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# Catenary vaults: a solution to low-cost housing in South Africa

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# *Catenary Vaults: A solution to low-cost housing in South Africa*

Ivanka Bulovic

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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## Declaration

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

Signature ……

Ivanka Bulovic

…… day of …… year 2014.

## Abstract

This report discusses the design approach of catenary vaults in the application of low-cost housing. It investigates the most efficient design, materials and construction methods to provide a sustainable and durable solution to low-cost housing.

Investigation into various materials was carried out and two specific blocks are used in the construction process: the dry-stack interlocking block and the splitter-brick block.

An innovative method of designing catenary curves was developed: The Segmental Equilibrium Method. This design approach focuses on equilibrium equations to define the geometric shape of a catenary under various loading. The method incorporates dead, live and wind loads. The solution obtained is exact and thus proves to be the most superior method in designing catenary curves. The method was compared to the Finite Element Analysis and errors ranged from 0% to 8.9%. Finite Element collaborated with the Segmental Equilibrium Method and verified that the proposed method of analysis can be used in the design of catenary curves.

Finite Element Method was used to analyse temperature loading on the catenary curve. A tensile stress of 0.95N/mm² and compressive stress of 1.02N/mm² were obtained. These values are within the materials capacity of the brick (1.1N/mm² Tension and 7-10 N/mm² Compression).

The final structure was built using a sliding steel form work. The construction process was closely documented and is discussed in the report. The problems during construction and solutions are presented. A cost analysis was carried out and compared to other leading projects in South Africa. It was found that the structure is economically competitive, with an average cost of R95 000 ($9 500).

The report concludes that thin shelled structures, in particular catenary vaults, are a viable option for low-cost housing in South Africa.

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## List of Symbols

| Description | Symbol |
|---|---|
| Cartesian x – coordinate | x |
| Cartesian y – coordinate | y |
| Section Modulus | Z |
| Applied Load | P |
| Thickness | t |
| Eccentricity | e |
| Stress | σ |
| Initial angle, theta | θ |
| Sum of Moments | ∑M |
| Sum of forces in the y direction | $\sum F_y$ |
| Sum of forces in the x direction | $\sum F_x$ |
| Dead Load | DL |
| Wind Speed | $v$ |
| Altitude Constant | $k_p$ |
| Wind Speed Multipliers | $k_z$ |
| Wind pressure | $q_z$ |
| External Pressure Coefficient | $C_{pe}$ |
| Internal Pressure Coefficient | $C_{pi}$ |
| Point Load | PL |
| Ultimate Limit State | ULS |
| Service Limit State | SLS |
| Live Load | LL |
| Wind Load | WL |
| Horizontal | H |

| | |
|---|---|
| Vertical | V |
| Capacity Reduction Factor | β |
| Characteristic Compressive Strength | $fk$ |
| Material Safety Factor | $\gamma_m$ |
| Length | L |
| Height | h |
| Characteristic Stength | $P_u$ |
| Yield Strength | $f_y$ |
| Radius of bar | r |
| Pie | $\pi$ |
| Throat thickness | $a$ |
| Total Service Load | $P_s$ |
| Compression | C |
| Tension | T |

# 1. Introduction

## 1.1. Problem Statement

Many South Africans live a life of extreme poverty with limited access to basic infrastructure, including housing. It is difficult to provide housing for everyone, and this is further exacerbated by the common use of large quantities of concrete as a construction material. Because of the expense, current concrete construction is not a sustainable solution to South Africa's housing problem. Either a new material or a new design must be established in order to achieve a more economical solution. A clear example of this is RDP housing and its ineffectiveness in alleviating poverty. The cost is high and the quality of construction is poor. In addition, on a daily basis, we are faced with extensive environmental issues caused by the use of concrete, e.g. pollution, flooding, exploitation of resources, heat islands, etc. (Birkinshaw, 2008). A new solution needs to be investigated where the form of housing is cheap, materials are locally obtained. The design and construction is robust and most importantly, the structure is environmentally friendly.

In 2007, it was found that 11 percent of the South African population live in shacks (FinScope, 2007). This number has increased considerably since 2007 and is still on the rise (Birkinshaw, 2008). Birkinshaw (2008) found that the number of South African households residing in shacks is increasing at more than double the rate at which the population is growing, with more than 2 million people currently residing in shacks. The living conditions of these people are extremely low and thousands of related deaths occur every year (Birkinshaw, 2008). Thus, it is important that the basic needs of people are met and their living conditions improved.

To improve living conditions, several factors must be investigated. Firstly, it is important that low energy and locally sourced materials are utilised in the construction process. This will reduce costs to a minimum and provide a more sustainable solution. Secondly, the structures need to be thermally efficient as a major cause of death in informal settlements is as a result of heating during winter. Uncontrolled shack fires are created whilst trying to warm households during the

winter months. Lastly and most important, a more structurally robust design needs to be determined to ensure that the inhabitants have a long term home, regardless of the prevailing weather conditions.

We need to respond, and therefore it is important to investigate creative solutions to the housing problems, experienced both in South Africa and around the world. In addition, we are faced with climate change and therefore we cannot construct in the usual manner. Other issues include excessive energy consumption in the production phase, pollution, temperature changes and lack of good thermal properties. The current solution is not sustainable.

Thin shells have been found to be a very effective solution (Joffroy, 1994). They are versatile and easy to construct, requiring minimal amounts of materials. Shell forms can eliminate expensive forces, such as shears and moments, and increase their durability considerably. Thin shells have the ability to resist extreme loading conditions; this is highlighted by a *Youtube* clip in The Weather Channel (2009), documenting a shell home which survived Hurricane Ivan. Thin shells, in conjunction with environmentally agreeable materials, are a superior solution in terms of strength, economy of materials and cost to the consumer.

## 1.2. Objectives

The objectives of this research report:

- Investigate properties of materials which have low energy consumption, are cheap and locally obtainable
- Investigate various housing forms and determine the most suitable form for low-cost housing, incorporating thin shells
- Establish an effective method of designing and analysing catenary vaults
- Design an effective low-cost housing prototype and identify the important design criteria that needs to be considered
- Construct a durable and structurally efficient low cost housing prototype

## 1.3. Scope

This research report comprises of ten chapters. The contents of each of the chapters are outlined below:

Chapter 2 highlights previous literature and research done on low-cost housing projects. It highlights the benefits of thin shells as a solution to low-cost housing as well as shortfalls in knowledge on designing catenary vaults. It also discusses various building materials and construction methods required in the use of thin shelled structures.

Chapter 3 investigates various forms and layouts suitable for low-cost housing. This chapter highlights the need for housing; which minimises on thermal energy and natural flow of the energy within the structure. A final prototype design is also presented.

Chapter 4 presents information regarding the various building materials which are used in the construction of the prototype. The advantages and shortfalls are highlighted and guidance as to how the user can produce his own building materials on site.

In Chapter 5, various methods of designing catenary curves are discussed and a new method of design is presented, based on equilibrium principles.

Chapter 6 utilises the method described in Chapter 5, and covers an in-depth step-by-step analysis and design of the catenary roof of the housing prototype. A case study of an existing site is also explored and analysed to highlight various design principles. Finite Element is used to compare the results of the proposed Equilibrium Method, as well as assess temperature loading on the structure.

Chapter 7 covers the design of the remainder of the structure including the slab, the walls, the thrust components and the foundations.

Chapter 8 discusses and illustrates the construction process of the low-cost housing prototype.

A short summary of the costing of the structure is provided in Chapter 9.

Conclusions and recommendations are made in Chapter 10.

# 2. Literature Review

## 2.1. Introduction

Throughout the ages, structures and their forms have revolutionised and changed civilization dramatically. This change has been due to technological advances as well as social demands. Thin shelled structures have been in existance from as early as the late 1800's. Architects and engineers, such as Eduardo Torroja, Heinz Isler, Dante Bini, and the like, were very active in the design and construction of these forms (Wilson, 2005). Architects are interested in and passionate for these structural types because of their diversity and ability to adapt to various climatic conditions (Joffroy, 1994). Their ability to cover larger spaces made them popular in the construction of religious buildings, schools, hospitals and simple low-cost housing (Joffroy, 1994).

Arches, vaults and the like have been around for thousands of years and many can still be found in the Middle East, North Africa and many European countries, where they were widely used (Joffroy, 1994). Even with a decrease in popularity, many of these countries still build these structures to continue the rich heritage and living traditions associated with these building forms.

Timbrel vaults form part of the thin-shell family of structures; however, their specific characteristics warrant a specific definition. It has been found that the most apt description is that "*timbrel vaults are masonry vaults made with brick and mortar, with a good strength in compression, and can be constructed with remarkable thinness and without the use of formwork. Their uniqueness derives from their construction: the bricks are placed flatly, forming one or more layers and they are constructed without centring or other support. The bricks are placed in arches or successive rings to complete the vault*." (Huerta, The Mechanics of Timbrel vaults: A Historical Outline, 2003, p. 89). Timbrel vaults are an ancient form of construction initially introduced in the fourteenth century, but not until the sixteenth century did it become common practice (Huerta, The Mechanics of Timbrel vaults: A Historical

Outline, 2003). Currently, shells are not commonly used, even though its popularity has increased.

However, it was Rafael Guastavino who put his foot in the door regarding vaulting and he was particularly active in tile vaulting. It was Guastavino's theory of 'cohesive construction' that allowed the methods of construction of timbrel vaults to make the transition into the 20th century and therefore make a monumental imprint in the history of thin shells (Huerta, The Mechanics of Timbrel vaults: A Historical Outline, 2003). He refined the thousand year old building system of 'Catalan Vaulting', which involves a technique involving the erection of thin terra-cotta tiles. Catalan vaulting is the same practice as Timbrel vaulting, varying only by the name given in the various regions in which it is being constructed. Guastavino's tile vaulting technique contributed considerably to many prestigious buildings of his time, but little of his legacy. However, the structural behaviour of the Catalan vault has received considerable attention in literature (Atamturktur, 2006).

Guastavino made a number of material and construction technique breakthroughs. His main construction technique -- "Cohesive Construction Technique"-- is defined as the bond between the terracotta tiles and the Portland cement, due to cohesive forces. His greatest contribution to the technique was altering the traditional gypsum mortar (Plaster of Paris) with rapidly hardening Portland cement, thus enabling him to build vaults that spanned three to five times the typical span of traditional Catalan vaulting (Tarragó, 2002). The technical advancements made by Guastavino, in terms of material breakthroughs, allowed him to enhance his career to world renowned standings, starting with the design and construction of the Boston Public Library. The Guastavino era marks the highest point of the tile vaulting industry and thin shelled structures (Atamturktur, 2006).

Thin shells have become less popular over the years. This has been due to a number of factors, including high labour costs and the high cost of formwork (Wilson, 2005). Many of these factors are also relevant to the decrease in the use of domes, arches and vaulted structures. A major factor in the modern world of construction is the social aspect of acceptance. Thin shells are rejected by people for a number of

reasons, ranging from cultural expectations to lack of modernism. Shell structures have been considered an expensive and difficult form of construction, but if designed for local conditions, they can eliminate many of the considered and current problems (Wilson, 2005).

These structures have many advantages. Domes and vaults have been found to be economical, safe and aesthetically pleasing. They require the minimum use of materials, which may be produced locally and at a low cost (Wilson, 2005). Joffroy (1994) outlines a number of advantages and opportunities in using vaults, which include job creation, foreign currency savings, great aesthetic potential, wide variety of uses and economic benefits. Huerta (2003) found that thin shells are an excellent alternative to floor and roof systems, as they provide exceptional fire resistance.

In most parts of the world, there is a significant need for earthquake-safe housing, and these forms have proved to be extremely effective in resisting these natural disasters (Joffroy, 1994). Through the use of innovative techniques, many of the above stated problems can be eliminated. The use of vaults and shells in construction are relatively foreign in this age; however, there is constant research and development programmes being carried out to improve the design and construction of shells. Recent interest and improved technology have allowed for the design and construction of these unique structures to be mastered once again and a considerable amount of increased knowledge to be added to this research field. (Joffroy, 1994).

A significant cost in the construction of low-cost housing is the roof structure, and the deficiency of good quality and readily available materials. An alternative structural form is necessary to minimise these costs, preserve tradition and make use of local and easily accessible materials. This form needs to satisfy local conditions which include cultural, economic and climatic aspects. In the form of vaults, Joffroy (1994) provides a valuable alternative.

"*Dome structures not only provide great strength, but do it by using less material than other structures."* (Wilson, 2005, p. 9)

## 2.2. Materials

Shell structures have been built for centuries using various building materials, ranging from straw and grass to reinforced concrete. The construction of thin shells in modern-day sees the use of reinforced concrete to be most effective due to its strength and durable characteristics. For this reason, most of the available literature refers to '*thin shell concrete structures'* and '*advancements in reinforced concrete shells*' (Cowan, 1977).

There are a number of material options that require investigation when designing and constructing a thin shelled structure. Wilson (2005) constructs his structures out of reinforced concrete as this allows for versatility in design and thus allows for the construction of any desired shape. It also allows for thicker, larger structures to be built, without the need for complex thin shell theory to be applied. Concrete is readily available in many locations and requires minimal maintenance if used correctly. However, it is an expensive method of construction due to the need for cement and steel reinforcing. Guastavino rejected the use of reinforced concrete due to the excessive cost incurred in their construction and "*problems with irregular setting of the concrete*" (Huerta, The Mechanics of Timbrel vaults: A Historical Outline, 2003, p. 104). Cement requires a large amount of energy in the production phase, and is responsible for emitting greenhouse gases into the atmosphere. Thin shells require a much smaller volume of material when compared to standard methods of construction, and this makes them more economical and therefore results in a large reduction in energy consumption and pollution (Wilson, 2005). A new building material needs to be established to further reduce the cost of construction. It is important to note that due to the thin nature of shells, bricks and tiles may be used in their construction.

