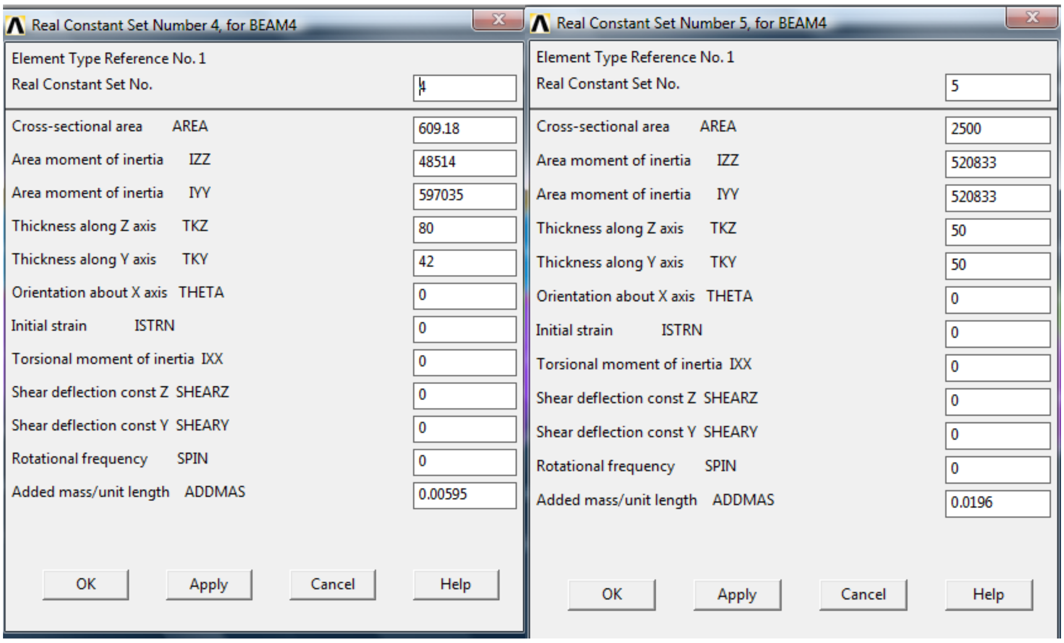


Figure 3-21..BEAM4 elements, real constants 4 and 5.

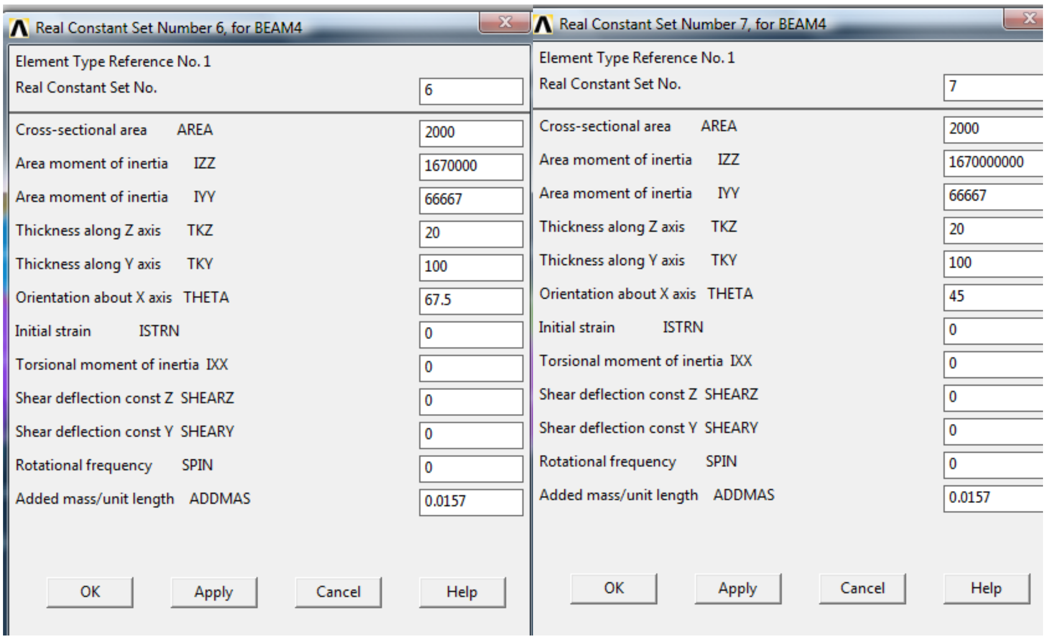


Figure 3-22..BEAM4 elements, real constants 6 and 7.

Those real constants were assigned to the structure, all lines in the ANSYS model that represent the type of beam in the 3-d model, have the same real constant.

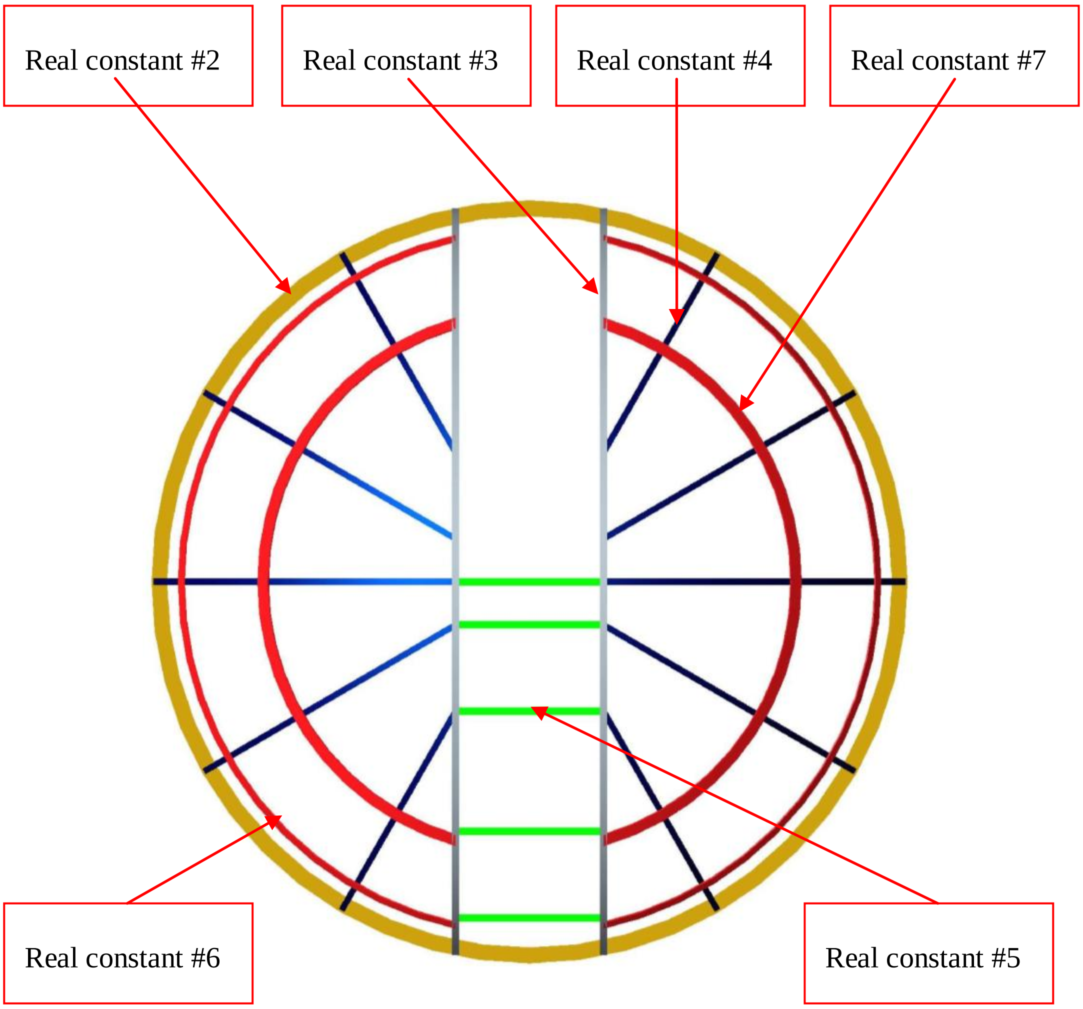


Figure 3-23. Real constants assignment.

To model the sheets in ANSYS, the element SHELL63 has been chosen; due to its characteristics make it the best options for the required calculations.

SHELL63 Element Description

SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses.

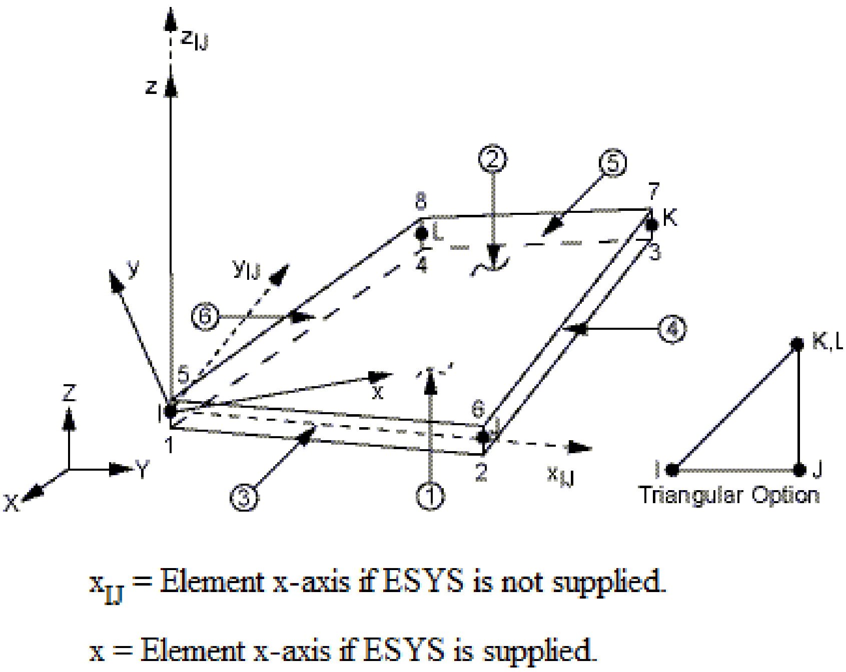


Figure 3-24.SHELL63, element description.

SHELL63 Input Summary

Nodes

I, J, K, L

Degrees of Freedom

UX, UY, UZ, ROTX, ROTY, ROTZ

Real Constants

No.	Name	Description
1	TK(I)	Shell thickness at node I
2	TK(J)	Shell thickness at node J
3	TK(K)	Shell thickness at node K
4	TK(L)	Shell thickness at node L
5	EFS	Elastic foundation stiffness
6	THETA	Element X-axis rotation
7	RMI	Bending moment of inertia ratio
8	CTOP	Distance from mid surface to top
9	CBOT	Distance from mid surface to bottom
19	ADMSUA	Added mass/unit area

Table 3-5. SHELL63, element description.

Material Properties

EX, EY, EZ, (PRXY, PRYZ, PRXZ or NUXY, NUYZ, NUXZ), ALPX, ALPY, ALPZ (or CTEX, CTEY, CTEZ *or* THSX, THSY, THSZ), DENS, GXY, DAMP

Surface Loads

Pressures

face 1 (I-J-K-L) (bottom, in +Z direction), face 2 (I-J-K-L) (top, in -Z direction),

face 3 (J-I), face 4 (K-J), face 5 (L-K), face 6 (I-L)

Body Loads

Temperatures --

T1, T2, T3, T4, T5, T6, T7, T8

The sheet for this model has been defined by a sheet of stainless steel of 5 mm of thickness, which data has been set into one real constant.