### 2.2.1. Tiles

There is a considerable amount of information covering the structural mechanics of reinforced concrete thin shells. However, there is far less literature on the structural behaviour of tile vaulting. Although this type of construction has been around for over

seven hundred years, interest in building these types of structures declined during the twentieth century (Ochsendorf, 2010). It is only recently that a renewed interest in tile vaulting has been established, as the properties of this material allows for more advantageous construction projects to be carried out with respect to available skills, flexibility within the structure and construction costs (Ochsendorf, 2010). Not to mention the much lower environmental impact in comparison with reinforced concrete shells.

Guastavino established that due to the lighter weight of the tiles, they create a lower horizontal thrust than conventional masonry structures. Tiles are brittle, and therefore they are strong in compression, but very weak in tension. This is important for the modelling and designing process as no unwanted forces are to be created in the construction phase otherwise the material may fail (Ochsendorf, 2010). The lack of space between and around the tile does not allow for safety reinforcing to be positioned in a structurally viable way.

Huerta (2003) identified that the main reason behind the use of "*fast-setting mortar*" and "*thin-brick*" (Ramage, 2004) or tiles is that not only do these materials allow for large areas to be covered "*gracefully and economically*", but have also found that low levels of tensile forces, shear forces and moments have been detected in these structures during various load tests.

Figure 2-1, by Guastavino, is a good example that demonstrates the construction process and hence the method of using tiles and fast setting mortar for construction purposes (Ochsendorf, 2010). Figure 2-1 explains how the first layer utilises fast setting mortar to obtain the correct geometry. Each succeeding layer is laid by applying a layer of mortar, the first layer which now acts as formwork.

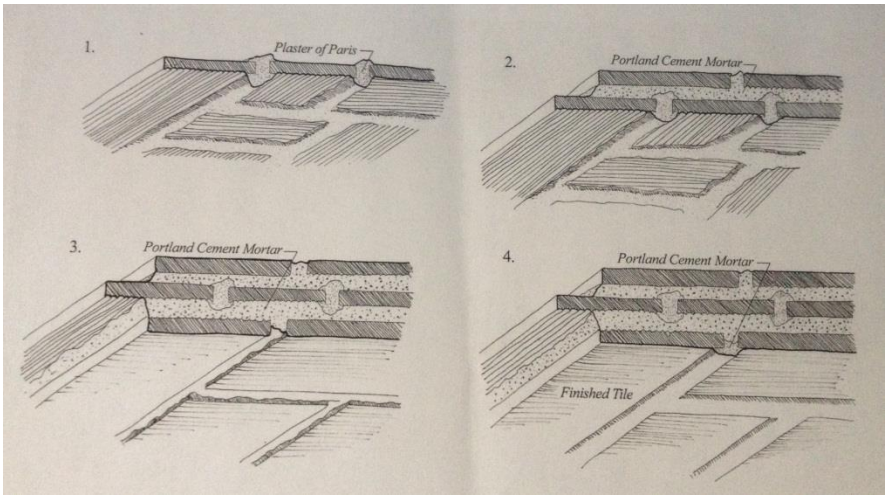



**Figure 2-1:** ***Four stages of mature Guastavino tile construction procedure*** **- Ochsendorf (2010, p 127)**

Investigations into the viability of the use of masonry methods for present times are currently underway, with the initiation of various projects around the construction of tile vaults. One such project is the construction of vaults from stabilized earth tiles in Mapungubwe in Limpopo, South Africa (Figure 2-2). A paper presented on this project states that "*Currently, research is being undertaken both to increase the strength of the tiles in compression, tension and shear, and to simplify the method of construction to facilitate less-skilled workers with relatively low levels of supervision*" (Fitchett, 2009b).This is an indication of attempts to re-employ the use of tiles in vault construction as it is proven to be a successful method. The Mapungubwe project was highly successful and won various architectural awards due to its aesthetic appeal.



**Figure 2-2: Mapungubwe Interpretation Centre**

### 2.2.2. Bricks and Blocks

#### *2.2.2.1. Solid Components*

Joffroy (1994) identifies various building materials and addresses their pros and cons in terms of construction. The adobe block is one which is prepared by moulding soil and allowing it to dry. This is done in wooden moulds and dried in the open air (Bahar *et al*., 2004). It is the least expensive material, easily adaptable to shape, size and method of construction. However, the strength of this block is low and exhibits poor mechanical properties (Joffroy, 1994). It also exhibits unsatisfactory results in terms of surface cracking, durability and water resistance. However, metallic moulds and mechanical compaction are used to improve the blocks performance (Bahar *et al*., 2004). This material is predominantly used in self-building housing projects in rural areas (Bahar *et al*., 2004).

Gothic cathedrals, and other old architecture, were constructed with the use of stones (Fitchen, 1961). Stones offer various possibilities, but they are heavy, time consuming to shape and possess highly variable mechanical properties (Joffroy, 1994).

The oldest form of earth construction is that of rammed earth. It involves pouring the material into pre-prepared formwork. The material consists of earth stabilised by natural fibres or binders, and is poured in sections and compacted manually to construct an entire wall. The properties of the soils used should include large grain sizes. There are a number of projects that can be found in Algiers, Algeria where prototypes and housing projects have made use of rammed earth methods (CNERIB, 1991). This method has also been used to construct low cost grain silos where earth material was stabilised with wheat straw (Bartali, 1991).

The fired solid brick is an expensive form of construction but generally performs well for all dimensioned buildings and is versatile in its shape and size. The fired hollow brick is lighter than the standard solid brick but requires special application techniques (Joffroy, 1994).

The compressed cement bonded earth block (CCBEB) is a viable alternative to more costly forms of construction, i.e. the fired brick. This block has good mechanical strength, but may deteriorate when exposed to water (Joffroy, 1994). Cement Stabilised Earth Blocks (CSEB) are blocks made from raw or mixed soils, stabilised with cement or fly ash, poured into a press and compressed with either a manual or mechanical press, forming the required building block (Auroville Earth Institute, 2012).

There has been considerable research done in CSEB, particularly in Algeria, as a solution to low-cost housing (Bahar *et al*., 2004). Earth construction is relatively abundant and makes use of cheap labour. Soil-based construction methods have been used throughout North Africa for centuries, particularly in the form of blocks, and in Algeria, the earth block is the most commonly used building material. However, it was found that the problems associated with earth blocks are that of shrinkage cracking, low strength and lack of durability. Therefore, continuous maintenance is required and technological improvements are needed to resist the effects of water. Furthermore, soils vary from one region to another and this needs to be incorporated in the experimentation and specification process. These historic structures are an inspiration to modern architecture, but there is a need to improve

the properties of these materials. Through considerable experimentation, it was found that the best option is that of cement stabilisation in conjunction with mechanical compaction (Bahar *et al*., 2004).

A major obstacle in masonry development is that of social status. Earth construction is considered a material for the poor, due to its low quality and durability, as well as affordability and abundance. However, materials such as cement, aggregate, steel and fired bricks are lacking. Sometimes these materials need to be imported, and are expensive. Concrete, besides the high cost, is found to have a low thermal performance. Therefore, it is important for future construction to lean more towards environmentally friendly and cheaper materials. Earth construction is a strong and viable solution, which has considerable traditional meaning within the local communities, as well as excellent thermal properties (Bahar *et al*., 2004).

#### *2.2.2.2. Binder Components*

Mortar is a component that is overlooked when discussing optimisation of material costs. The four major alternatives in the use of low-cost housing are: earth mortar, stabilized earth mortar, lime-sand mortar, gypsum mortar and cement-sand mortar (Joffroy, 1994). All of the above alternatives vary depending on whether bricks or tiles are used in conjunction with the binder for construction and their components.

Cement-sand mortar is the most readily used binder, but also has a high cost. It is important to limit the amount of cement used in the mortar so as to minimise the costs without jeopardising the overall strength. The mortar is very effective in bonding good quality fired earth bricks as well as sand-cement blocks. They have been effective in the construction of medium-span vaults (Joffroy, 1994).

Earth mortar is historically used to bond adobe blocks, fired bricks and stone. The mortar has excellent sticking abilities and allows for easy construction of vaults, without the need for shuttering. However, it is extremely susceptible to shrinkage so it is important that straw or sand is added to a mix which contains an excessive amount of clay content (Joffroy, 1994).

Stabilised earth mortar is earth mortar with the addition of a stabiliser in the form of cement, lime, plaster or bitumen. This mix is also effective in conjunction with fired bricks or compressed earth blocks (Joffroy, 1994).

Lime-sand mortar is useful in that it is very malleable and sets extremely slowly, thus increasing the workability of the mortar. However, this mortar does portray average characteristics and relatively low strength. There are methods to improve it through the addition of crushed brick or pozzolanas. It is generally used in conjunction with fired blocks or stone (Joffroy, 1994).

Lastly, gypsum mortar sets extremely quickly allowing the application of adhesive techniques to be used. This mortar can be stabilised through the addition of lime. Therefore, smaller scale vaults or models can be made quickly and efficiently using this mortar (Joffroy, 1994). It has been found that a fast setting mortar, such as gypsum mortar, has needs that must be met to ensure that the construction is done correctly and the bricks adhere effectively. Ramage (2004) found that by soaking the bricks in water, before applying the plaster, allowed the mortar to adhere better to the brick. The mortar also needs to be mixed in small batches and applied to one brick at a time.

### 2.2.3. Surface Protection

Depending on the type of materials the engineer decides to use, various maintenance problems can occur, i.e. durability problems, infiltration, cracking, etc. In particular, it is important to protect vaults and domes from infiltration of rainwater and preserve its durability. This can be done in a number of ways with the main aim consisting of channelling the water away from the building using downpipes or waterspouts. Depending on the budget at hand, various methods of surface protection can be applied (Joffroy, 1994).

Various forms of materials, as discussed previously, differ in terms of maintenance and effects caused by weathering. Almost all shells made of earth bricks, concrete or clay bricks are extremely susceptible to cracking when constructed with tension-weak materials. This leads to infiltration and water damage. While adobe blocks and

other earth based blocks and bricks require more maintenance as water damage will cause durability issues (Joffroy, 1994).

An earth plaster is the cheapest solution but requires regular maintenance depending on the quantity and nature of rainfall, the area in which it is situated and the various forms of weathering it is exposed to. A sand-cement mortar would crack as it is too rigid; therefore, a corresponding membrane should be used in conjunction. The better render solution is one of lime-sand and gypsum-lime-sand, as they have greater malleability but some maintenance would still be required (Joffroy, 1994).

A further option for surface protection is a form of roof covering. Adding another layer of material on top of the vault will protect the primary layer. Previous and current solutions include thatch, tiles, stones, etc. These can also provide another means of directing the water away from the roof without much notable infiltration. If done correctly, these solutions can still be cheap and extremely effective, requiring minimal maintenance (Joffroy, 1994).

A common method which has been applied to a number of projects is the use of membranes as a layer on the outer surface of the vault or dome. This can be done in a single or multiple layers of bitumen-based membrane, metal leaves or acrylic-fabric membranes. Another popular membrane is that of waterproof paint. This solution, although effective, is relatively expensive (Joffroy, 1994). An example of this form of waterproofing can be found at The Sparrow Aids Village in Johannesburg (Figure 2-3). This village has experienced considerable cracking and a membrane has been applied on the outer surface of the domes to minimise water damage. The membrane used is a fabric over which an acrylic waterproof paint is applied. This material is extremely effective, as it is flexible and capable of withstanding thermal movements. It has improved the domes quality considerably, and now there is minimal, if any, water infiltration within the domes.



**Figure 2-3: *Left:* A cracked dome at the Sparrow Aids Village; *Right:* A membrane layer is applied to the cracked dome**

The choice of the shape is crucial in terms of construction and economic efficiency. The ideal option in minimising infiltration problems is to construct a sloping roof. This allows for the water to drain naturally off the structure and not gather in a section of the roof, resulting in infiltration. Infiltration is generally not an issue for rounded structures, as these forms are quite steep and only a small gradient is required to allow for natural drainage.

## 2.3. Forms, Modelling and Spacing

Form finding is an extremely complex process which entails finding a shape which is structurally sound. This step is generally done well through the observation and identification of problems in other structures of similar form. Mimicking natural shapes is extremely important in order to achieve a strong solution; with one of the best examples being that of an egg. Although an egg is made of somewhat weak and soft materials, its oblong shape is extremely strong. There are many forms of vaults ranging from the barrel vault, being the simplest, to more complex vaults like the domical vault and so forth (Joffroy, 1994).

Safety is essential when designing structures, and many countries worldwide need to design for seismic action. Thin shells have been found to be extremely effective in terms of withstanding earthquakes, hurricanes and the like (Wilson, 2005). Building a domed house is a safer, more economic, longer lasting and easier option than building a standard similar sized house (Wilson, 2005). A good example of this is the

construction of a home on Pensacola Beach, Florida, designed by Arnold Wilson. The house withstood Hurricane Ivan with minimal damage, while surrounding properties, following standard designs, collapsed (The Weather Channel, 2009). Furthermore, the structure withstood a further two hurricanes, Denis and Katrina. Wilson (2005, p. 13) states that "*The storm surge forced water through the ground floor garage and tore away the breakaway staircase. The living quarters were undamaged*."

Fire is another safety feature that needs to be incorporated in all designs. The South African Standards Code of Practice stipulates that there must be a specified amount of time that the structure needs to be standing so that all personnel in the building can evacuate safely (SABS 0100-1: South African Standard Code of Practice; The structural use of concrete, 2000). In 1988, a large domed grain storage facility in Alabama caught alight and burned for 20 days without collapse (Wilson, 2005). Eventually, a dust explosion occurred within the structure and the top of the dome burst off, allowing for a relief valve to be created, and in turn saved many lives as well as the surrounding property (Wilson, 2005).

The process of form finding, with regards to thin shells and vaults, is not well covered. One exception is the engineer Heinz Isler – who is considered the pioneer of the fabric form-finding method. "*A method of form-finding used by Heinz Isler is to suspend a membrane between supports disposed in the same relative positions as in the real structure and leave it to deform under its own uniform weight. Under this load the membrane takes up a shape such that, within it, only tensile forces are present, as a cloth affords no resistance to bending or compression*" (Chilton, 2000, p. 35). Once the cloth is suspended from all four points, it can be soaked in water and frozen or covered in self-setting polyester resin, until a solid form is achieved. The form is inverted so that the cloth will be in pure compression as opposed to its natural, hanging tensile state, thus achieving the desired shape (Chilton, 2000).

Atamturktur (2006) investigates the effects of vibration and dynamic testing of spherical structures in order to test the structural form. He also utilises his research to investigate various design methods.

Atamturktur bases his design procedure of domes on the Finite Element Method of modelling. He describes finite element analysis (FEA) as an "*approximate numerical method that solves for the distribution of forces, displacements, or strains in a system*" (Atamturktur, 2006, p. 90). His approach in completing an FEA is to "*build an analytical model, which idealizes the variables of the structure under study: geometry, material properties, and boundary conditions, as well as existing or possible loadings…fine tuning the FE model by comparisons of analytical and experimental frequencies and mode shapes*" and finalizing the procedure "*with the determination of the static state of stress, strain and displacements*" (Atamturktur, 2006, pp. 90-91). As with any project, it is important to make valid assumptions in order to design the structure efficiently. The most important assumptions that are noted by Atamturktur include: a uniform thickness of the shell, all materials can be assumed to be isotropic and homogeneous, the structure is subject to linear elastic behaviour of materials and minimal deflections occur.

Various research has been completed in the construction of medieval vault erection, in particular gothic cathedrals. Gothic cathedrals date back to as far as the 12$^{th}$ century and many of them are still around today. Their structural knowledge was far advanced in comparison to their technology and various observations have been made that are of significant importance (Fitchen, 1961).

Fitchen (1961) identifies that the simplest and truest type of vault is that of a semi-cylindrical barrel vault. They are structurally sound and extremely simple to construct. The semi-cylindrical barrel vault was extremely common and extensively used within the gothic cathedrals, but a problem with this form was that it did not span very effectively, prohibiting the maximum height that was to be achieved, as well as minimising the amount of light made available within the structure. The semi-cylindrical vault was found to be a poor form structurally for cathedrals. A new shape and solution needed to be found.

As the Gothic era progressed, it was found that many of these vaults tended to be strongly pointed at the tip and this caused many structural troubles in the form of cracking and even collapse. Thus, after considerable experimentation, it was found

that a structure which carried no surcharge and therefore, only supports itself would prove to be the ideal form. This, in short, is the catenary form (Fitchen, 1961).

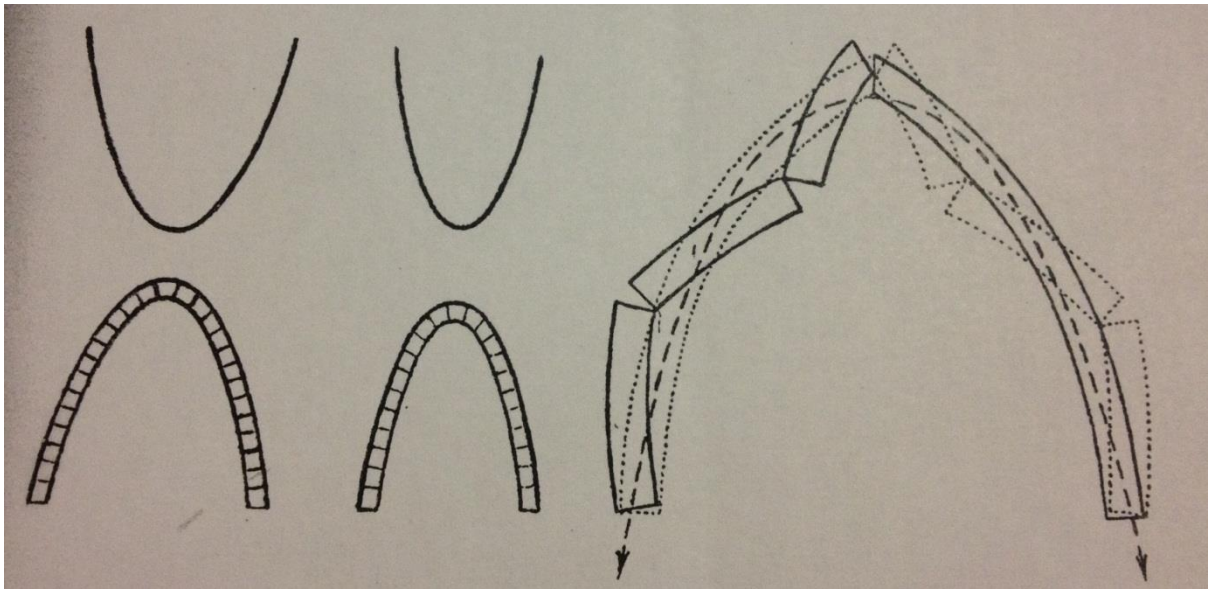


**Figure 2-4: *The catenary Curve and the Gothic Pointed Arch* - Fitchen (1961, pp. 81)**

A catenary is a curve which is created when a chain or cable is allowed to hang loosely from two edge points, and creates a natural curve that is in complete tension (Figure 2-4). If this chain was rigid so that it does not deform when flipped, it would be found to be completely in compression. This compressive form is a catenary. This method is particularly effective as it ensures that the line of thrust is on the centre line of the shell, which therefore eliminates the creation of the pointed arch. However, due to other forms of loading, including wind, thermal loads, etc., it is important to ensure the thrust line is kept within the middle third of the thickness of the structures to prevent the development of tensile forces and possibly cracking. (Fitchen, 1961).

Conant (1944, p. 127) states:

"*the pointed arch is an approximate catenary, and it is a fact that unless an arched structure has the catenary form, extra strength is needed in the arch to keep itself intact, quite aside from the thrusting action generated in an arch of any kind.*"

Fitchen (1961) discusses that because no gothic cathedral or arches had an actual catenary curve, the builders had to make adjustments to prevent them from deforming or cracking. This was done by placing a layer of light-weight rubble, tiles, copper coverings or any other such material, on top of the curved structures.

Research has found that the catenary is the most effective shape, predominantly due to the natural shape of the curve under self-weight. Joffroy (1994, p. 9) states that *"The catenary vault is very common as its form gives maximum stability for a minimum use of material".*

There are various aspects that need to be considered when selecting your form and design. Joffroy (1994) suggests the following as the most important architectural and engineering design considerations:

- Building
- Spatial considerations
- Building complexity
- Architectural appearance
- Acoustics
- Stability of vaults/arches and supports
- Details and finishing

The method of building is an area which plays a significant role in determining the overall cost of the structure. The size and shape will depend on the building method, as well as amount of scaffolding necessary to complete the project. These aspects will determine the preferred dimensions for the structure (Joffroy, 1994).

Spatial considerations in designing are of extreme importance. An advantage of using vaults and arches is that of both increased variable space and height. However, the challenges of creating dead space needs to be considered when designing a dome. Architecturally, this is important in terms of usability. The building should not contain dead space; particularly within low cost housing. The maximum space needs to be available to the home owner for usability and flexibility to move between these spaces (Joffroy, 1994) (Figure 2-5).

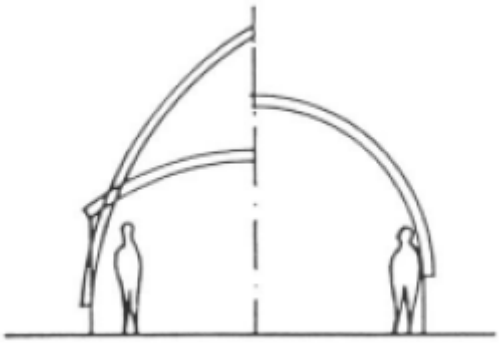


**Figure 2-5: Maximising on space and usability in various forms and designs - Joffroy (1994, p 16)**

The method of constructing these structures can range from basic construction methods to extremely complex. A sophisticated system is the most efficient and optimal route and makes use of its materials effectively and keeps costs at a low. However, a sophisticated system can be challenging as construction is more complex, increasing the chances of mistakes during construction. A simple construction process is generally preferred to eliminate the possibility of any mistakes, and to ensure that the structure is as optimal as possible (Joffroy, 1994).

The architect plays an important role in the design phase of the project. They can offer many design variations of the structure whilst adding considerable aesthetic appeal. The architect can effectively optimise the space availability of the structure. They are essential in ensuring social acceptability and cultural preservation (Joffroy, 1994).

Acoustics is an aspect generally over looked but very common in curved shapes. Depending on the intended use of the space, a high degree of reverberation can be created, and this can serve as a disadvantage or an asset. There are various simple methods that can be implemented to minimise the acoustical effects; such as suspending cloths (Joffroy, 1994).

Vaults and arches, due to their high thrust forces, need to be designed and supported effectively in order to prevent the structure from collapse. A thrust force is that force which pushes out the supporting bases. The size of it will vary depending on its degree of flatness, the span and weight of the structure. Therefore, the structure needs to be as close as possible to the line of thrust to ensure that the form

is stable. There are a number of ways to contain the thrust force; these include cancelling it out by juxtaposition, widening the walls, adding buttresses and ties or ring-beams (Joffroy, 1994). The use of buttresses is very common in the design of shells. The function of the buttress is to channel the outward thrust from the vault to the vertical walls and in turn, to the ground, safely (Ochsendorf, 2010).

The catenary form allows for more flexibility and leeway to the desires and needs of the designer, such as high levels of light. One of the distinctive features of gothic cathedrals is the numerous glass windows and the amount of light. This was identified and applied to many of the cathedrals that can still be seen today.

Joffroy (1994, p. 17) emphasises the importance of using catenaries: "*In the case of vaults, for evenly distributed loads, the best form resembles that of an inverted suspended chain (catenary). This applies both to flatter and slender forms."*

Some examples of projects that have successfully made use of catenaries include:

- Keleti Railway Station, Budapest, Hungary
- Casa Mila, Barcelona, Spain (Figure 2-6)
- Sheffield Winter Gardens, Sheffield, England (Figure 2-6)
- Gateway Arch, St Louis, United States (Figure 2-7)
- The Pantheon, Rome, Italy (Figure 2-7)

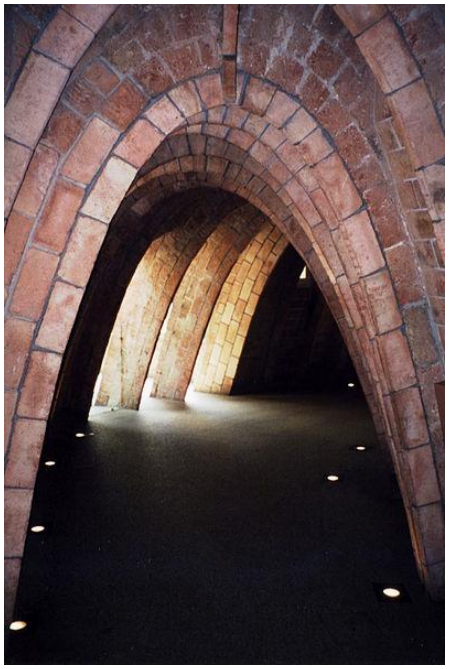



**Figure 2-6: Casa Mila, Barcelona (left - (Sennott, 2004)) and the Sheffield Winter Gardens, England (right - (Hymers, 2005))**




**Figure 2-7: Gateway Arch, US (left (Grigonis, 2011) -) and the Pantheon, Rome (right)**

## 2.4. Construction Methods

"*In all cases, the professional training which is given during project implementation is an asset which can benefit the whole community. Involving local tradesmen,*

*entrepreneurs, architects, engineers and draftsmen, ensures the possibility of spontaneous and correct replication of the building models proposed and their dissemination."* (Joffroy, 1994, p. 12)

Shell structures have a unique shape which requires skilled labour for successful construction. Professional training needs to be provided to construction workers to ensure that the desired form, which is of critical importance, is achieved to prevent structural damage or failure. This technique can be mastered relatively quickly with the use of correct tools and effective training. In addition, the engineer also requires specialised knowledge and understanding in the theory of thin shells before attempting to design such a structure (Joffroy, 1994). The architect needs to have a broad knowledge of the form to enable the efficient use of technology in terms of creativity and evolution (Joffroy, 1994).

There are various forms of construction that have been identified and used in the medieval times. The foremost construction methods used include earth mounded form (both in full and in section), continuous wooden boarding formwork, and a sectioned boarded formwork using much less wood. As can be noted, wood was the predominant material used in formwork, due to its inexpensiveness and availability (Fitchen, 1961).

We have advanced considerably in both technology and knowledge on construction since medieval times. Various more modern construction methods have been explored all over the world using an assortment of materials. The majority of the information that is available is on reinforced concrete shells are found in publications such as Wilson (2005), Allen and Zalewski (2010) and Cowan (1977). There is very little information on tile or brick construction, but there are a few recurring methods which appear in majority of the reviewed journals e.g. inflatable formworks, visual guides, Cupola Tracer, etc. (Gohnert, 2011).

### 2.4.1. With Formwork

Arches, vaults, domes and cupolas require different methods of construction. The focus will be predominantly on arches and vaults, which are built in a very similar manner.

The first suggestion is one of constructing a formwork of the same shape as the arch or vault. The formwork material is usually, but not exclusively, wood or metal. The formwork needs to be collapsible and therefore easily removable once the structure is complete. This not only eases the construction process, but also allows for the reuse of materials. Therefore, the formwork should be robust and precise to ensure maximum quality. This method is effective in low-cost housing schemes where structures have the same shape; therefore, the formwork can be reused, minimising construction costs. Other types of formwork include that of earth formwork and balloons. Earth formwork is used as a base when building with blocks and bricks, which are covered by a layer of mortar forming the desired shape. However, this is not a reusable type of formwork and is also more time consuming (Joffroy, 1994).

A sliding formwork is limited to only barrel vaults, but proves to be a very effective option. The sliding formwork method is extremely economical as the formwork is simply repositioned through sliding, as stages of the vault are completed (Joffroy, 1994). The method of sliding was used in the construction of several abandoned buildings in the township of Bapong, South Africa (Figure 2-8 and 2-9). These structures have been standing for decades, but are in excellent condition due to their high quality construction. It is important to note that even if the design is excellent, the method of construction is just as important and sliding formwork allows these precise shapes to be constructed effectively.