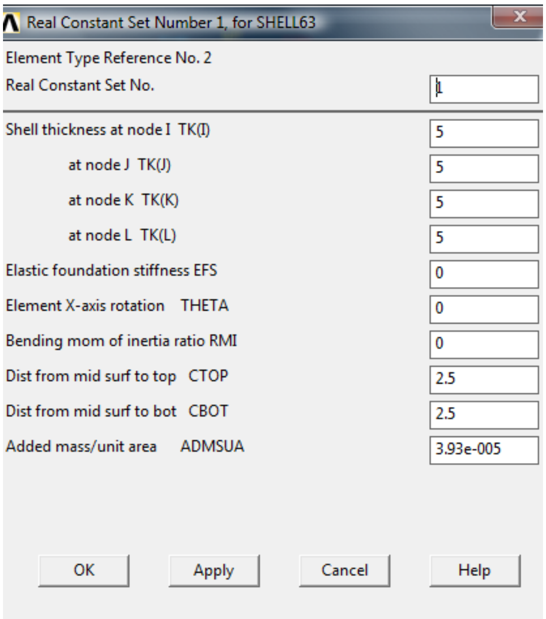


Table 3-6. SHELL63, real constant #1.

For each area this real constant #1 has been set.

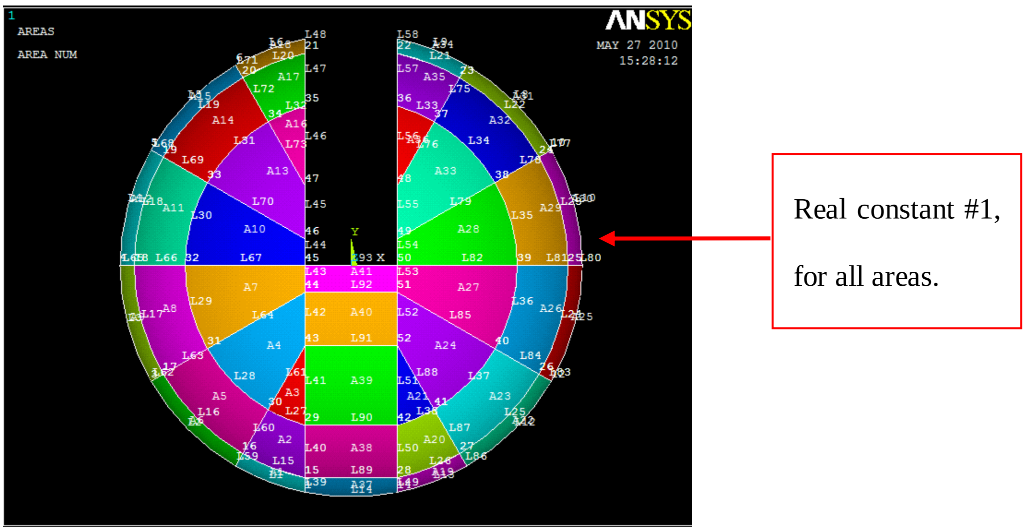


Figure 3-25.SHELL63, real constant assignment.

From figures 2.15 to 3.25 the model in ANSYS of the dome has been shown, to emphasize, lines (beams) and areas (sheets) are connected to each other in the structure analysis.

3.3.3.- Material properties

The material used in the calculation is **AISI 304, stainless steel**, with the following properties

	Temperatures (K)				
	293	195	150	80	77
Tensile strenght (MPa)*	662.3	1158.3	1287	1495.5	1508.8
Yield strenght (MPa)*	247.34	297.35	284.77	272.56	272.6
Elongation(%)	60	48	44.8	40	40
Young's Modulus (GPa)	162.34	173.06	179.26	188.60	189.33
Thermal Conductivity (k) (W/mK)	15.16	12.9	11.5	8.3	8.1
Integral conductivity (W/m)	3009.59	1622.1	1067.7	358.6	333.8
Coefficient of thermal expansion (x 10-6)Tref=293K	15.93	13.76	12.21	7.55	7.23
Specific Heat (J/kg.K)	349	298	256	125	117
Integral Specific Heat (J/kg)**	211621	56760	26567	4148	5167

Density at 293K : 7.86x10e-6 kg/mm^3.

Poisson module: 0.27

Table 3-7. Material properties for calculation.

3.3.4.-Mesh of the structure

To get good results throughout calculation, it is necessary to mesh the structure several times and compare the results with one another (stresses and displacements), if the difference between those results is less than 5-10 %, then the mesh can be assumed within the calculations.

After several calculations for area elements and lines elements, the mesh with an edge element of 50 mm in length, results in a variation between 5-10%.

This mesh used in the calculation is shown in the picture bellow and gives 31154 elements for the whole structure.

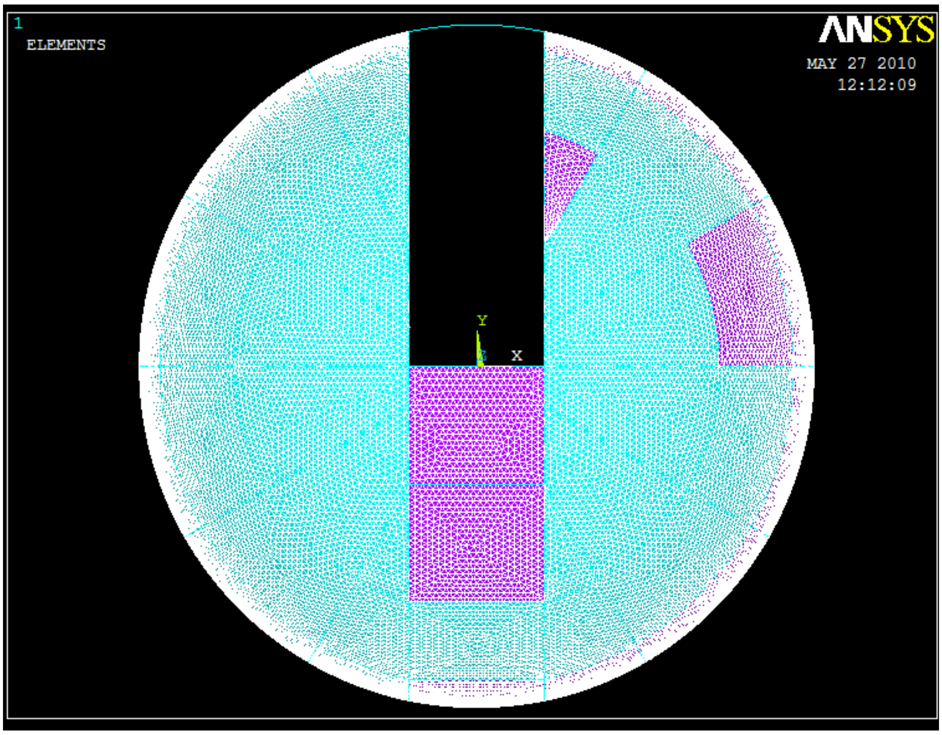


Figure 3-26. Mesh of the structure, view 1

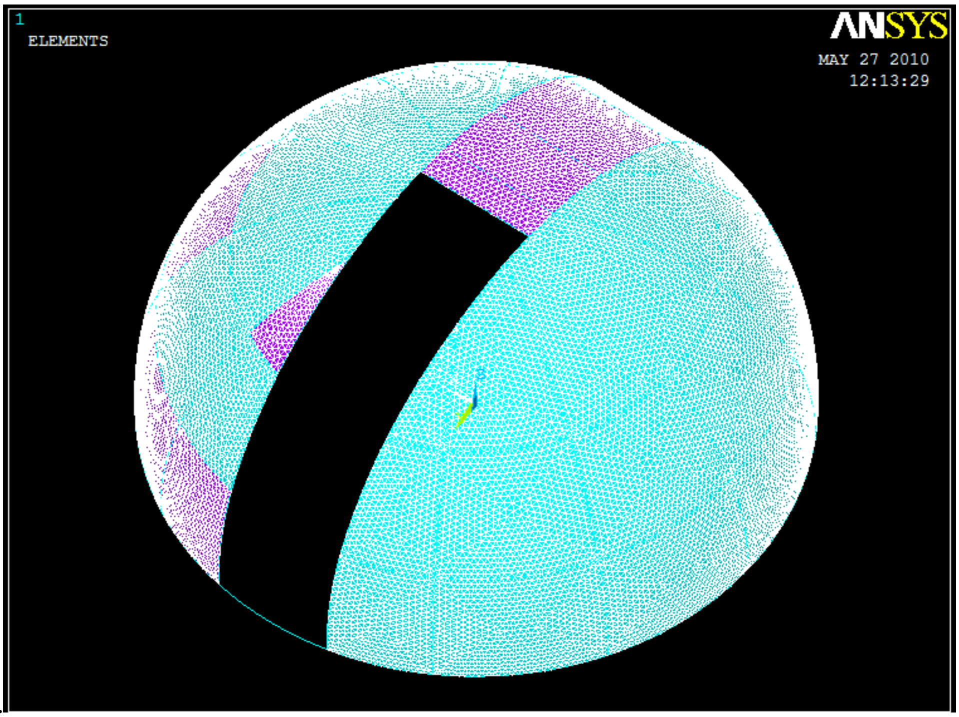


Figure 3-27. Mesh of the structure, view 2.

3.3.5.-Loading.

The calculations for the structure consist of a **static analysis of loading**, it means all loads are applied in a static case, assuming the structure does not move, and the variation of the loads with the time is sufficiently slow to assume a static case of loading.

3.3.5.1.-Boundary conditions.

The boundary conditions of the analysis applied to the structure are; the sub-structure #1 cannot move in the x-y plan, it means, the structure cannot experiment any translational displacement in the x-y plane (horizontal movement), and also the structure cannot move up or down regard to z-axis.

In this way the boundary condition is as the following picture shows.

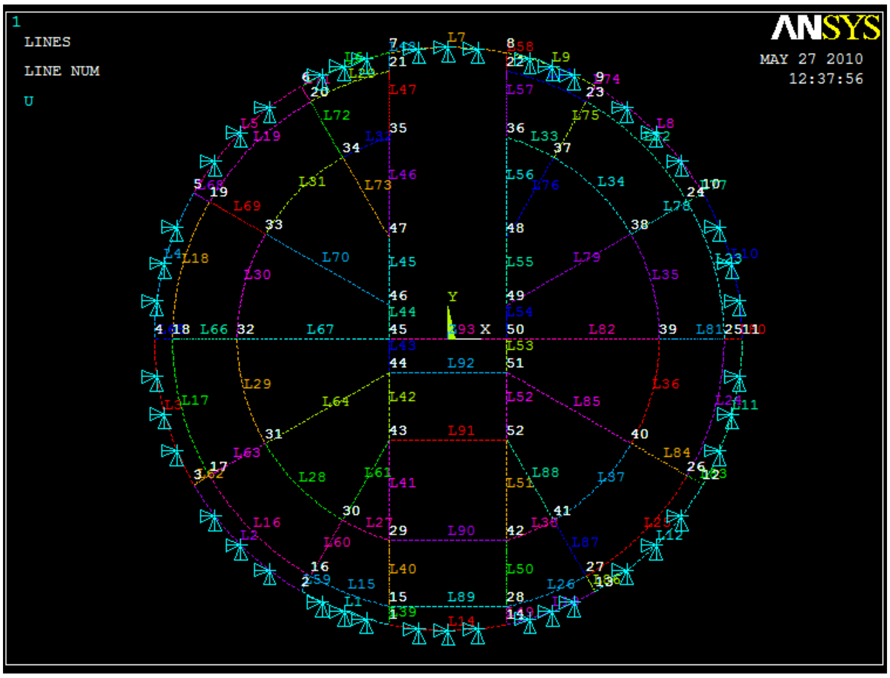


Figure 3-28. Boundary conditions analysis, view plane x-y.