**Figure 2-8: A sliding formwork used to construct a vault (Joffroy, 1994, p 20)**



**Figure 2-9: The vaulted roof in Bapong Township was constructed with a sliding formwork**

Another method of construction, which has not been used as much as standard formwork, is one of an inflatable balloon. It is an effective way of building as it is extremely economic since it can be easily reused (Wilson, 2005). This method was suggested by Wilson (2005) and the use is demonstrated in Talocchino's (2005) masters' dissertation. Wilson (2005) used the balloon method to create a shell out of reinforced concrete. Talocchino's (2005) shell was constructed in Johannesburg (Central Johannesburg College). The shell was constructed by inflating a large balloon, with a shape identical to the shape of the shell. Contrary to Wilson, Talocchino was able to reuse his formwork, since it was deflated and removed after construction.

Other projects done in Southern Africa have used other innovative methods of construction. In Buane, Mozambique, a Cupola tracer was used to form a shell which rotated around a centre pole as formwork. This formwork was built using the exact dimensioning of the domed shape, thus guiding the workers during construction. They only had to turn the rotating arm to place the bricks in the correct positions. The major drawback with this method was the difficulty in constructing the apex, as the bricks were slipping with the use of conventional mortar. Thus, an earth mound formwork was used for the final stages of construction. This caused major inconsistencies in the construction as the precise shape could not be achieved at the apex (Gohnert, 2011).

Using formwork eases and speeds up the process of construction, however, certain structures have curves and forms that are too complicated or expensive to replicate and manufacture; therefore, construction without formwork needs to be explored.

### 2.4.2. Without Formwork

Arches can be built in a simple manner without the use of formwork. This is done by constructing each succeeding course slightly higher than the preceding one and so the previous layer is used as formwork.

The ‘Splice’ method is the most economic and efficient method. By using small and fairly thin members, each successive layer makes use of the previous layers mortar, improving its cohesion. It is therefore laid in layers, face on, at a steep angle to the vertical so that it doesn’t collapse. This principle can be used with varying shapes and sizes to build barrel, groined, dominical, etc. vaults (Joffroy, 1994).

Joffroy (1994) also determines that one can build a structure ‘by eye’ with the assistance of light tools and guides, such as masonry to ensure the accurate shape is obtained.

The final method of construction is that of *increasingly inclined rings*. This is a method which consists of constructing rings of tiles or bricks in layers, from the bottom up to the apex. Each successive layer decreases in diameter as construction moves up towards the centre. The technique is similar to that of the ‘slice’ method, where a simple rotating guide is implemented to delineate the general shape in the air before the correct form is built (Joffroy, 1994).

An example of the ‘no formwork’ construction method is that of Ramage (2004). Ramage constructed his own Catalan vault in hope of investigating various construction methods and highlighting their various strengths and weaknesses.

Ramage (2004) refers to Catalan vaulting as a “*monumental construction method*”, which relies on fast-setting mortar for construction and the structural form for strength. This method, also referred to as the Cohesive Construction technique, requires no formwork, even when spanning large open spaces. This is important as

the most valuable aspect of the vault is the final form once completed. This technique allows for effective spanning of large areas, gracefully and economically.

The groin sections (of parabolic shape) in Ramage's vault were not constructed using this technique and thus formwork had to be built for these sections, allowing for easy construction. The central vault is therefore defined by the curves of the groin. Wooden battens were cut to length and used as a guide to direct the builder during construction. After the formwork had been designed and finalised, construction began and the first layer was laid using Plaster-of-Paris, setting in approximately 10 seconds. "*This is the key to the system: a fast setting mortar on two edges of a tile allows it to hold itself after being tapped into place. No formwork is needed*" (Ramage, 2004).

This structure was made using thin bricks (not tiles) and proved to be extremely effective. He started construction at the corners, working his way to the centre of the vault. The second layer is applied directly on the first layer, which now serves as formwork. The second layer was laid in conjunction with weatherproof Portland Cement Mortar instead of quick-drying plaster, as instant setting is no longer a concern. Ramage built his structure by standing on the outside to allow for easier access, but it is important to note that typically such a structure is built whereby the builder stands at the centre of the form and builds in a circular fashion around him and eventually from below. The application of these techniques, and essentially the shape and form of the vault, ensure that the structure is of the highest strength and within a day, the tiles have set and are able to hold their entire weight.

The Mapungubwe project utilized a very simple but effective method of construction: '*Without formwork or centring, the masons construct much of the vault by sighting between completed portions and curved plywood guides'* (Fitchett, 2009b, pg. 4). The construction process does need to be monitored by an experienced contractor to ensure that every tile gets placed in the correct position. It is also important to construct large reinforced concrete buttresses as the span of the vault needed several layers of tiles to achieve the required strength, hence creating a greater horizontal thrust (Fitchett, 2009b).

Atamturktur (2006) makes a very important note on horizontal thrust. He discusses how Guastavino and other scholars believed that a unified dome exerts minimal horizontal thrust, but since these structures are clearly not perfectly rigid, a larger horizontal thrust needs to be considered in the designing process. Despite Guastavino's arguments, his calculations have always taken horizontal thrust into account. Thus, it is important that a base is set during construction to resist horizontal thrust, i.e. steel ties or buttresses.

The construction market is a relatively conservative market and a new idea is generally relatively difficult to implement. Thus, prototypes and pilot projects are necessary to promote such activities and convince the market of the success of this form. This can also be done through the construction of buildings of interest, which the general public is more likely to appreciate and support. The public has a social responsibility in determining what an acceptable structure is. By providing them with an understanding of the possibilities that these structures can offer, we will more likely be successful in convincing the public that these forms are the future. This can be utilised to implement a more economic housing project. However, in developing countries, where funds are not as readily available for construction, rash and successful pilot projects of housing can be sufficient, but are more risky in not being socially accepted (Joffroy, 1994).

High quality design and construction are important factors in gaining public confidence around new types of structures. For example, excessive cracking and sloppy construction can create uneasiness within the public about the structural robustness of such a form. Efficiency is a good indication; a structure which takes months to build with constant delays does not offer a sustainable and effective solution to the public. Thus, good organization and effective planning on site will provide the public with the confidence they require to accept the newer structural forms, such as thin-shelled structures (Joffroy, 1994).

## 2.5. Conclusion

Thin-shelled structures are a possible solution to the low-income housing problems experiences in South Africa and other developing countries across the world. The

aim of this thesis is to establish a proficient low-cost housing solution through the process of form-finding, design and construction of a prototype home that will be monitored in the future. This research attempts to design the cheapest, most efficient, and strongest shape for the specific purpose that these structures become an answer the South Africa’s housing problem.

# 3. Layout and shape establishment

## 3.1. Design Considerations

*"House design can be defined as the organization of space in such a manner as to provide for the domestic needs of present day society in the most economical and efficient way"* (Calderwood, 1953, p. 33)

There are a number of aspects that need to be considered when selecting the internal layout of a house. The circulation of the house is defined by the overall flow and practicality of each room in relation to the remaining rooms to create a normal living environment. A good circulation throughout the house indicates a good layout where each room needs to be strategically positioned (Calderwood, 1953). Low-cost housing has less flexibility in changes in design due to the lack of space. Because of this it is even more essential to establish a good layout to maximise on the space that is available.

There are a number of key elements that have been highlighted by Calderwood (1953). Window arrangements, kitchen to bathroom distances and bedroom placement are essential. It is essential that bedrooms have some sense of seclusion, even in a low-cost house. Various examples of bad circulation were examined. The main areas of bad practice include: minimal seclusion of bedrooms, all rooms opening off the kitchen, common bathrooms placed between bedrooms, etc. Highly complex arrangements are also ineffective and expensive. They generally tend to create a lack in comfort and ease of living i.e. external bathrooms, major storage areas, etc. Figures 3.1 and 3.2 are examples of poorly designed houses. A simple design is usually the most effective solution, as demonstrated in Figure 3.3.

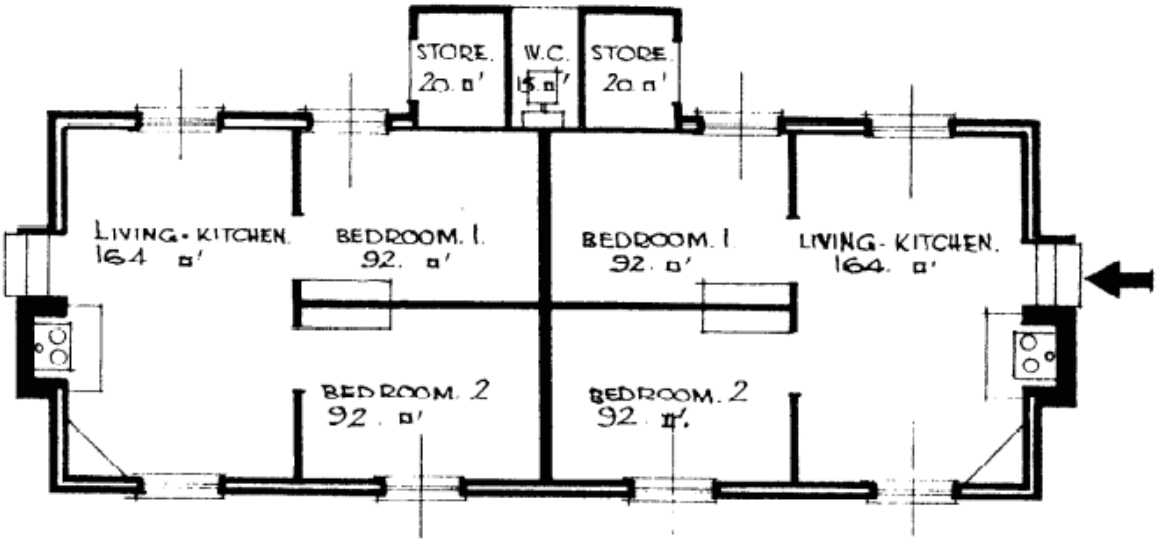



**Figure 3-1: Type Plan Built in MacNamee Village, Port Elizabeth (Calderwood, 1953, p19-21)**

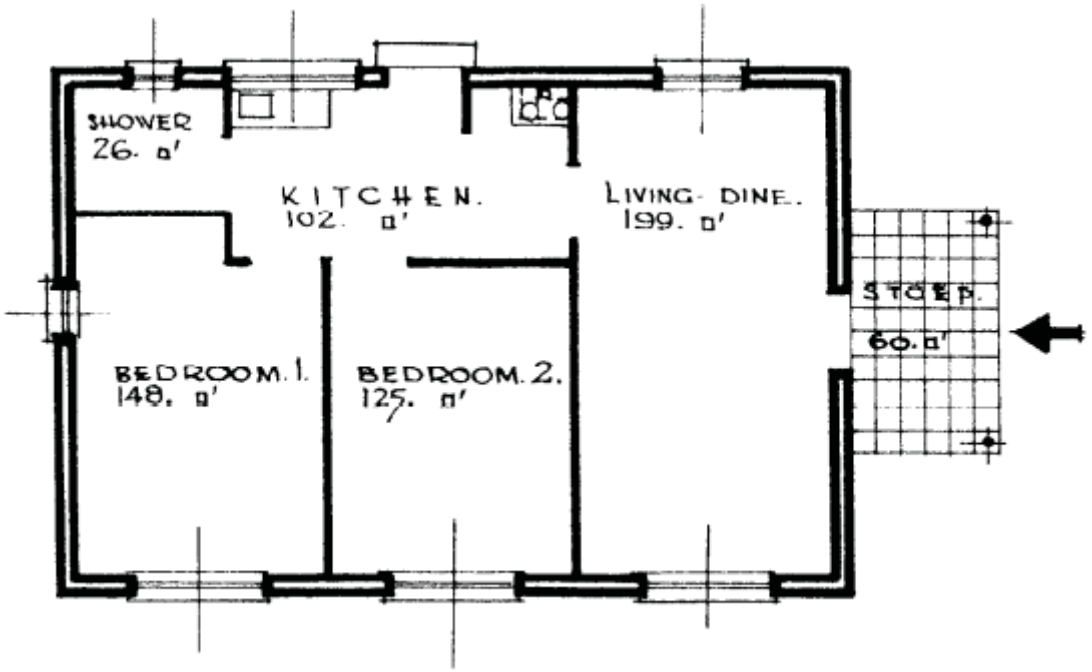



**Figure 3-2: Type Plan Built in Orlando, Johannesburg (Calderwood, 1953, p19-21)**

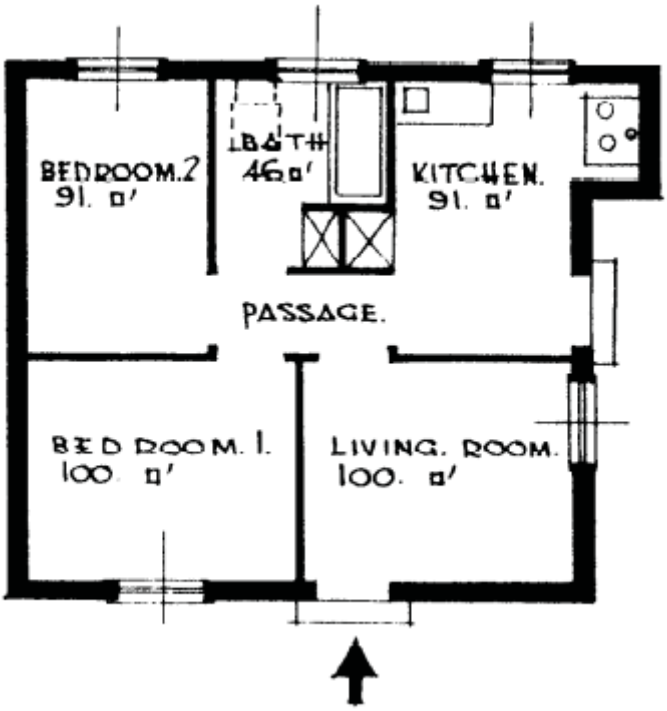



**Figure 3-3: Type Plan Built in Sharpe Township, Vereeniging (Calderwood, 1953 p19-21)**

When selecting a layout for low-cost housing, it is essential to ensure that all basic needs of people are met in such a small space. This incorporates protection to people against weather conditions, crime and other such elements. However, the main challenge is providing a flexible plan which can satisfy people's needs at present as well as for future generations (Calderwood, 1953). Social design is important as demands of people are constantly changing and acceptance by society is important to ensure that the project/prototype is effectively implemented. The design needs to be simple to ensure that all costs are minimised, but also to allow for adaptiveness. This may be in the form of design, construction materials or methods.

Another field that is extremely important in the housing construction industry is that of site selection. Site selection has direct bearing on the success of a project. The type of environment established and developmental costs vary considerably, with different sites. When selecting a site, the following aspects need to be taken into consideration: zoning, health, transport, job opportunities, services, topography, soil conditions, social survey, area and shape of the site and the cost of the land

(Calderwood, 1953). For many low-cost housing programmes, choice in site is limited, but these areas can still be explored in improving the existing site.

## 3.2. Design Selection

The currently implemented low-cost housing scheme in South Africa is RDP (Reconstruction and Development Programme) housing. This housing project has proven to be unsuccessful and has created considerable outcry amongst communities. The sizes of the houses range from approximately 36-45 square metres (City of Johannesburg, 2008) and cost between R50000 and R70000 to construct (SAPA, 2011). The aim of this research is to provide a house for people which is more spacious and environmentally friendly, while still being competitive in the cost market.

When selecting a layout and shape, the major aim is to optimise costs and space. The most efficient shape for housing is a square one. Even though this shape appears to be smaller than a rectangular one, it is in fact the optimal solution to provide maximum space.

It is difficult to cut down on construction costs, particularly in the low-cost sector, so it is important to perform a general cost breakdown to establish which area uses up majority of the funds. Two sources, Taylor (2011) and Braxton (2013), discuss the cost breakdown when constructing a typical house. They found that approximately 25 percent of the funds are spent on the roofing system. In some instances, as much as a third of the costs were used for roof construction (Minke, 2000). Thus, this indicates that the roof is the most economically sensitive area in a house. Walls are found to be the least sensitive, as they can be constructed using almost any material. Services and finishes are the areas which utilise the most funds and are variable depending on the extent of finishing required.

The typical roofing system is trusses and tiles, or in the case of low-cost housing, sheet metal. Both of these solutions are impractical as the cost is either too high or the quality too low. However, even though there are many options in the roofing sector, none of these provide a cheap and structurally effective solution. Within the low-cost housing sector, it is extremely common that people make use of corrugated

steel as a roofing material. This solution is not sustainable, however cheap. Some of the major problems highlighted with this form of roofing include poor thermal properties, high maintenance costs due to poor resilience to weather and noise created during rain or hail. Rhyner *et al*. (1998) found that there are major energy savings when constructing with curved forms. There is an approximate energy saving of 22% when using curved instead of flat roofs.

Thus, a new option needs to be considered in the low-cost housing sector, which will keep costs at a minimum, improve structural performance, resilience and thermal efficiency. Thin shells have proven to be an extremely economical and structurally exceptional solution. Therefore, the concept of designing a square household with a vaulted roof was created. These structures have the ability to span very large areas and have been found to be the most economical means of construction. A vaulted roof would create more space, while simultaneously keeping the costs at a minimum, as only a single layer of bricks are required. However, the shape of the vault is an essential aspect in the structural success of the solution.

Talocchino (2005) did considerable research in form finding and identifying the ideal shape. During his investigation, he stated that the catenary was in fact the best structural shape as it eliminated all forces except for compressive forces, but it had a high level of wasted space (Talocchino, 2005). This is essential when considering low-cost housing solutions, as space is minimal and needs to be optimised to its best ability. However, the difference between the two investigations is that Talocchino's made use of thin shells for the entire structure while the proposed design uses them as the roof structure.

Both housing ideas are extremely innovative. However, a vaulted roof and standard lower floor is a combination of both current and novel design methods, and thus more likely to be socially accepted. The lower level is designed as an ordinary house, while a vaulted roof allows for more space within the structure. Therefore, a catenary vault is selected to act as the roof structure. If the roof is constructed at a very steep angle, there is minimal space wastage as the upper floor can be utilised and minimal dead space is created. It is also important to consider furniture within a

house, i.e. fridge, cupboards, beds, etc. By creating a square lower level, this allows for no loss of space whilst still minimising construction costs with the construction of a vaulted roof.

A number of other areas were also considered in the selection of the design, but most importantly, the ability for this prototype to act as a home. Even though this is a low-cost housing solution, it is still important that it exhibits homely characteristics to ensure social acceptability and an overall approval from society.

Low-cost houses are extremely cramped. Unfortunately this is inevitable and thus it is important to create a sense of space, even if there isn't much. The idea of maximising on space with a high roof was also justified when it was decided to create a double volume area. The high roof would allow for more air and light to penetrate the house and in turn create this desired sense of space. A general design was selected (Figure 3-4) and an analysis was performed to ensure that the design is a structurally viable solution.

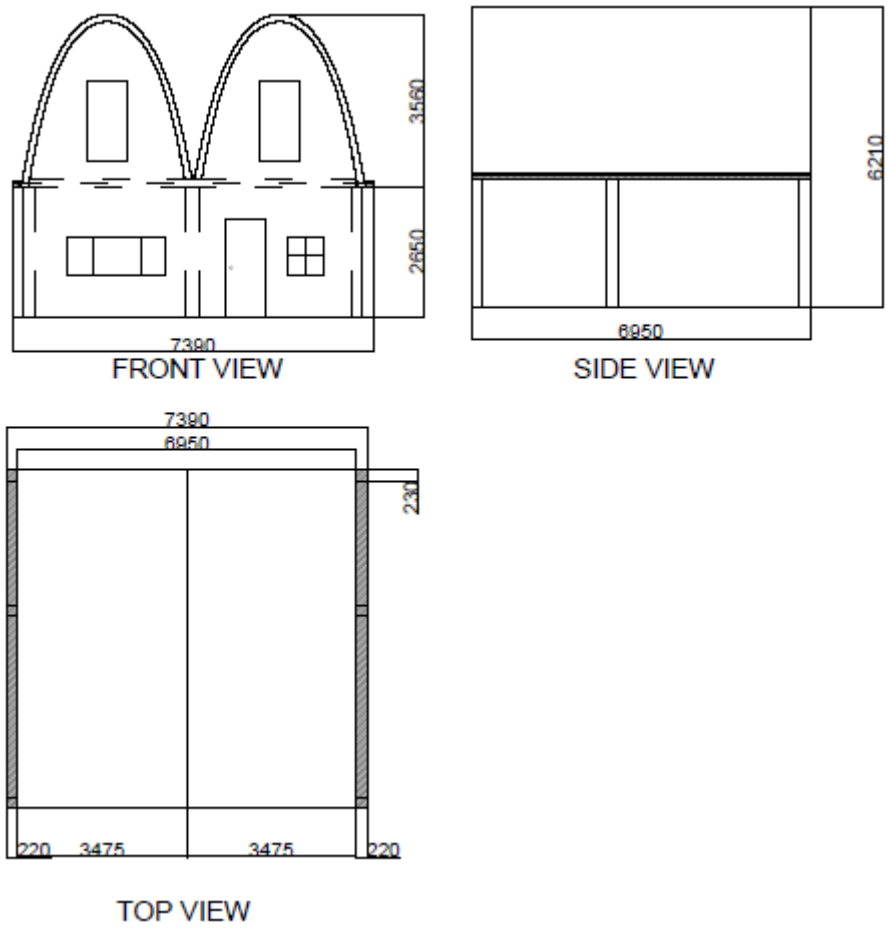



**Figure 3-4: Layout of housing prototype**

The general layout of the housing prototype is illustrated in Figure 3-4, while the selected internal layout is shown in Figure 3-5 below. The internal layout is orientated so that the lounge and bedroom face eastwards, thus maximising on morning sun. The upper floor space is utilised as a bedroom that is not generally found in typical housing designs. This space was selected to maximise on the number of residents per house without creating a sense of overcrowding.

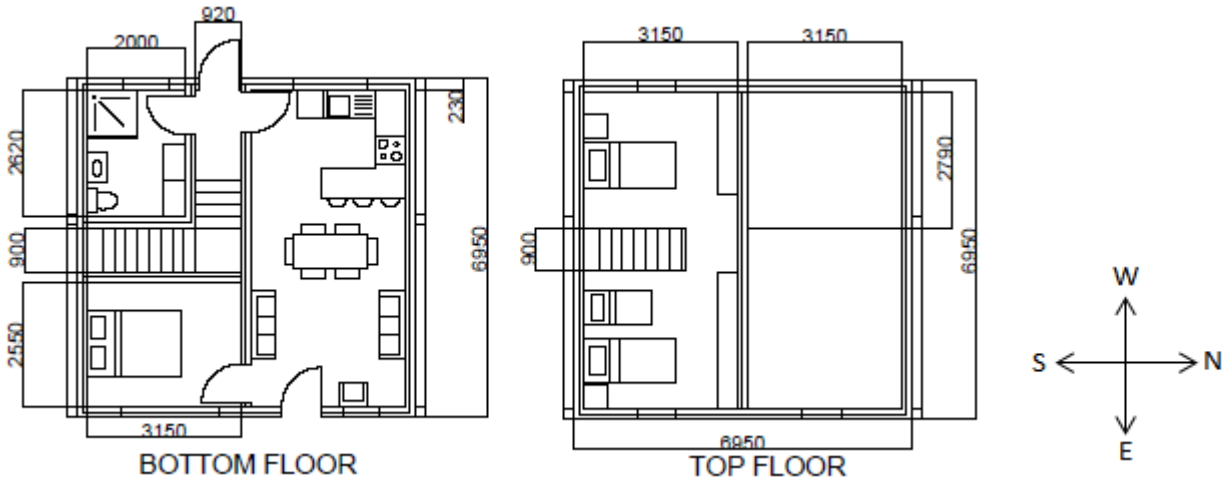



**Figure 3-5: Interior Layout of housing prototype**

# 4. Materials Investigation

Majority of houses in South Africa are built using ordinary clay or cement bricks. Even though these materials are very cheap, they are not a sustainable solution as they are environmentally harmful, particularly in the production phase. Transport is also a major concern when it comes to rural construction. Transporting the materials to site is expensive and difficult, creating major unnecessary cost increases. Thus, it is necessary to consider other more sustainable options. In this section, we will discuss the material properties that are required when constructing a low-cost house. In particular, Hydraform produced cement stabilised earth bricks will be analysed. A thorough investigation into Hydraforms material selection, testing and brick production will be discussed.

## 4.1. Introduction

Cement Stabilised Earth Bricks (CSEB) are a relatively new material in the construction industry, showing its face for the first time in the 19$^{th}$ century in Europe (Auroville Earth Institute, 2012). Since then, the concept has rapidly grown in popularity and its various uses can be seen throughout the world. The use of soil as a building material has been investigated extensively before it was able to compete with the current cement bricks. A major problem with soil is that it lacks strength and durability. However, after continuous research and testing in stabilisers, compression machines and material studies, CSEB has improved drastically. Today, the CSEB is able to compete with conventional bricks in terms of performance and cost, where savings are approximately 18% (Uzoegbo & Hobona, 1999). Rhyner *et al.* (1998), found that the insulation properties of these bricks are excellent and a 33% saving in electrical energy is possible.

Although CSEB have many favourable properties, there have been many debates regarding their appropriateness. They are generally perceived as inferior, due to the lack of standards in the construction industry, as well as social unacceptability, primarily with people with low income. CSEB also has a poor reputation, and assumed to be weak in compressive strength.

However, Houben & Boubekeur (1998) found that these bricks have sufficient strength to construct a two to three storey buildings. Since 1998, there has been considerable ground breaking work in the production and use of CSEB. Hydraform, a leading brick and block making Machine Company, are achieving compressive strengths of as high as 10MPa. These strengths are considerably higher than what is needed for the construction of a simple house.

Hydraform have put a foot in the door with their innovative and affordable brick machines worldwide. They have proved that the CSEB, if made properly, is just as effective and durable as the current cement bricks. The dry-stack interlocking block has also reduced construction speeds by approximately half, with its quick and efficient stacking system. The other block that is used in the construction of this prototype house is the Hydraform splitter-brick block.

## 4.2. Production process

The materials, mix ratios and other specifications in the production of these bricks can be found in the Hydraform training manual (2012). A two week research programme at the Algerian research facilities, CNERIB, was completed during the duration of the project. Research, tests and investigation into various materials were performed. Bricks were produced and various tests were carried out to investigate their strength and durability. This section covers the general method of producing CSEB. The information provided is a combination of Hydraform methods, as well as the research and work experience obtained in Algeria.

### 4.2.1. Soil Selection

In order to achieve the best blocks, it is important to ensure that the correct soil is used in the production process. The type of soil is particularly important in ensuring that the correct strength is achieved. Hydraform use a sandy-loam soil, found at least 1m below the ground, which contains more sand than clay and fines, and no organic material (Hydraform, 2012). Auroville Earth Institute (2012) stipulates that no top soil may be used due to having a high content of organic matter. Correct amounts of both clays and sands are important, as the clay improves the bricks workability while the sand is the binder which essentially provides the strength. This is not always

possible as soils vary considerably at different sites. When one considers that the aim of this project is to establish a housing solution, which can be implemented anywhere, a soil selecting guide is of utmost importance in ensuring that the most suited soil in the area is found and used. Hydraform (2012) provides a guide that helps the user to locate the most suitable soil at a perspective site. The three most important considerations when selecting a soil include: finding a well-graded soil (clay content ranging between 15% and 35%) and a soil that is free of roots, leaves or any other organic material (Hydraform, 2012).