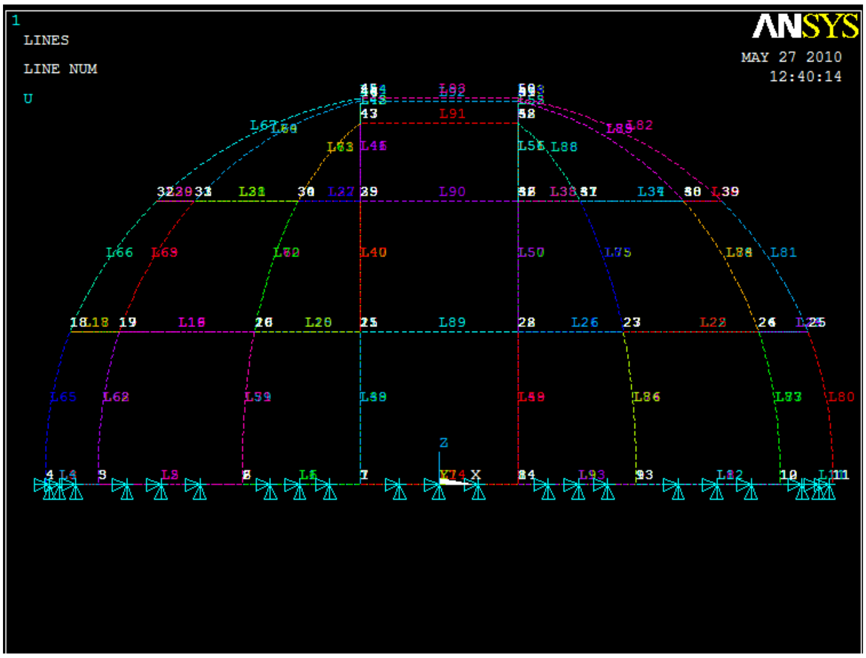


Figure 3-29. Boundary conditions analysis, view plane x-z.

Two types of loads applied have been set to the structure, temperature load and pressure load due to the wind load.

*3.3.5.2.-**Temperature Load***

In the analysis the temperature of the assembly has been assumed as +23ºC, and the temperatures that the structure can take on are, one difference of +25º C and another one of 20ºC. Obviously this difference of temperature depends strongly of the place where the dome will be used, but for this analysis, the important is to know how the structure behaves against such loads.

This temperature load will be set in lines (beam) and areas (sheets).

3.3.5.3.-Wind load

The wind load has been set as a pressure on the areas, in this case is more important the effect of this load on the structure acting through areas (sheets).

The wind load depends strongly of the place where the dome will be used, a meticulous study should be executed to know the characteristic of the wind.

In this project the wind load has been set by using polish standards, to specify the reference according to EN 1991-1-4:2005 (polish reference), all picture of wind loads have been taken from that standard.

This load has been calculated, a further process has been followed.

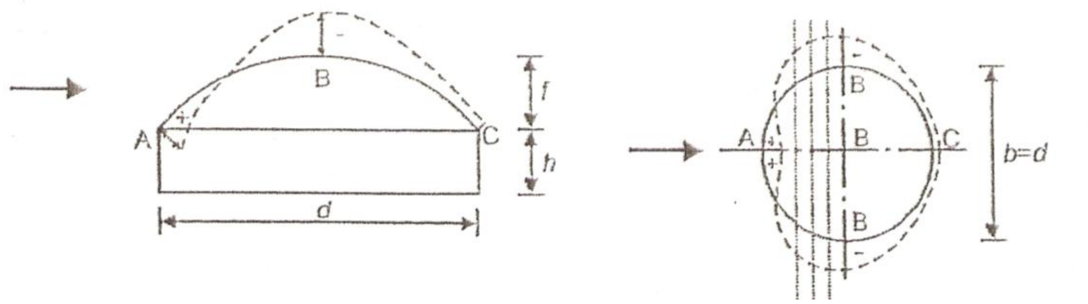


Figure 3-30. Wind load pressure.

The wind load is applied as a pressure on the structure, as Figure 3-30 shows, in this picture a cross section is shown with the wind pressure, it can be assumed as a constant in each meridian of the dome (see right side of Figure 3-30) . Looking at the pressure diagram (picture shown on the left side of Figure 3-30), in each part of the structure there has to be applied a different value of pressure regarding to the “z-position” of each point of the dome, but in this analysis this pressure is applied with a constant value in each panel, taking a lineal variation between point A, B and C.

To calculate the value of the pressure in points A, B and C, the standard used gives the following equation;

$$W_e = q_p(z_e) \times C_{pe}$$

Where

$q_p(z_e)$ C_{pe} : Characteristic wind pressure

: Coefficient

To get the characteristic wind pressure, first a place in the polish map has been chosen, in this case area 1, as the following picture shows;

Figure 3-31. Polish division of the wind load area.

Tablica NA.1 – Wartości podstawowe bazowej prędkości wiatru i ciśnienia prędkości wiatru w strefach

Strefa	$v_{b,0}$ (m/s)	$v_{b,0}$ (m/s)	$q_{b,0}$ (kN/m²)	$q_{b,0}$ (kN/m²)
	$A \le$ 300 m	A > 300 m	$A \le$ 300 m	A > 300 m
1	22	$22 \cdot [1 + 0{,}0006\,(A - 300)]$	0,30	$0{,}30 \cdot [1 + 0{,}0006(A - 300)]^2$
2	26	26	0,42	0,42
3	22	$22 \cdot [1 + 0{,}0006\,(A - 300)]$	0,30	$0{,}30 \cdot [1 + 0{,}0006(A - 300)]^2 \cdot \left[\frac{20000 - A}{20000 + A}\right]$
UWAGA: A – wysokość nad poziomem morza (m)				

Figure 3-32. Polish division of the wind load area, data**.**

Regarding to the Figure 3-32, the value of the characteristic wind pressure is

$$q_p = 0.30\ {}^{KN}/_{m^2}$$

This value has to be multiplied for other factor, this factor depends of the category of the land, the following picture shows this factor, in this analysis the category of the land is the II category. Taking the height of the building (where the dome could be placed) as 10 m.

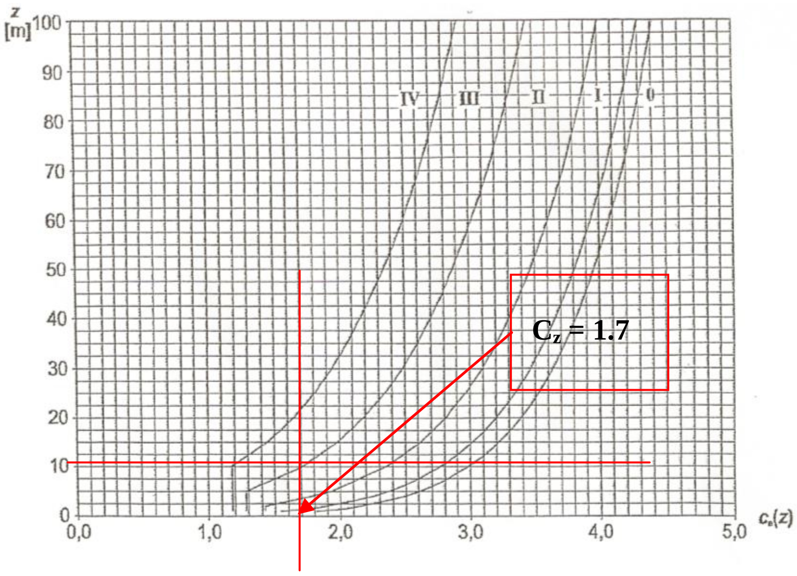


Figure 3-33. Category of the land for the wind pressure characteristic value.

In this way, the characteristic wind pressure is;

$$q_p(z_e) = 1.7 \times 0.30 \; {}^{KN}/_{m^2} = \; 0.51 \; {}^{KN}/_{m^2}$$

To calculate the accurate coefficient the following steps have to be followed; this coefficient depends of the point of the structure that the wind load pressure is calculated, points A, B and C in picture Figure 3-30.

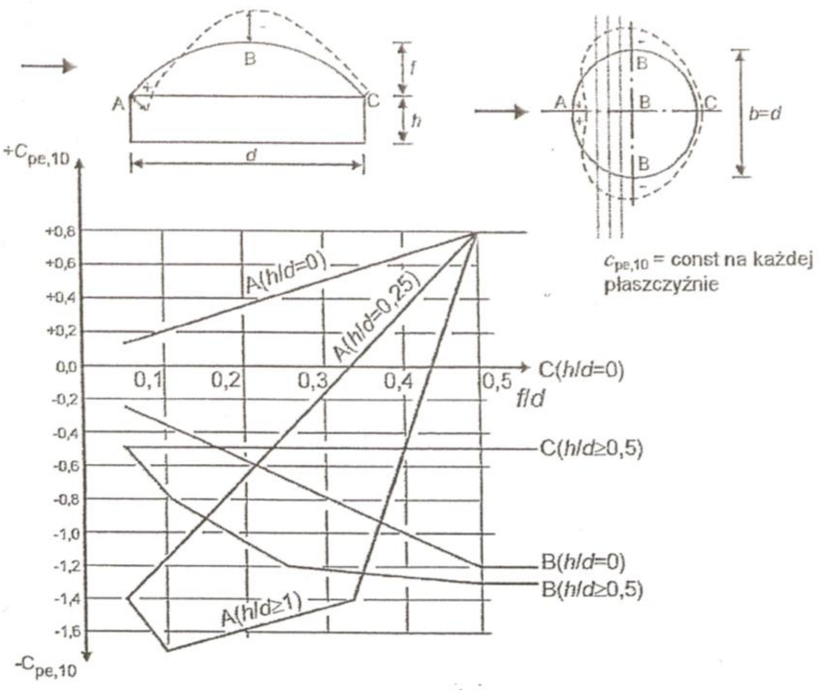


Figure 3-34. Calculation of the Cpe coefficient.

- **For the point A:** h/d= 0 (Location of the point, shape of the structure),and f/d = 0.5 (spherical shape), this gives in the diagram $\mathbf{C_{pe}}$ **= +0.8.**

- **For the point B:** h/d= 0 (Location of the point, shape of the structure),and f/d = 0.5 (spherical shape), this gives in the diagram $\mathbf{C_{pe}}$ **= -1.2.**

- **For the point C:** h/d= 0 (Location of the point, shape of the structure),and f/d = 0.5 (spherical shape), this gives in the diagram $\mathbf{C_{pe}}$ **= 0.**

Once all values have been obtained, the results are shown in the following table.