There are a number of field tests which can be done to check the adequacy of the soil, i.e. the visual test, the wash test, the jar test and the shrinkage test. Each of these tests have different indicators which determine the quantity of clay and sand present in the mix. (Hydraform, 2012)

#### 4.2.2. Mix ratios

Mix ratios for block production vary depending on the required strength. The blocks used in this project are 10MPa in strength. For this strength a general mix ratio for cement to soil is 1:8. This strength is sufficient to support a double storey building. The colour of the blocks will vary according to the type of soil that is used and can be modified with the use of cement dyes (Hydraform, 2012) or oxides.

Hydraform (2012) provides a valuable site guide in measuring the correct mix ratios. By using a wheelbarrow, an accurate material mix is established with minimal effort, e.g. one bag of cement (50kg) mixed with four wheelbarrows (65L each) produces a 10MPa block. This is extremely effective, since simplicity is crucial in low cost projects.

There are many advantages associated with CSEB. However, there is one area in which these materials suffer from durability issues. Durability is an aspect in which CSEB are lacking. Since the blocks are predominantly made up of soil, they are affected by water. There has been considerable research in water proofing the blocks with various additives. In the blocks made by Hydraform, a chemical called Pareflo is used. Pareflo is added into the mix, prior to production. This chemical acts as a water repellent without affecting the mechanical strength of the block (Chryso,

2008). Pareflo has improved the material durability, but it has also been found to be environmentally sustainable (Chryso SA, 2012).

### 4.2.3. Production

The production process of the bricks and blocks is very simple. First, the material is sieved to ensure any unwanted particles are removed. A 8-10mm sieve can easily be made on site by using local materials to create a frame and some mesh. Secondly, the desired mix ratio is determined and the materials are mixed together while slowly adding water. It is important that the correct clay content is achieved otherwise the soil will be difficult to handle. The soil should have a clay content between 15 and 35 percent. The clay content can be determined using a number of tests; i.e. visual test, jar test, wash test, etc., but the most accurate is the shrinkage test. By measuring the shrinkage of the soil in a mould, the clay content can be determined. The soil-cement mix is mixed either by hand or by using a pan mixer. The mix is determined by the material volume (Hydraform, 2012).

The mix is then checked to ensure it has the correct moisture content. A drop test is used to establish whether more water or soil/cement mix needs to be added (Figure 4-1). The water content can also be checked by producing a block and observing any cracking or changes in block length that may occur. A short, wet block with cracks indicates too much moisture. While a very dry mix will produce a long, brittle, unworkable block. The water content required depends on the moisture content of the soil but is usually approximately one litre per block. However, sometimes the water content is correct but the blocks still vary in length. This can be due to insufficient material being poured into the chamber, or the operator is not allowing the machines to complete the full compressive action before removing the bricks from the chamber. Thus, it is necessary that the machine operators have sufficient training so that the blocks produced are of good quality.

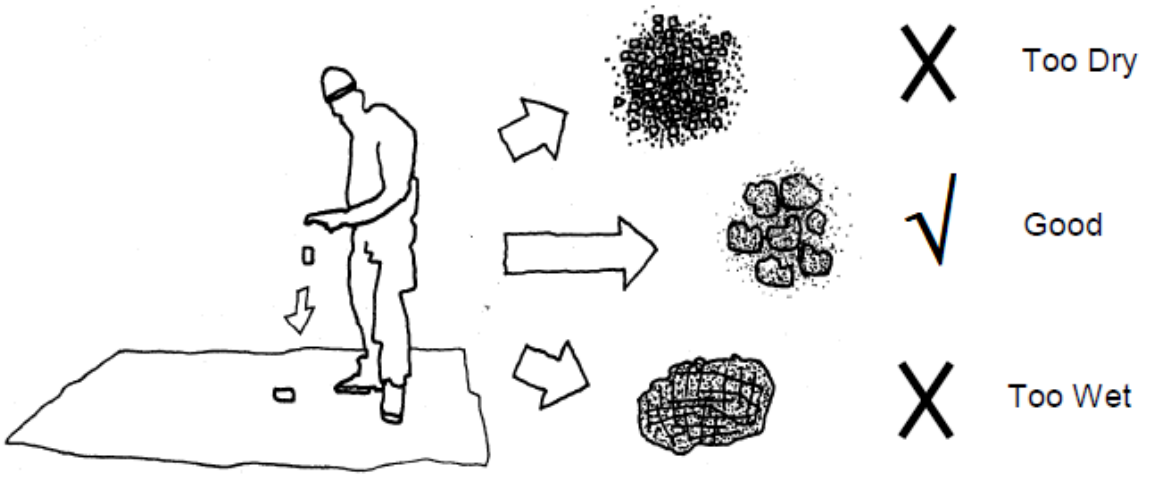



**Figure 4-1: The Drop Test (Hydraform, 2012, p 32)**

Once the blocks have been produced, they need to be stacked and allowed to cure. As these blocks are predominantly soil based, they cannot be stacked too high so as not to damage the bottom blocks. It is advised that the blocks are stacked more than five bricks before they are covered with a plastic sheet and left to cure for seven to fourteen days. Undoubtedly, if the blocks are cured for longer then they gain further strength. It is important to note that the blocks are cured and not burnt, as is common with normal fired bricks. This further decreases the environmental impacts that are associated with brick production. Figure 4-2 describes the strength development for a 7MPa CSEB.

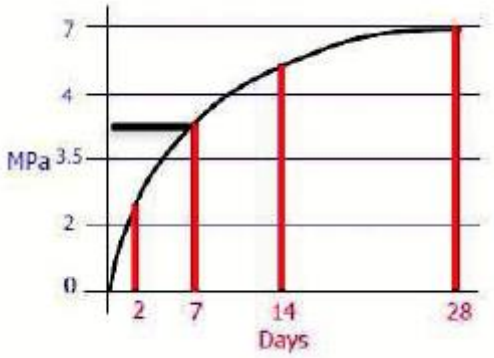



**Figure 4-2: Curing curve for a 1:12 block (Hydraform, 2012, p 37)**

When building, in a barren rural area, it is important to consider the water requirements of the blocks. There needs to be access to water, or sufficient water on site, to ensure that the blocks can be constructed and that enough water is available for curing. Generally the latter of the two is overlooked. And, if the blocks are not cured properly, then they may not gain their required strength.

#### 4.2.4. Problems in production

There are many challenges in the production phase of the building materials. A major one is a lack of training in the use of the machines, resulting in the production of poor quality blocks. This also includes the lack of expertise in maintaining the machinery, which is demonstrated when blocks with rounded edges or reduced interlocking are produced.

Inadequate mix ratios are an even more common challenge in block production and are likely to occur. This includes having too much or too little water, and having cement or soil in the mixing step. Inadequate mix ratios result in problems such as rough surfaces, cracks in the block and varying block dimensions.

## 4.3. Material properties

Hydraform are the current leaders in the production and testing of CSEB blocks in South Africa. Hydraform (2012) performs a number of tests to ensure that the necessary compressive strength is achieved. Thus, a simple compression test is performed throughout the production phase to provide a rough estimate of the strength of the bricks and blocks. This test is not as accurate as laboratory tests, but it is designed to give a rough estimate to ensure that the mix is sufficient. The block tester consists of a simple device that utilises a jack and gauge to obtain the failure compressive strength of the produced bricks. Such a test is vital when working and producing blocks on site, if there is no access to sophisticated laboratory tests.

Material properties of CSEB blocks obtained from various literature and for different experiments are summarised in Table 4-1.

**Table 4-1: Material properties of CSEB**

| ***Property*** | **Hydraform** | **Auroville** | **Wits University** |
|---|---|---|---|
| *Density (kg/m³)* | 1950 | 1900-2200 | 1900-1950 |
| *Poisson's ratio* | - | 0.15-0.35 | 0.2 |
| *28 Day Compressive Strength (MPa)* | 7-10 | 5-7 | 5-5.4 |
| *28 Day Tensile Strength (MPa)* | ~1.1 | 1-2 | 1.18-1.4 |
| *Youngs modulus (MPa)* | - | 700-1000 | 3500 |
| *Thermal conductivity/coefficient of thermal expansion (mm/m°C)* | - | 0.01-0.015 | - |

The reported values were obtained from Auroville Earth Institute (2012), Magaia (2003) and Fernandez (2003) from Wits University, and publications and testing from Hydraform.

The two blocks that are utilised in this project are the Hydraform dry-stack interlocking block and the Hydraform Splitter-brick Block. The dry stack block is used to speed up the construction process and minimise costs. The splitter brick block is used in the vault due to its relevant size and to ensure that a strong joint is created between the bricks. This is attributed to the grove in the brick, allowing it to act as a key between each layer.

### 4.3.1. Dry-stack interlocking Blocks

Dry-stack interlocking blocks have proven to be one of the most ingenious inventions since the introduction of CSEB. Hydraform makes these blocks so they are almost identical to standard clay bricks in terms of strength, while also possessing many more added benefits. They can be produced from either soils or recycled material and still achieve a very high compressive strength.

Many benefits have been noted when changing from standard brick-mortar construction to dry-stack interlocking construction. It is common for a house to be constructed with double brick, connected with mortar. However, Hydraform have managed to eliminate the need for any mortar by merely interlocking the blocks. This results in considerable cost and time savings, as construction is quick and efficient. These bricks also provide a lovely face brick finish, eliminating the need for plaster.

These blocks are particularly effective in walls and other vertically loaded structural members. Since they are dry-stack, they can only support nominal horizontal forces. The blocks, however, can be used like conventional mortared bricks if they are required to carry horizontal forces. In this case, the user would still have cost savings as the mortar required would be approximately three quarters of that required for double brick, because there are a smaller number of joints and no centre joint.

All the interlocking bricks used in this project are 10MPa in compressive strength, after 14 days of curing. A 1:8 mix ratio is used to achieve this strength. Hydraform provide a number of machines and moulds to satisfy the various sizes of required blocks. The block dimensions used in the production of the low-cost house are presented in Figure 4-3 and an image of the final product in Figure 4-4.

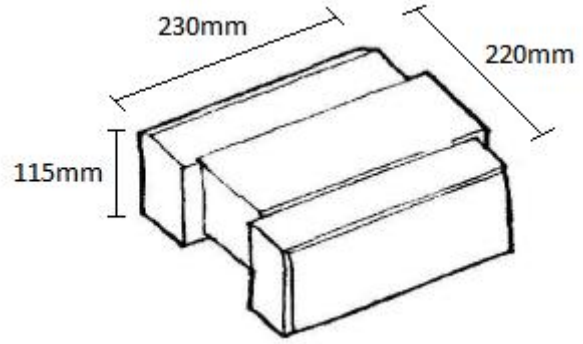



**Figure 4-3: Dimensions of the dry-stack interlocking block**



**Figure 4-4: The Dry-stack Interlocking Blocks used in the construction of the prototype**

### 4.3.2. Splitter-Brick Block

The current splitter-brick block is a single block which splits up into three separate normal sized bricks as shown in Figure 4-5.

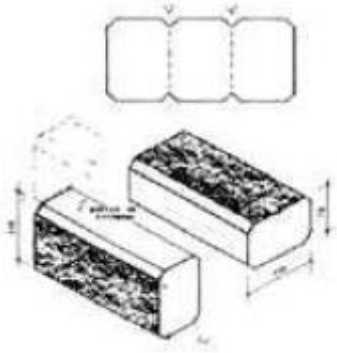


**Figure 4-5: Image of the split-brick block that separates into 3 individual bricks (Hydraform, 2012, p 53)**

A problem with this type of block is that the central piece has two rough sides as opposed to the outer ones which have one each. This is generally undesirable as most users are looking for a smooth finish rather than a rough one. The middle brick is usual disposed of due to its undesired look. This results in considerable wastage

of material. Therefore, in this project, Hydraform is testing a new mould that has been developed which splits a single block into two separate bricks instead of three. The rough sides can now be hidden or mortared in and there is minimal wastage of material.

An image of the brick used in construction, and its dimensions, are shown in Figures 4-6 and 4-7.

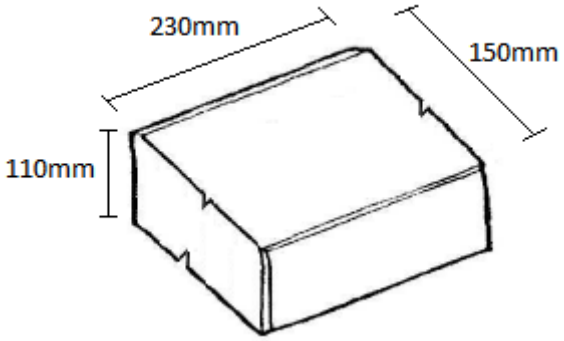



**Figure 4-6: Dimensions of the "half" split-brick block used in the prototype**

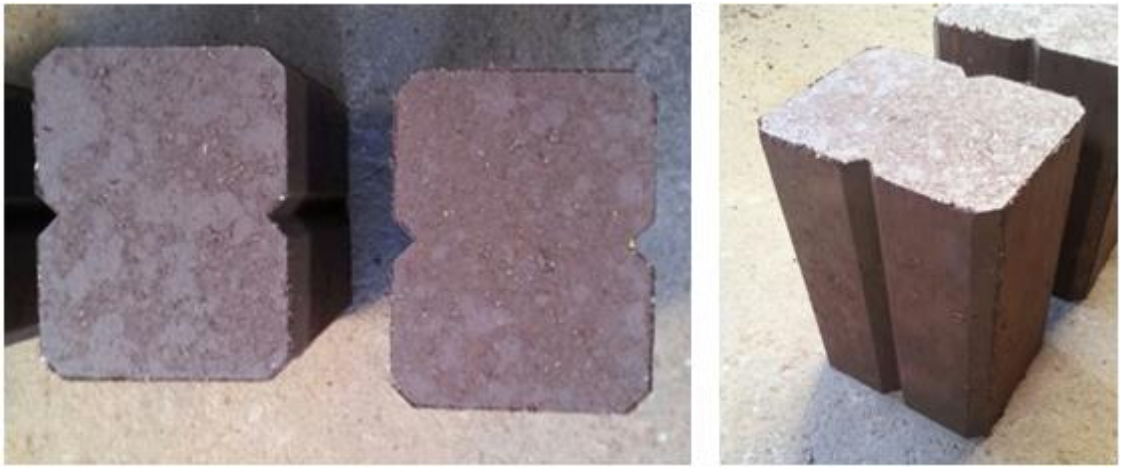


**Figure 4-7: Image of the split-brick block used in the construction of the vault roof in the prototype as supplied by Hydraform**

# 5. Method of Analysis for a Catenary Curve

## 5.1. Introduction

"*The ideal shape for resisting loads distributed uniformly along a surface is a* catenary, *the curve taken under its own weight by a hanging chain or cable"* (Allen & Zalewski, 2010, p. 65)

The process of designing and analysing a catenary curve is a field which has not been extensively explored or discussed. Allen & Zalewski (2010) briefly discuss the method of design using Hooke's Law and then elaborate on the Graphical Method of design. Catenary curves are the most natural and efficient form, yet they are not utilised or explored as much as they should be. If a simple and effective method of designing a catenary curve can be established, the curve can be utilised at a greater scale, encouraging more efficient and structurally sound design.