Point Structure (regarding Figure 3-30**)**	$q_p(z_e)$	C_{pe}	$W_e = q_p(z_e) \times C_{pe} \, {}^{KN}/_{m^2}$
A	0.51	+ 0.8	+ 0.408
B	0.51	- 1.2	- 0.612
C	0.51	0	0

Table 3-8. Wind load calculations.

How is the wind load pressure applied to the structure?

The wind during the day, week, year appears from different directions, and the dome can be oriented in a lot of different directions against the wind, due to it, so many cases of load can be studied in the analysis, to simplify the calculations, some presumptions have been assumed.

- The direction of the wind regarding to the structure is only as one, this direction has been assumed as the Figure 3-35 shows.

- The wind pressure is applied to the structure as a normal pressure in each area.
- Each area regarding to the "z-position" has one constant pressure value, following the pressure diagram in Figure 3-34. This values are shown in the Figure 3-36.

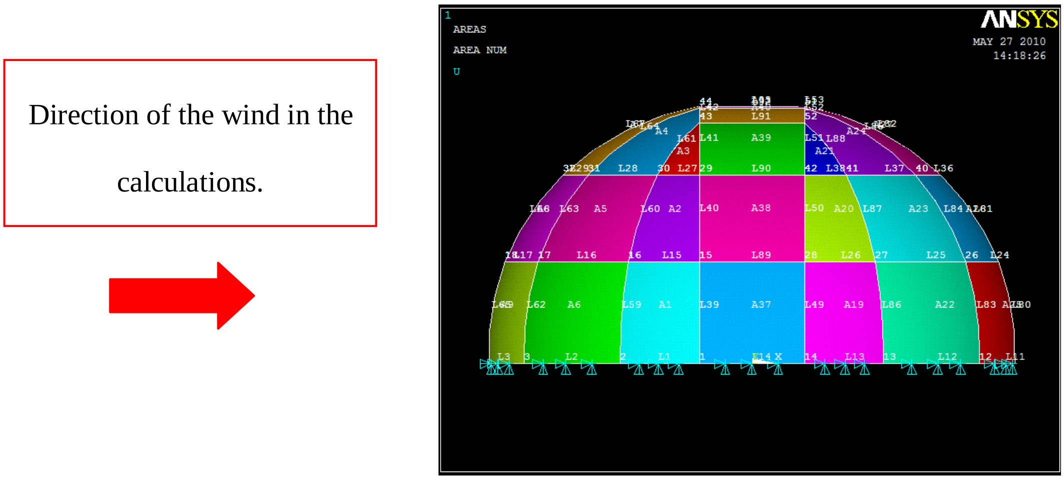


Figure 3-35. Direction of wind assumed in the calculations, regarding to the orientation of the dome.

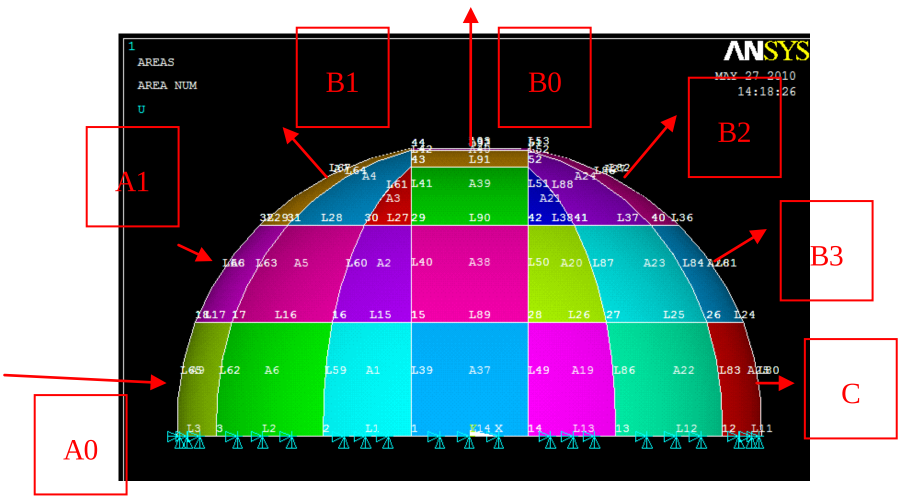


Figure 3-36. Wind Pressures applied to the structure.

To calculate the values of the pressures shown in Figure 3-36, a lineal variation between each point has been assumed, and a positive value of the pressure means, from outside of the structure to inside, “pushing the areas”, and a negative value means, from the inside to the outside of the structure, “pulling the areas”.

The results are shown in the next table.

Pressure point	Value (KN/m^2)
A0	+ 0.408
A1	0
B0	-0.306
B1	-0.612
B2	-0.408
B3	-0.204
C	0

Table 3-9. Pressure wind values.

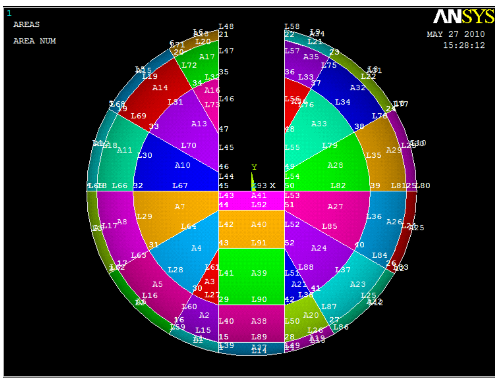


Figure 3-37. View areas of dome to apply wind pressures**.**

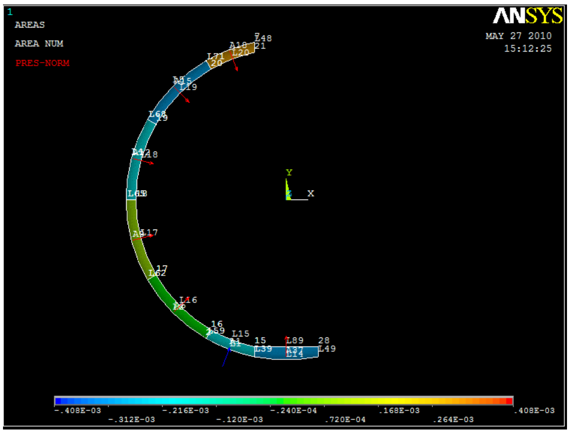


Figure 3-38. Areas to apply pressure A0.

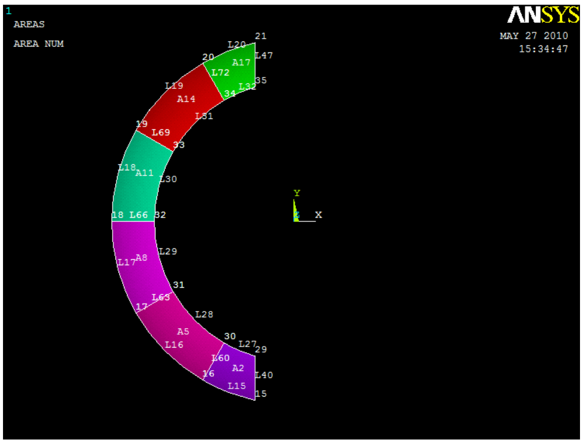


Figure 3-39. Areas to apply pressure A1.

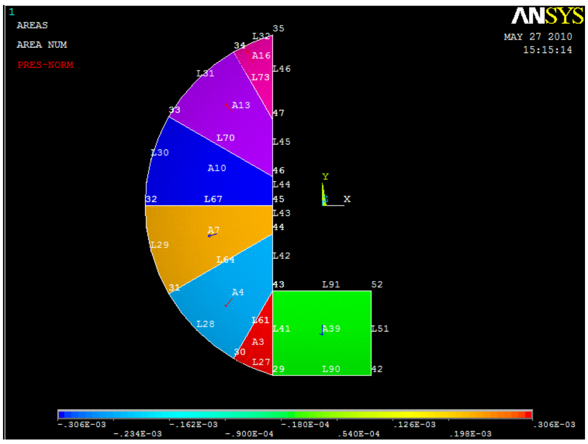


Figure 3-40. Areas to apply pressure B1.

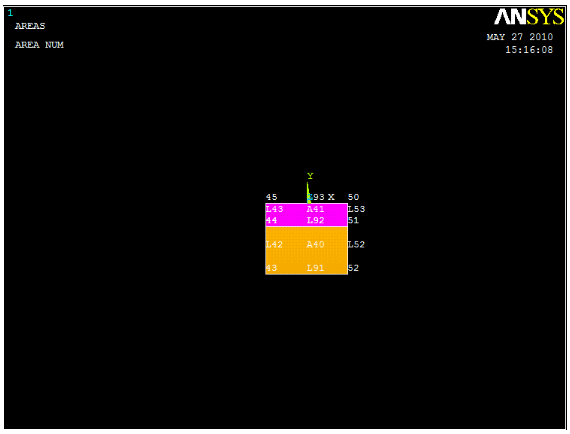


Figure 3-41. Areas to apply pressure B0.

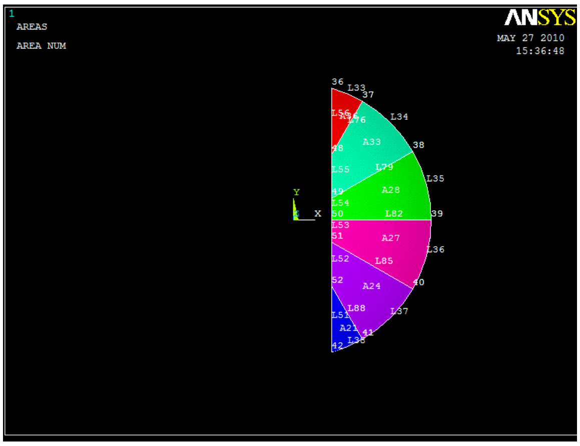


Figure 3-42.Areas to apply pressure B2.

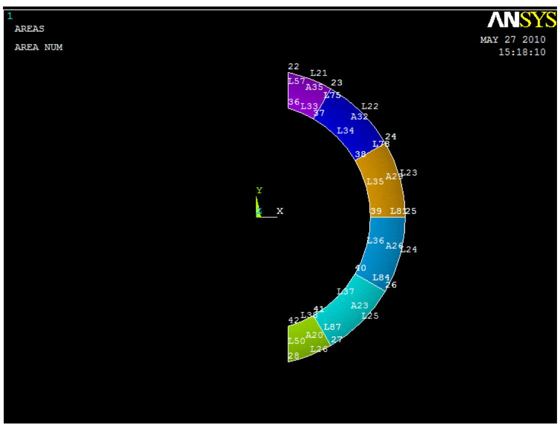


Figure 3-43. Areas to apply pressure B3**.**

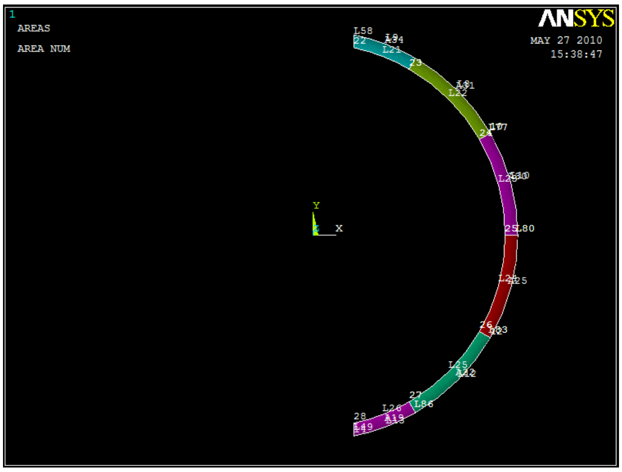


Figure 3-44. Areas to apply pressure C.