## 5.2. Mathematical definition

The catenary curve equation was established in the 17$^{th}$ century by Huygens, Bernoulli and Leibniz (Carlson, 2013).

Mathematically, it is defined by the following equation:

$$y = a\cosh\left(\frac{x}{a}\right) \tag{5-1}$$

Where *'x'* represents the vertex when x=0, and '*a'* is a parameter that can be any number except zero, and controls how rapidly the curve "opens up". The parameter '*a'* can also be described as the scaling factor for the curve. (Weisstein, n.d.)

This mathematical representation of the curve is ineffective in design as it fails to take variable loading into account. The equation merely describes the shape of the curve and the relationship between its '*x*' and '*y*' variables.

## 5.3. The Graphical method

The Graphical method is a method of approximation which is carried out by assuming a curve and then working backward to establish the actual, true curve. The

final result is achieved using an iterative approach. The method was established to suit the geometrical properties of a parabola (Allen & Zalewski, 2010).

Allen & Zalewski (2010, p. 65) provide an in-depth example of designing a cylindrical shell roof using the graphical method. It can be summarised as follows (Figure 5-1):

1. Select three main points that the curve should pass through. These usually include the two end points and the midpoint. The aim is to develop a “pole” that will allow the curve to pass between these three unique points. A pole is a reference point that is used to generate the required polygon e.g. the centre pole for a circle.
2. Select a general curve. This is usually achieved initially assuming a parabolic curve. If the parabolic curve is flat, the parabolic curve approximates the catenary curve.
3. Separate the curve into the desired number of increments and estimate the loads exerted on those sections. These are calculated as surface loads, not horizontal projections. Note that the loads are not uniform in each segment and a total load is merely required.
4. Once the total value is calculated, it can be applied as a horizontal line load. The aim is to create a “trial” polygon which will then be used to establish the true curve.
5. A convenient trial pole is selected and used to construct the trial force polygon. The base of the polygon is drawn using the same increments established in step 3 and connected to the pole. The trial force polygon is then used to establish the angles of the segments along the curve, i.e. o’a, o’b, etc. Refer to Figure 5-1.
6. Connect points x’ and z’ to y’ to draw lines x’y’ and z’y’.
7. Through the trial pole draw two lines with the same gradients as x’y’ and z’y’ which cut on the base at m and n.

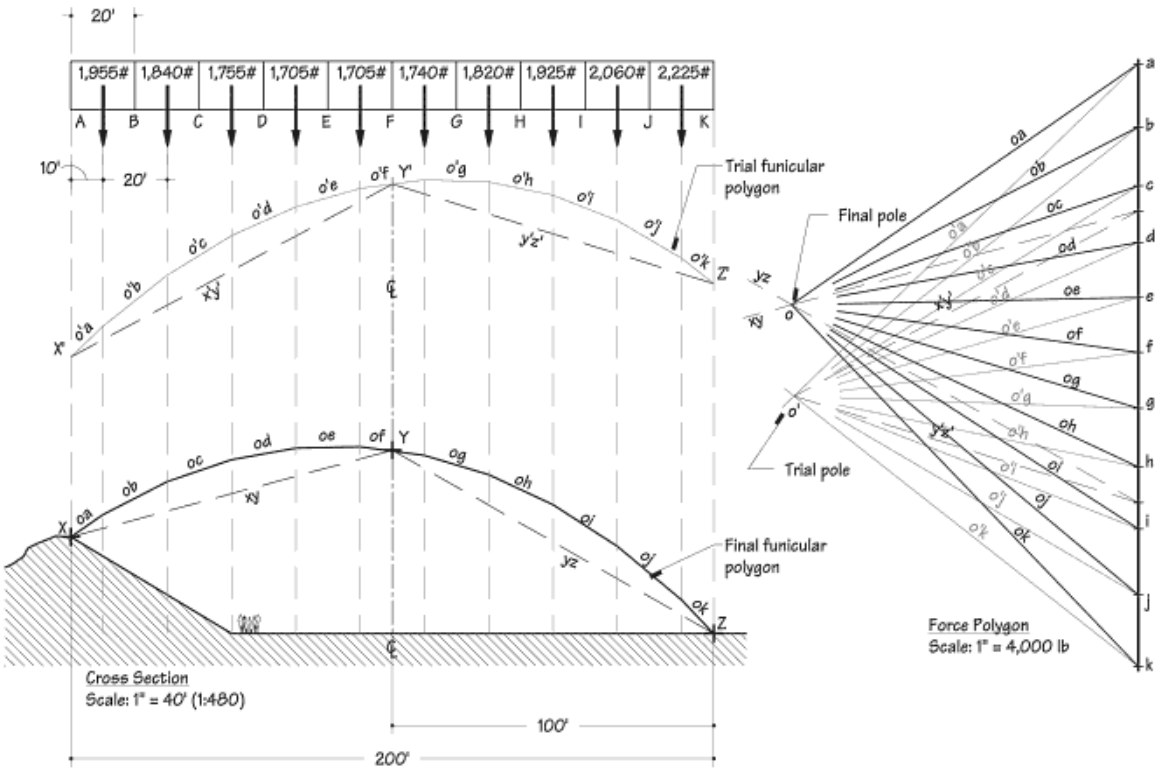



**Figure 5-1: The graphical method (Allen & Zalewski, 2010, p 76)**

8. At the true curve, connect the end points to the midpoint creating lines xy and yz. These are the true closing strings. Through point's m and n, draw lines of the same gradients as xy and yz. Their intersection creates the real, final pole.
9. New rays are drawn from final point o to the respective base points *a* to *k*. The rays are used to determine the angle of each segment *oa* to *ok* and the true curve is determined.

This method has been found to be accurate in determining the internal forces of any structure and it works well for vertical loads. The method is, however, labour intensive and complex when dealing with a form other than the parabolic form (Allen & Zalewski, 2010). There is considerable difficulty in modelling and analysing horizontal forces when using the graphical method. There is little guidance in designing and modelling complex lateral forces such as wind or snow. Allen & Zalewski (2010) suggest that this method not be used when modelling such complex shapes, particularly under lateral loading, but to rather design an approximate shape

and then stiffen the curve to provide resistance to these forces. Otherwise, a new method needs to be explored.

## 5.4. Segmental Equilibrium Method

### 5.4.1. Introduction

In the 1670's, a Scientist by the name of Robert Hooke expressed considerable interest in catenary curves and how they work. His aim was to determine the ideal shape of an arch. With this in mind, Hooke established that the inverted catenary was the ideal shape for an arch. He also stated that if an arch of another shape is effective, it is merely because somewhere in the thickness of the membrane, a catenary can be found (Huerta, 2006).

Hooke performed most of his experiments using hanging chain models. When analysing the models more closely, Hooke found that in order for the hanging chain to be in pure tension, and therefore the inverted arch to be in pure compression, both have to be in equilibrium. Thus, Hooke's principle was born (Allen & Zalewski, 2010).

The graphical method struggles to incorporate any lateral forces, due to the complexity of the method. It is important to establish a mathematical method which incorporates both horizontal and vertical forces i.e. the segmental equilibrium method.

### 5.4.2. Theoretical basis

The equilibrium method is a mathematical method which utilises the loading on the structure to establish the thrust line of the curve. The line of thrust is a representation of equilibrium within the structure. It can be described as "*a theoretical line that represents the path of the resultants of the compressive forces through the structure"* (Allen & Zalewski, 2010, p. 219).

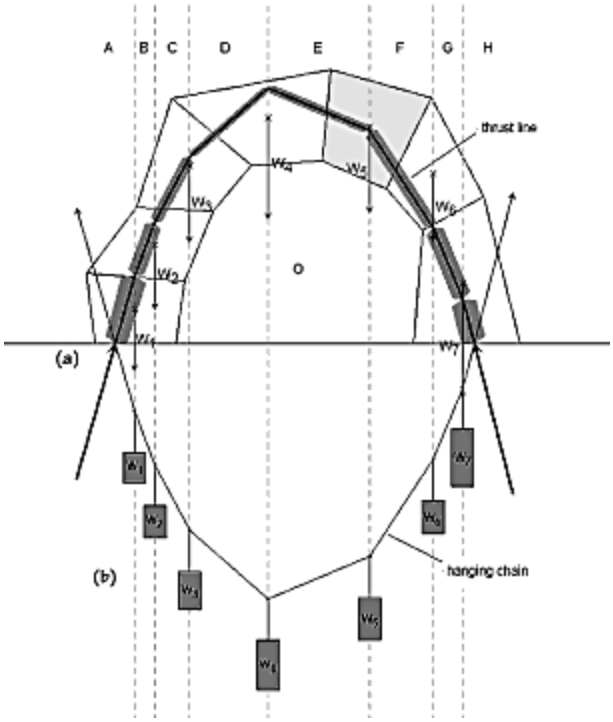



**Figure 5-2: Hanging chain with its inverted form and corresponding thrust line through the thickness of the curve ( Allen & Zalewski, 2010, p 220)**

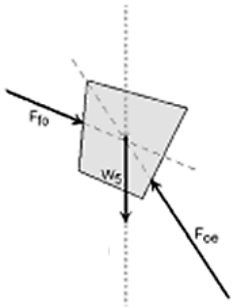



**Figure 5-3: All internal and external forces applied to each segment, in equilibrium (Allen & Zilewski, 2010, p 220)**

Figures 5-2 and 5-3 demonstrate how equilibrium is used in each section to determine the overall thrust line of the structure. Each individual segment is analysed, incorporating all the forces and loads exerted on it. The arch is held in place by the compressive forces, applied from one block to the other. Since we know that each block carries the compression force exerted by blocks on either side of it,

they can be combined with the external loads, as well as its' self-weight to determine the line of thrust of the structure (Allen & Zalewski, 2010).

If the equilibrium line, i.e. the thrust line, extends to the edge or outside of the thickness of the material, tensile forces are created which result in cracking, and possibly failure. If the thrust line reaches the edge cracking will occur, or in some instances hinges will form, as high stresses are created at those particular points (Figure 5-4).

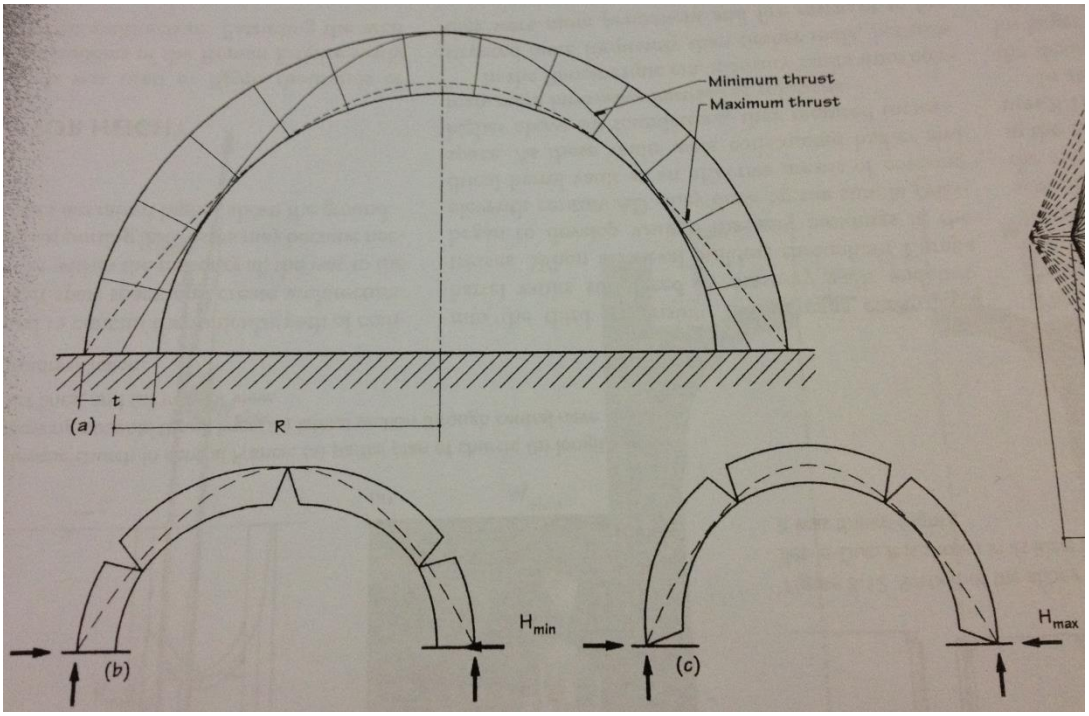
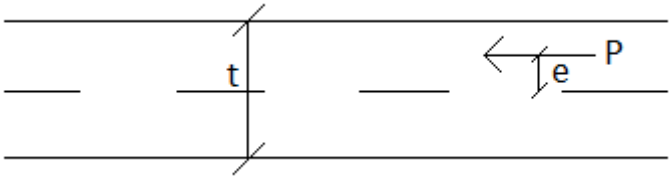