Once the values of temperature load and wind pressure have been calculated, two different cases of load are analysed,

Load Case	Loads
1	(Temperature difference = +25ºC) + wind pressure + own weight of the structure
2	(Temperature difference = -20 ºC) + wind pressure + own weight of the structure

Table 3-10. Loading cases.

3.4.-Results of the calculations.

3.4.1.-Load Case 1.

3.4.1.1.-Displacements

The calculations made for this load case give the subsequent results.

For the displacement vector sum, the maximum is 1.224 mm. This maximum value is located in the zone where the mechanism to move the door shutter will be installed, in general the structure is expanded. See Figure 3-45, this is shows with the red colour. The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underforrmed model (white colour). The units for displacement are measured in mm.

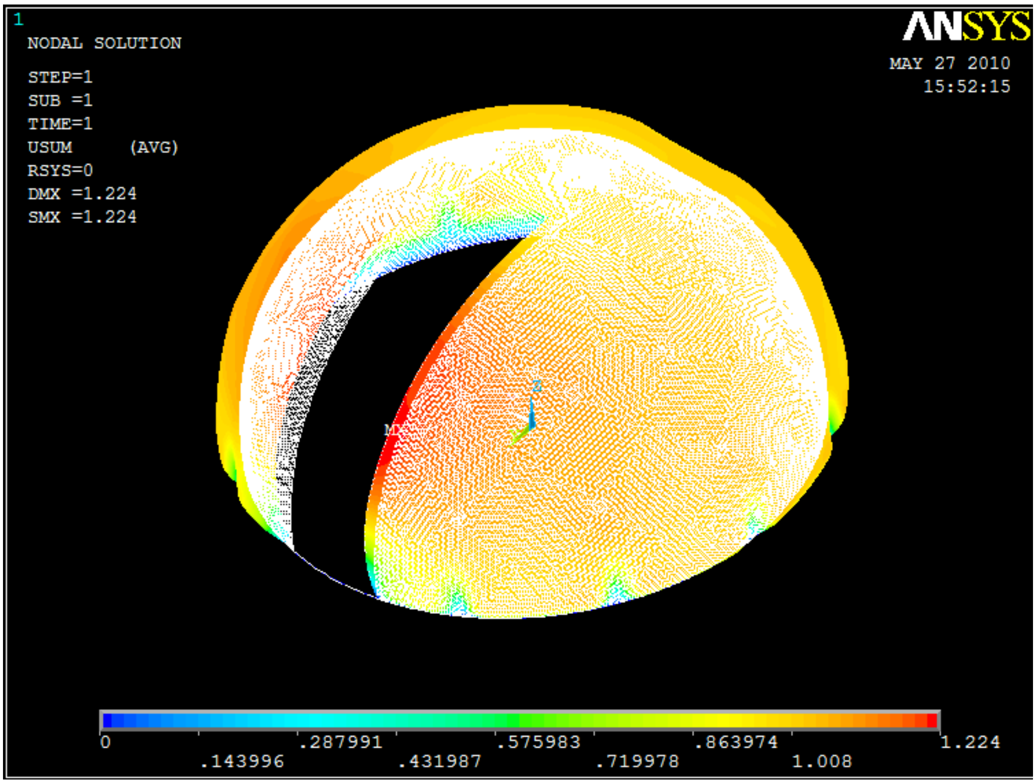


Figure 3-45. Load Case 1, Displacement vector sum.

For the x-component displacement vector, the maximum values are +1.035 mm and -1.038 mm, these maximum values are located as the Figure 3-46 shows, red colour for +1.035 mm and blue colour for -1.038 mm. In the zone where the mechanism moves the door shutter will be installed, the displacement in x-axis is between -0.5 and 0.5 mm, located respectively in each side of the structure. This means that the clearance for the door shutter is expanded approximately 1 mm. The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underforrmed model (white colour). The units for displacement are measured in mm.

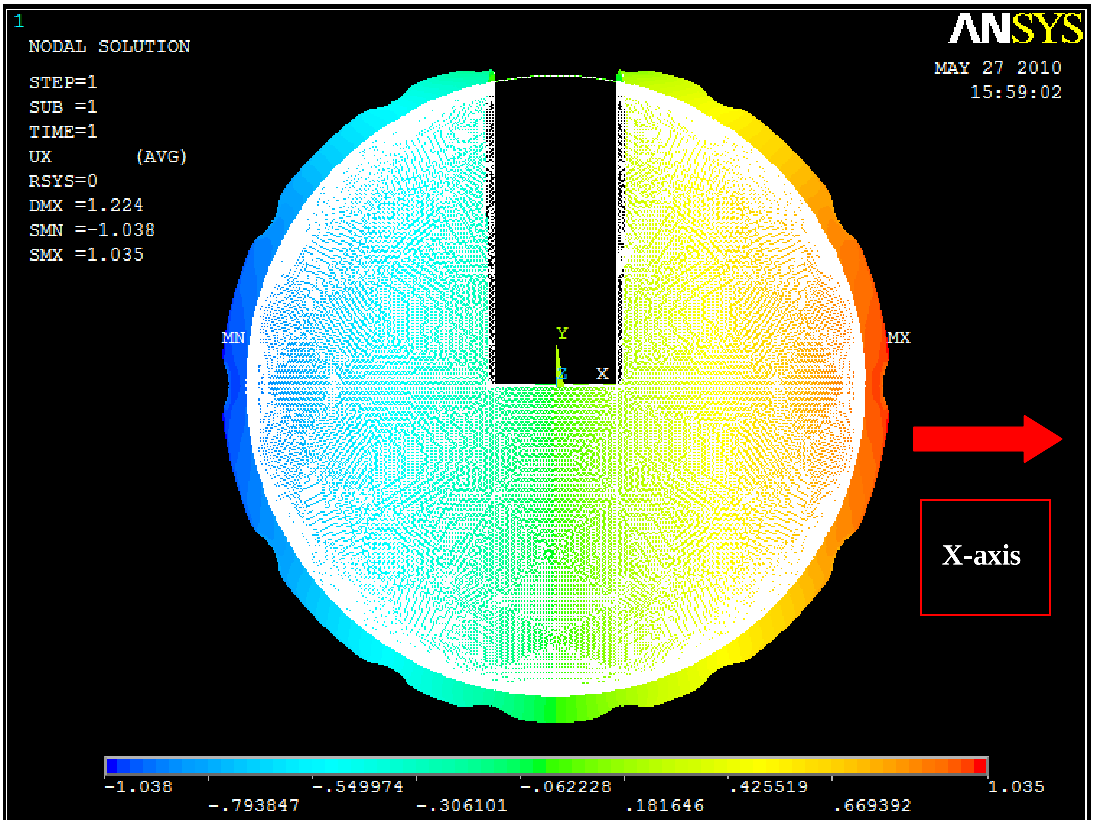


Figure 3-46. Load Case 1, X-component of displacement.

For the y-component displacement vector, the maximum are +0.963 mm and -1.149 mm, these maximum values are located as the Figure 3-47 shows, red colour for +0.963 mm and blue colour for -1.149 mm. In the zone where the mechanism to move the door shutter will be place, the displacement in y-axis is the maximum positive value +0.963 mm, it means that the clearance for the door shutter in pulling is 1 mm approximately. The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underforrmed model (white colour). The units for displacements are measured in mm.

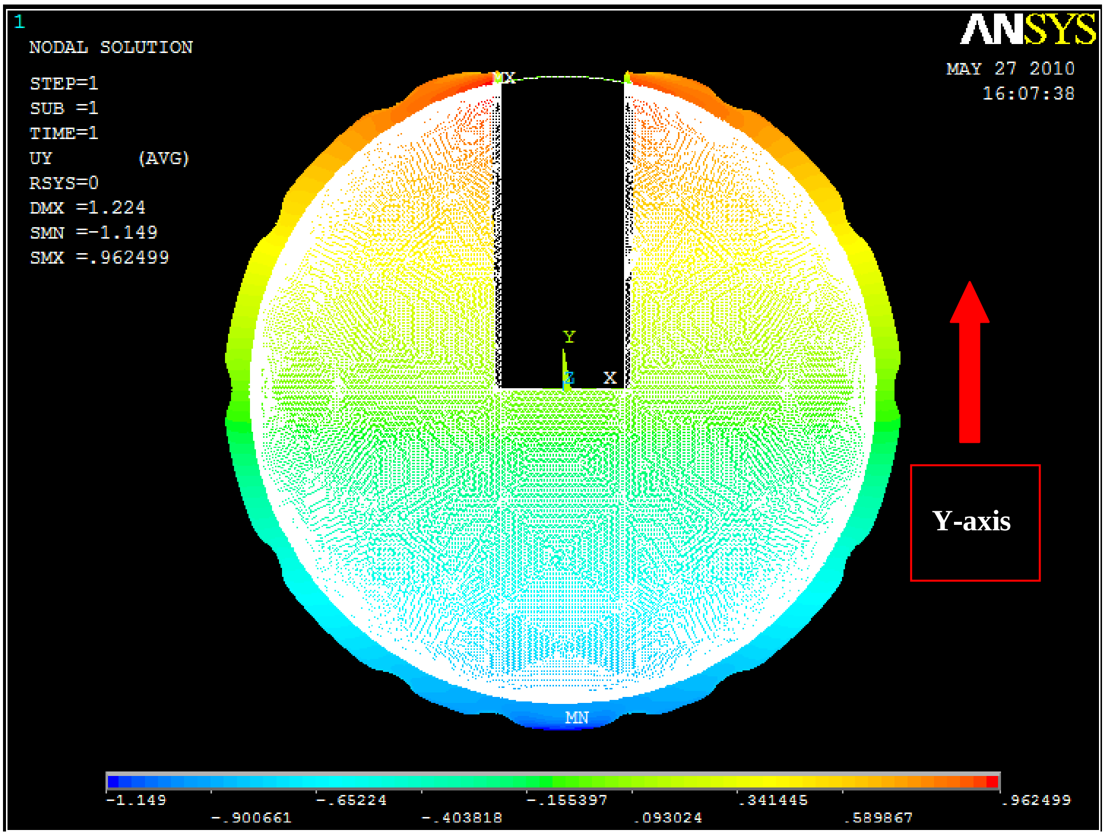


Figure 3-47. Load Case 1, Y-component of displacement.

For the z-component displacement vector, the maximum are +1.008 mm and 0.000 mm , these maximum values are located as the Figure 3-48 shows, red colour for +1.008 mm and blue colour for 0.000 mm. In the zone where the mechanism to move the door shutter will be installed, the displacement in z-axis has different values according to the position in z-axis of each structural element, it shows a maximum of +1.008 mm on the top of the dome (pulling the structure) and 0.000 mm on the bottom the structure (where the boundary conditions were applied). The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underformmed model (white colour). The units for displacement are measured in mm.

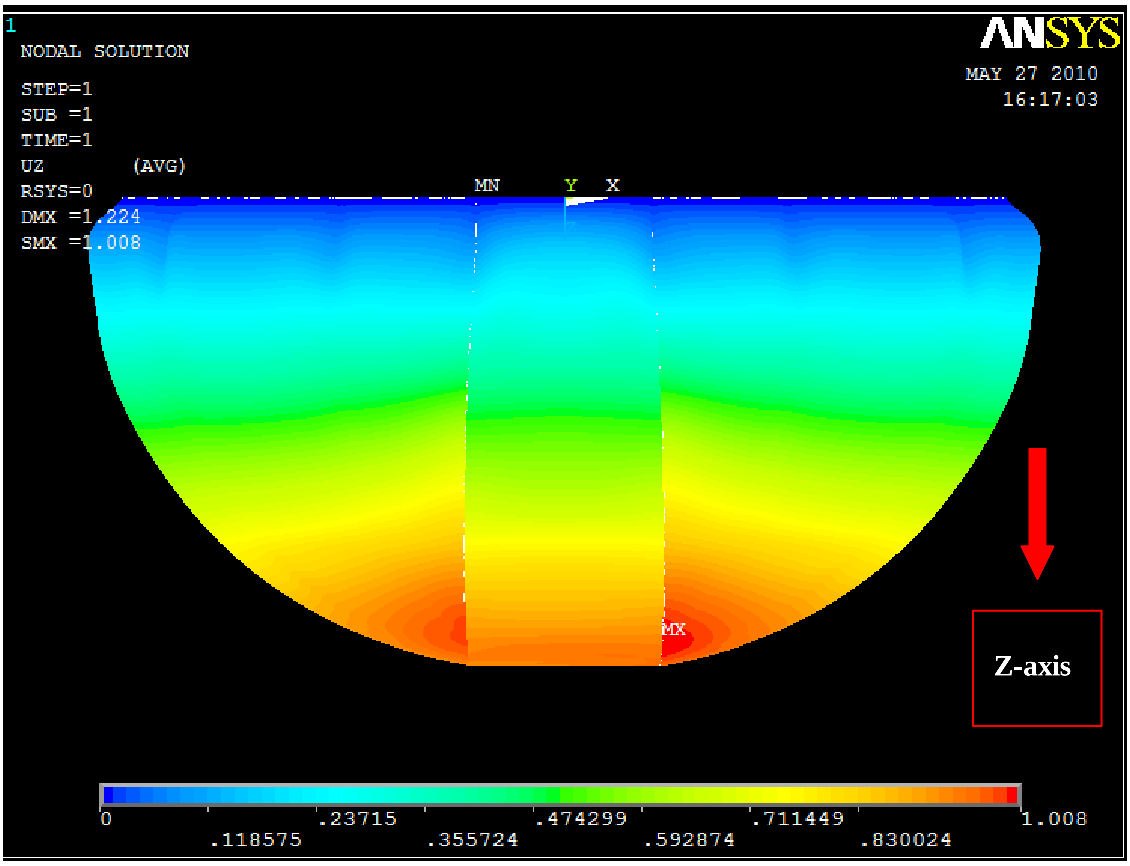


Figure 3-48. Load Case 1, Z-component of displacement.

*3.4.1.2.-**Stresses***

The Stresses experimented by the structure in this load case are located as the Figure 3-49and Figure 3-50 shows, there is a maximum of 113.42 MPa located in the bottom of the structure. Those pictures show the Stresses in MPa.

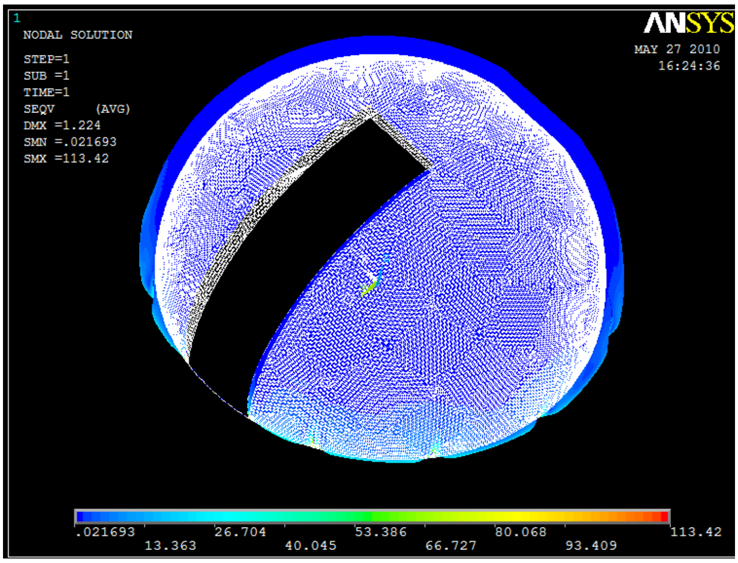


Figure 3-49. Load Case 1, Von Misses Equivalent Stress, view 1

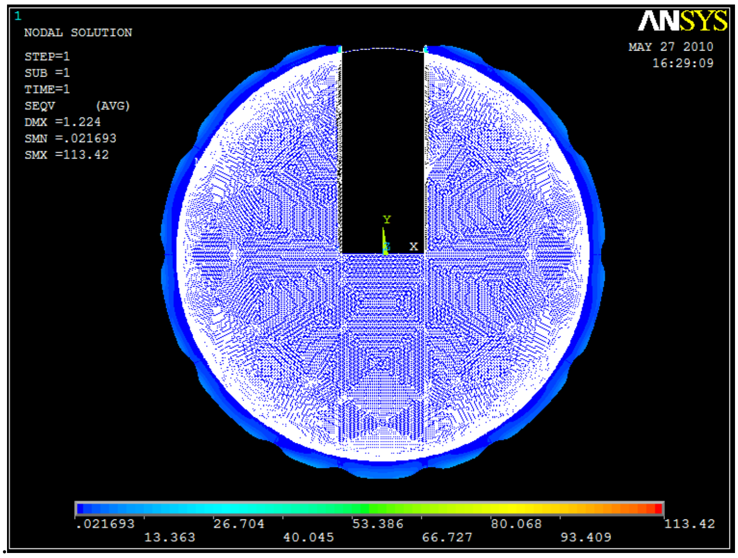


Figure 3-50. Load Case 1, Von Misses Equivalent Stress, view 2.

3.4.2.-Load Case 2

3.4.2.1.-Displacements

The calculations made for this load case give the following results.

For the displacement vector sum, the maximum is 0.980 mm. This maximum value is located in the zone where the mechanism to move the door shutter will be installed, in general the structure is contracted. See Figure 3-51, this is shows with the red colour. The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underforrmed model (white colour). The units for displacement are measured in mm.

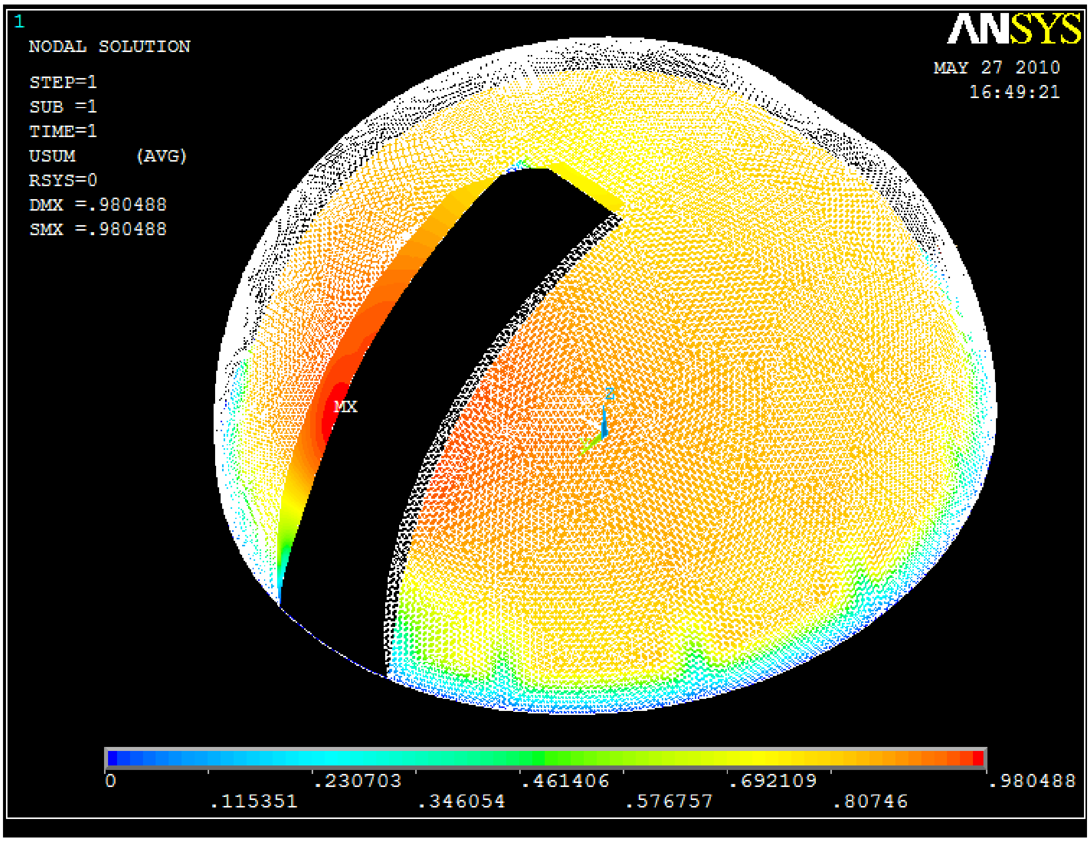


Figure 3-51.Load Case 2, Displacement vector sum.

For the x-component displacement vector, the maximum values are +0.8264 mm and -0.8263 mm, these maximums are located as the Figure 3-52 shows, red colour for +0.8264 mm and blue colour for -0.8263 mm. In the zone where the mechanism to move the door shutter will be installed, the displacement in x-axis is between -0.3 and 0.3 mm, located respectively in each side of the structure, it means that the clearance for the door shutter is contracted 0.6 mm approximately. The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underforrmed model (white colour). The units for displacement are measured in mm.

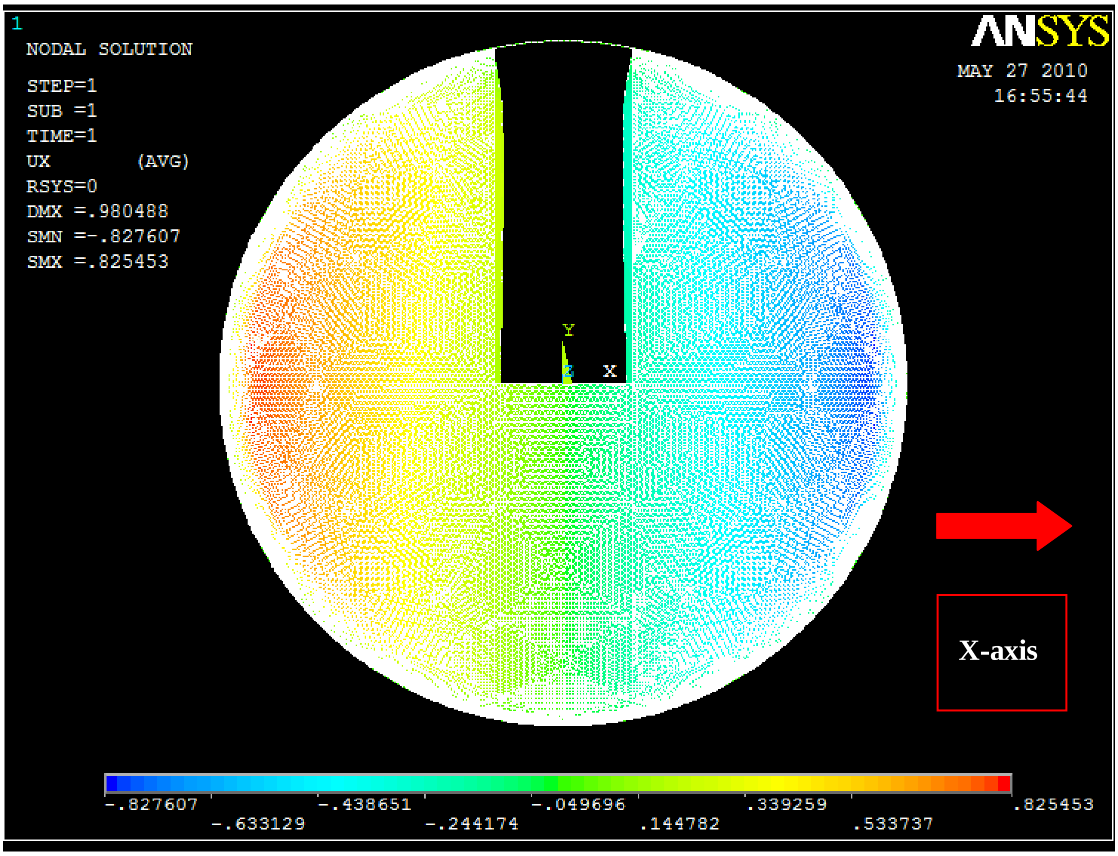


Figure 3-52. Load Case 2, X-component of displacement**.**

For the y-component displacement vector, the maximum are +0.927 mm and -0.779 mm, these maximum values are located as the Figure 3-53 shows, red colour for +0.927 mm and blue colour for -0.779 mm. In the zone where the mechanism to move the door shutter will be place, the displacement in y-axis is the maximum negative value -0.779 mm, it means that the clearance for the door shutter in pushing 0.8 mm approximately. The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underforrmed model (white colour). The units for displacement are measured in mm.

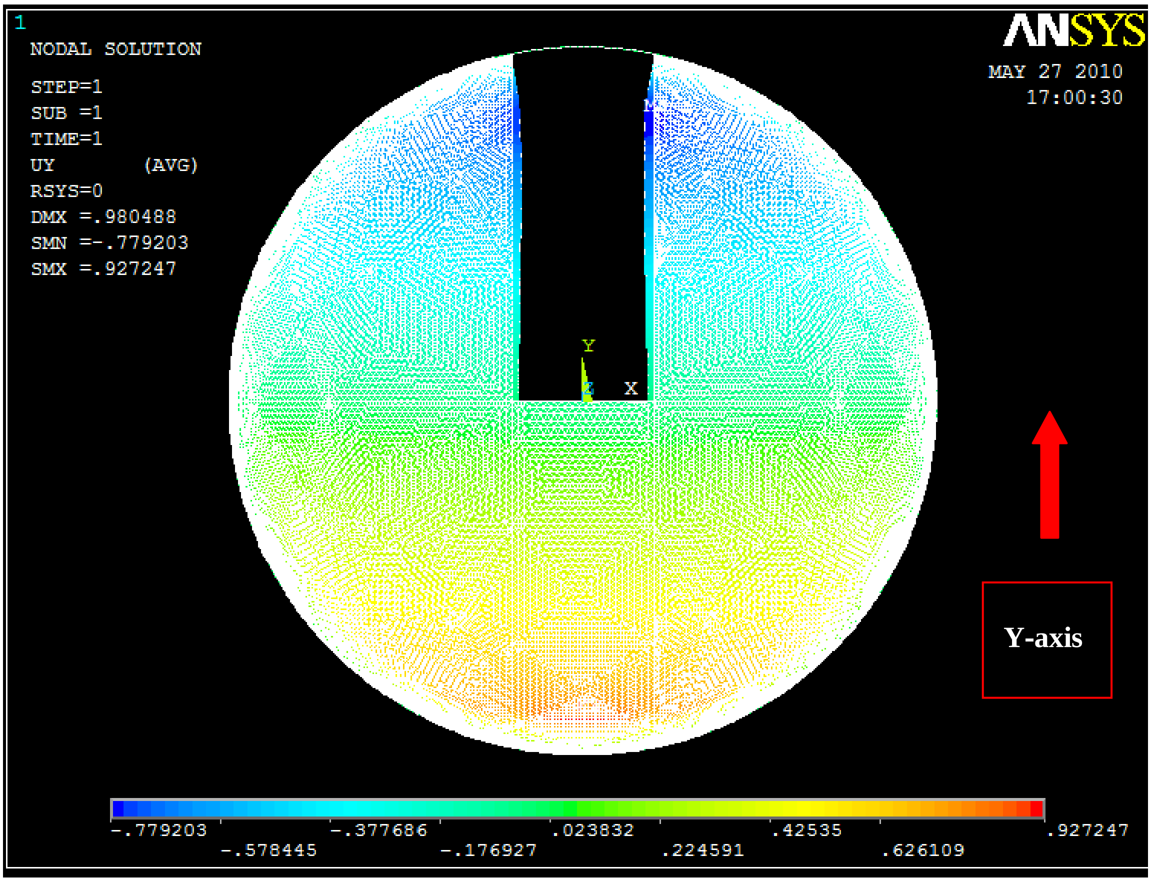


Figure 3-53. Load Case 2, Y-component of displacement

For the z-component displacement vector, the maximum are 0.000 mm and -0.779 mm , these maximum values are located as the Figure 3-54 shows, red colour for 0.000 mm and blue colour for -0.779 mm. In the zone where the mechanism to move the door shutter will be installed, the displacement in z-axis have different values according to the position in z-axis of each structural element, it shows a maximum of -0.779 mm on the top of the dome (pushing the structure) and 0.000 mm on the bottom the structure (where the boundary conditions were applied). The picture shows the deformed model (colourful, with the factor scale auto calculated by ANSYS) with the underforrmed model (white colour). The units for displacement are measured in mm.

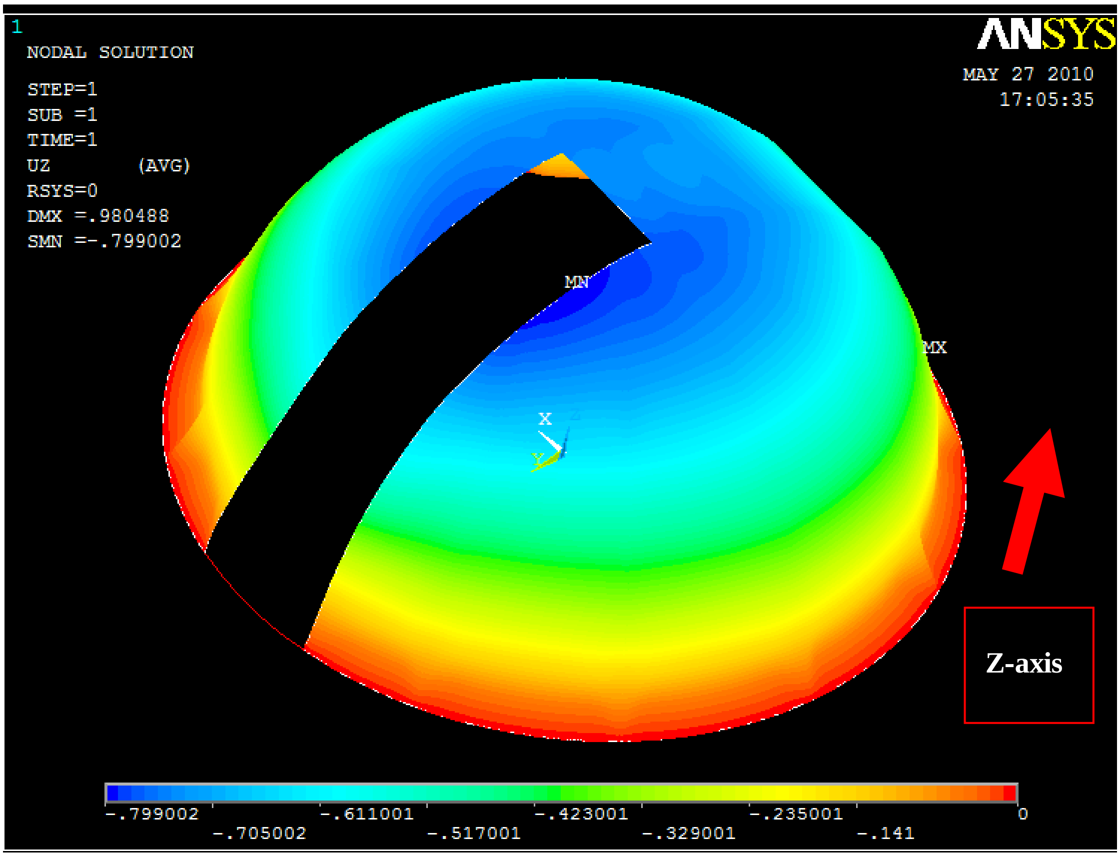


Figure 3-54. Load Case 2, Z-component of displacement

*3.4.2.2.-**Stresses***

The Stresses experimented by the structure in this load case are located as the Figure 3-49and Figure 3-50 show, there is a maximum of 90.568 MPa located in the bottom of the structure. Those pictures show the Stresses in MPa.

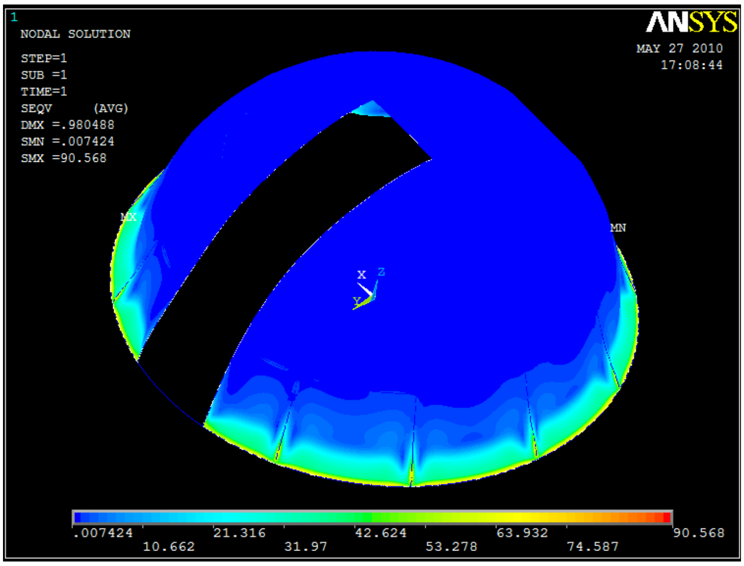


Figure 3-55. Load Case 2, Von Misses Equivalent Stress, view 1

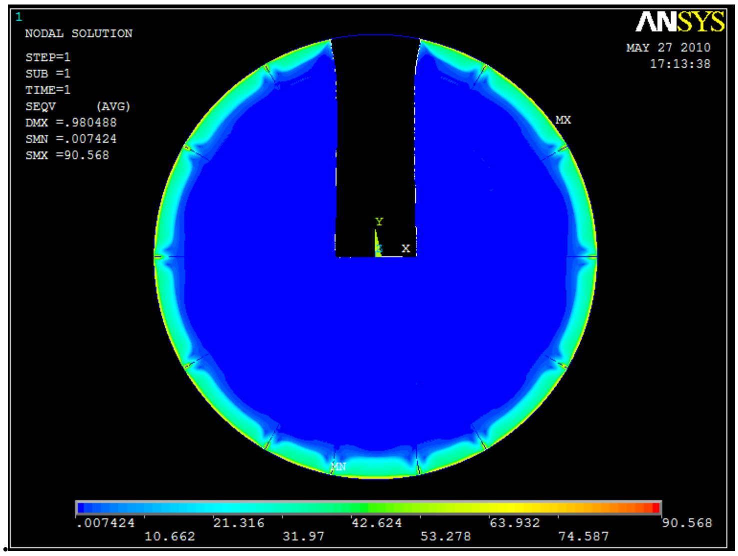


Figure 3-56. Load Case 2, Von Misses Equivalent Stress, view 2**.**

3.4.3.-Conclusions

The results for each load case were presented and described in the previous points of this thesis, as a summary of them; the next table shows the most important data.

Load Case	Stress (MPa)	Displacement (mm)			
		x-axis	y-axis	z-axis	Vector sum
1	113.42	- 1.038	- 1.149	+ 1.008	1.124
2	90.568	+ 0.980	+ 0.927	-0.779	0.980

Table 3-11. Results of the calculations of the dome structure**.**

In the Table 3-11 the results for the “vector sum “column, is the average vector for all displacements, and it is written as a positive value, but the direction is given for the components of the vector.

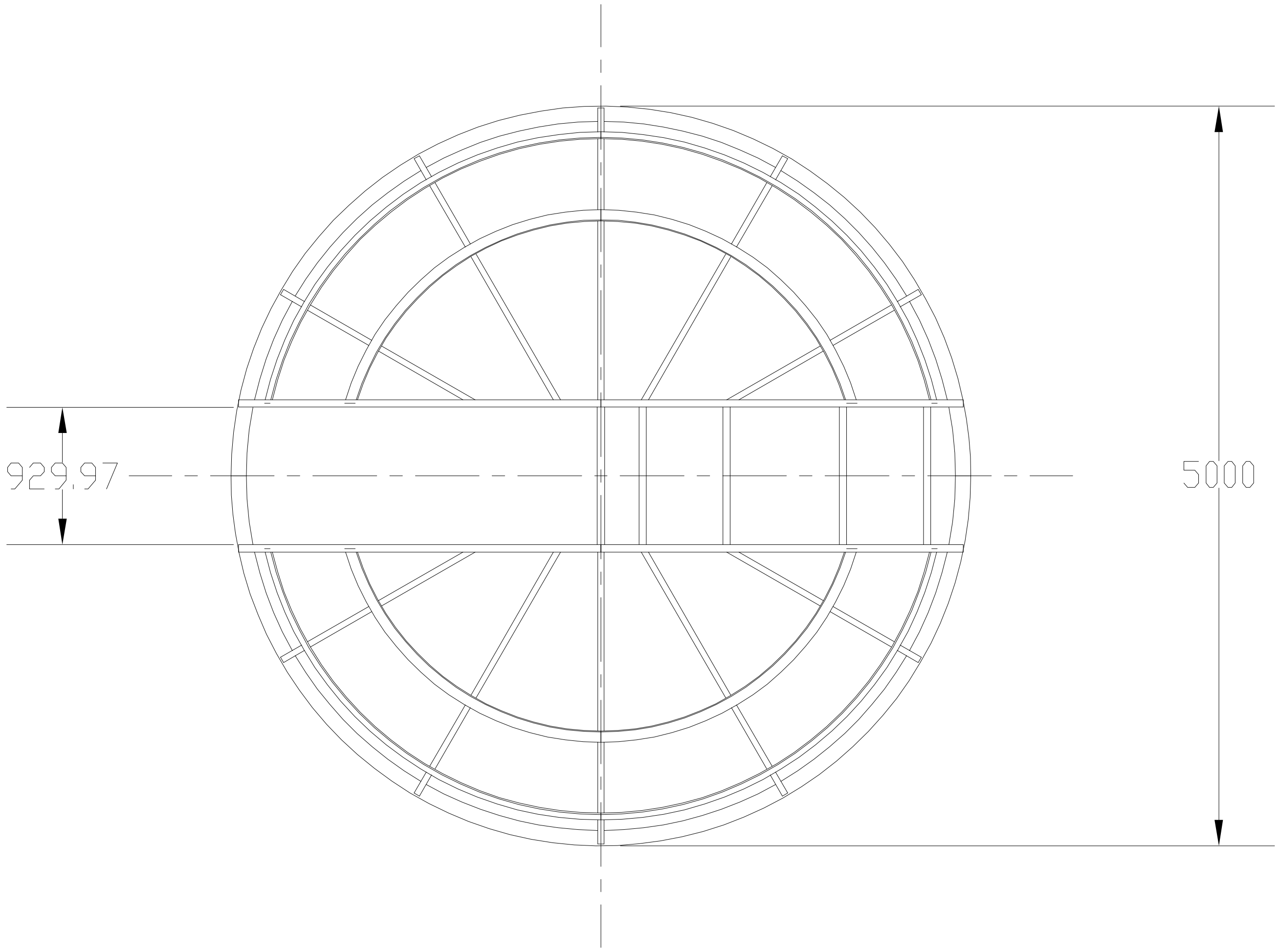
According to the results obtained in each of the proceeded calculations, several things can be mentioned;

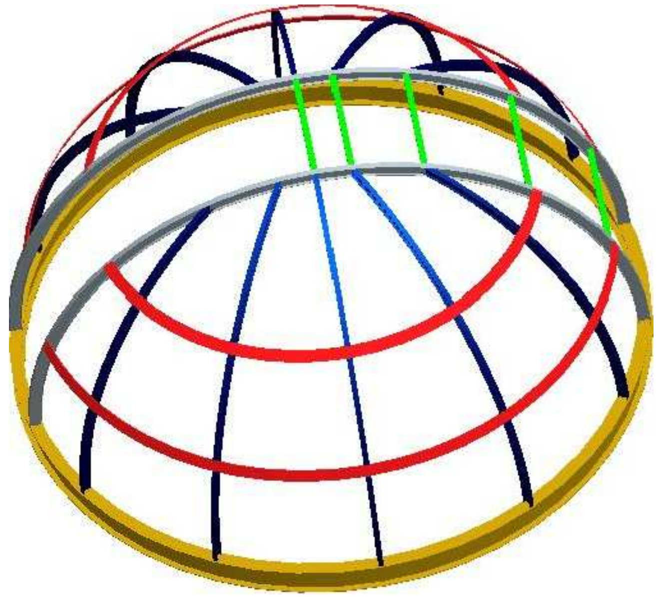
- The mechanism used to move the door shutter has to be able of resist the maximum displacements expected from the structure in each load case, the work of the structures mechanism has be as minimum as possible, the maximum value of displacement expected, thus ensuring the proper functioning of the mechanism

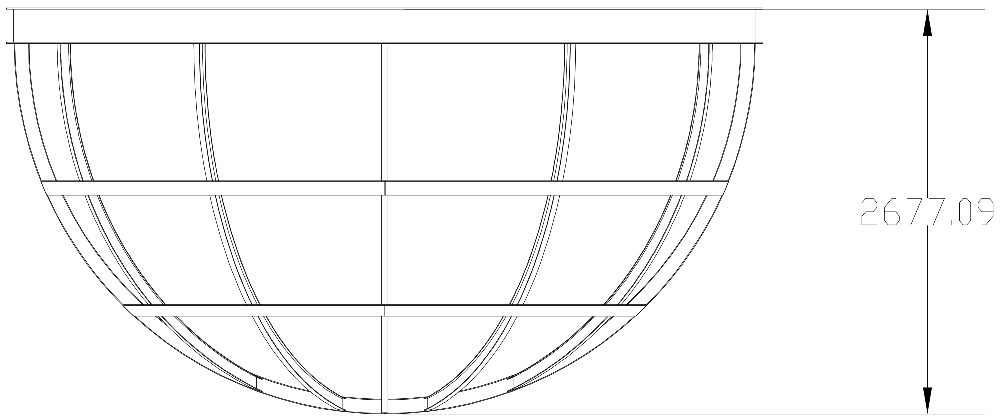
- Comparing the maximum values for Von Misses Equivalent Stress in each load case, with the maximum allowable stress for lineal behaviour of the material (247.34 MPa) gives a security factor of the structure of 2.18 for Load Case 1, and 2.73 for Load Case 2. It can be assumed as a good security factor for this structure.

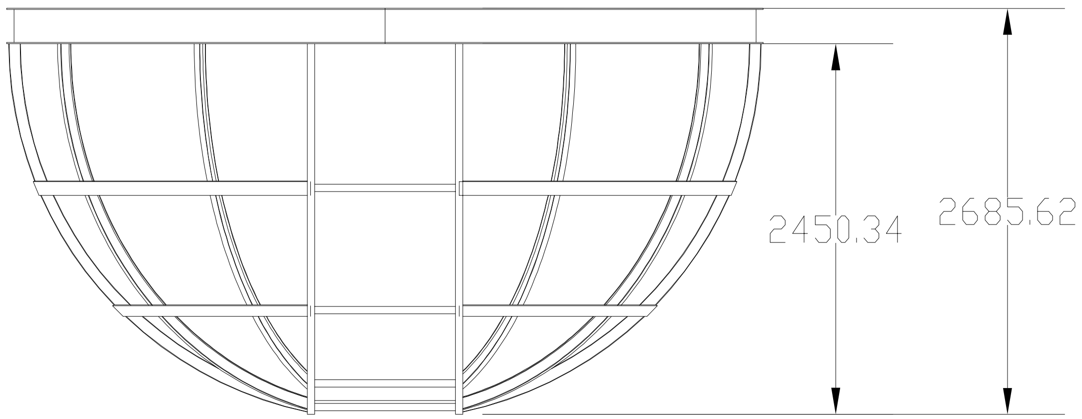
FIGURE INDEX

TABLE INDEX









SILESIAN UNIVERSITY OF TECHNOLOGY DEPARTAMENT OF CIVIL ENGINEERING		
tittle of drawing: General Dimensions of the Dome Structure		
Designer:	Alexander José Pérez García	June, 2010
Superviser:	Rafał Krzywoń Pro. Nzw Pol. Sl	Scale : 1:50
English Study on Civil Engineering		Draw Nº: 1