**Figure 5-4: (a) Maximum and minimum thrusts lines within the vault, (b) Minimum thrust lines and (c) maximum thrust lines can cause cracking in the vault (Allen & Zalewski, 2010, p 221)**

### 5.4.3. The Middle-Third concept

There are a number of ways to analyse the design results of a catenary. The more effective method is that of the middle third. This consists of choosing a constant thickness for the vault and checking that all the thrust lines, for the various load cases fall within the middle third of the section. This method was chosen as the

thickness of the CSEB remains constant throughout. Majority of the vaults that have been built are made from either concrete or bricks. Both of these materials have minimal tensile strength. If the thrust line falls within the middle third of the section, the material will be in compression. However, if the thrust lines move out of the middle third, those areas will be subjected to tensile forces and cracking may occur (Allen & Zalewski, 2010). The aim is to avoid any tensile forces, since most masonry materials are not designed to carry these forces effectively. The middle-third theory is substantiated as follows:




$$\sigma = \frac{P}{A} \pm \frac{Pe}{Z} \tag{5-2}$$

$Z = \frac{bt^2}{6}$ and the section width=1

$$\sigma = \frac{P}{t \times 1} \pm \frac{Pe6}{t^2 \times 1}$$

Solve for σ=0

$$\cancel{t \times 0} = \frac{P\cancel{t}}{\cancel{t}} - \frac{6Pe\cancel{t}}{t^{\cancel{2}}}$$

$$\frac{\cancel{P}e6}{\cancel{P}t} = \frac{\cancel{P}}{\cancel{P}}$$

$$\frac{e6}{t} = 1$$

$$e = \frac{t}{6}$$

*e* is only half of the middle third

$$\boldsymbol{2e = \frac{t}{3}} \tag{5-3}$$

### 5.4.4. Method of Design

The segmental equilibrium method of design is a new method of determining the shape of a catenary shell. Not only is the method computerized but incorporates complex loading arrangements, such as wind and non-symmetrical gravity loads. It must also be noted that the finite element methods are used to analyse a pre-determined shape. The segmental equilibrium method determines the shape, as well as the membrane forces (i.e. thrust line). This method is easily set up in Excel and allows for analysis and design of catenary curves. A step-by-step explanation of the method is provided.

1. Begin by inputting all the necessary material properties. These include density and Youngs modulus.
2. Pick a set of general dimensions for the structure, including the height and width of the curve. It is important to have some idea of the size of the curve that is desired. The solution is iterative and therefore these dimensions will change slightly throughout the analysis. If the desired curve is flat, the user may estimate the shape of the curve using a parabolic equation.
3. Input the length of barrel vault you wish to design. It is simplest to pick a 1m length, a segment which represents the length of the shell.
4. Select an initial segment size. The segment height is not necessarily a true reflection of the actual segment height, but rather a segment height so that the coordinates of the curve can be calculated. The shorter the segment height, the more segments, but the more accurate the curve will be. The height can be an arbitrary value or it can represent the size of the brick and mortar joint.
5. Select an initial angle at the reaction. This angle is the starting angle at the left hand base of the shell. This angle is depicted in Figure 5-5. The angle of the reaction is also the angle at the base of the shell.

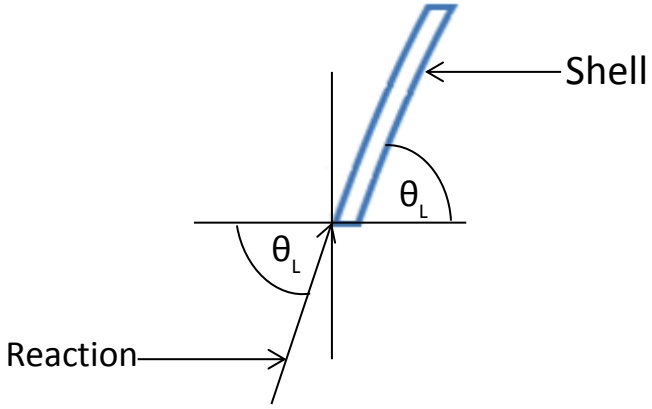



**Figure 5-5: The Initial angle at which the reaction force is orientated**

Note that the higher the value of θ, the steeper the curve. The angle will vary depending on the nature of the load.

6. Choose the number of segments that are needed in the analysis. This can be adjusted accordingly. The flatter the segments, the more you will need to complete the length of the curve and vice versa.
   Note: Steps 4 to 6 are incremental. The thrust force and thrust line will change with each loading pattern. However, it is easier to select a finite number of segments, which remains constant for each loading pattern.

   All the required material properties and geometric parameters have now been inputted. These are inputted in the corresponding columns in Table 5-1. Next step is to set up the loading.

7. The following loads can be incorporated into the spread sheet: Dead Loads, Live Loads, Wind Loads, and Snow Loads. Snow loads will be ignored in this analysis, as they are not relevant to Southern Africa. Once the loads have been calculated, they are transformed into point loads and applied at the centroid of each segment.
   Note: Before the loads are transformed into point loads they are calculated as follows: the dead load as a surface load, live loads as horizontal projections and wind load as a surface pressure.

8. The following ultimate load cases are investigated, according to the loading code SABS 0160-2 (2009):
    - 1.5*Dead Load
    - 1.2*Dead Load + 1.6*Live Load
    - 1.2*Dead Load + 0.5*Live Load + 1.3*Wind Load
    - 0.9*Dead Load + 1.3*Wind Load
9. Now set up your spread sheet (Table 5-1). The following headings are recommended, but can differ depending on the user and what is required in the calculations.

**Table 5-1: The spread sheet layout for the equilibrium method (Figure 5-6)**

| Segment No. | Height of Segment | Weight | Left Angle | Left Thrust x | Left Thrust y | **Left Thrust Resultant** | Right Thrust x | Right Thrust y | **Right Thrust Resultant** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | X | Y |

10. The first step is to calculate the actual shape of the curve. Therefore, only gravitational forces are taken into account.

    *Assumption*: The thrust line established from the self-weight is the centre line of the curve.

    When applying live and wind loads at a later stage, the same analysis process applies.

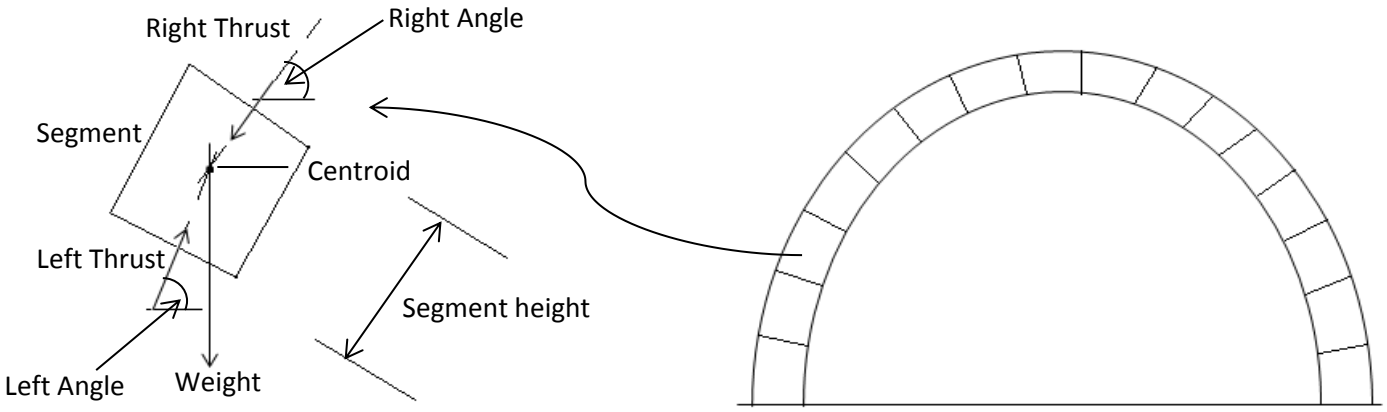



**Figure 5-6: A diagram illustrating the meaning of each heading in table 5-1**

11. The gravitational loading is applied as a point load at the centroid of each segment. At this moment, all the loading is constant and vertical, inputted in the column labelled *weight*. This value will vary with the various loading combinations and patterns. Each segment is loaded individually.
12. Columns marked *Segment no., Height of Segment* and *Left Angle* consist of the values chosen in steps 4 to 6.
13. The first force, *Left Thrust y,* is now calculated. The first and last vertical reactions are merely the total weight divided by two as the curve is symmetrically loaded. This can also be calculated through equilibrium equations such as ∑M=0.
14. Now *Left Thrust x* and ***Left Thrust Resultant*** can be calculated. This is done through the use of trigonometry as depicted in Figure 5-7.

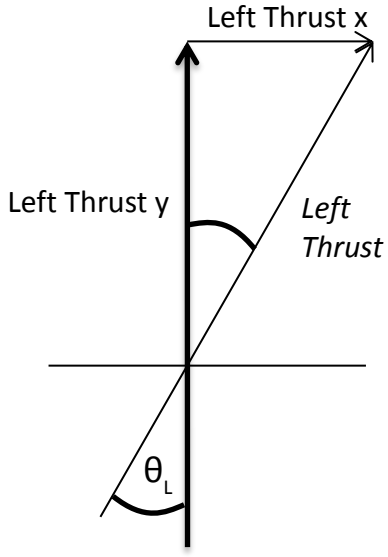



**Figure 5-7: Trig is used to obtain the remaining components of the *Left Thrust y* Force**

15. From here the *Right Thrust x, Right Thrust y and* ***Right Thrust Resultant*** are calculated. These forces are calculated at the centroid of the segment and therefore the loading on the segment is incorporated into these calculations. The following equilibrium equations are used in this step: ∑Fy=0 and ∑Fx=0. This is applied as follows:

$$\sum Left\ Thrust\ x + Right\ Thurst\ x = 0 \qquad (5\text{-}4)$$

And

$$\sum Left\ Thrust\ y + Selfweight\ of\ the\ segment + Right\ Thrust\ y = 0 \quad (5\text{-}5)$$

When other loads are analysed, they are also applied at the centroid of the segment and the different loading components need to be added correctly into the above equations (Figure 5-8).

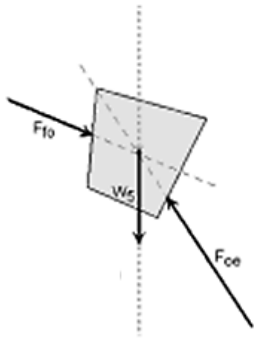



**Figure 5-8: Equilibrium at the centre of the segment, combining internal & external forces (Allen & Zilewski, 2010, p 220)**

16. The ***Right Thrust*** is now calculated using Pythagoras theorem.
17. The new angle for the next section of the thrust line is calculated using trigonometry as demonstrated in Figure 5-7.
18. Lastly, the co-ordinates are calculated. Each co-ordinate represents the centroid of each segment EXCEPT for the first and last co-ordinates. Co-ordinate (0,0) is NOT the first co-ordinate established. This point is a selected point of axes from where the curve is chosen to begin and is manually inputted by the user. The first calculated co-ordinate is at the centroid as seen in Figure 5-9. Since the calculated co-ordinates are representing the centroids of the segments, the very first and last co-ordinates are inputted to ensure that the extra *length* of structural segment is also depicted in the curve.

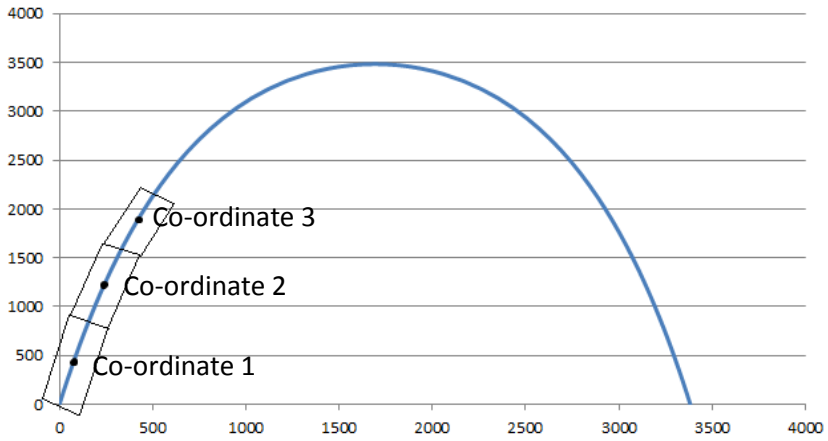



**Figure 5-9: Each co-ordinate represents the centroid of the segment. The first and last are inputted manually to account for the geometry (length) of the segment**

The co-ordinates are calculated through trigonometry; where the variables used are that of the length of the segment with the corresponding angle, continuously added to the preceding co-ordinate.

19. The remainder of the rows of calculation (i.e. rows two to the final row) in the spread sheet are calculated in an almost identical fashion. The first row of calculation is unique. For rows 2 to the final row, there are two changes in the formulae:
    - The new *Left Angle* is equal to the previous rows *Right Angle*. This is because of vertically opposite angles at a point (refer to Figure 5-7)
    - The new ***Left Thrust Resultant*** force is equal to the previous rows ***Right Thrust Resultant*** force. You are now looking at the succeeding segment, thus the left thrust in the new segment is the right thrust in the old segment.
20. Steps 1 through to 19 can be applied to various curves with different loading cases. The self-weight case determines the centre line for the curve and all other load cases will be adjusted accordingly to best fit the geometry of the curve.
21. Once analysis is finished for all the load cases, it is vital to check that all the curves fall within the required boundary. This boundary is the middle third of

the thickness of the material (refer to section 5.5.3). The check is best done by plotting the curves on the same set of axis as the middle third boundaries. The middle third is drawn in the same way as the centreline however the geometry is set and properties are adjusted to suit.

22. The final step in the design is to ensure that the material is capable of supporting the curve. The maximum stresses from all analysed load cases are obtained and compared to the materials strength capacity. If all the curves fall within the middle third, then only the compressive strength need be compared. If the curves fall outside of the middle third, then the tensile strengths also need to be checked or the thickness of the shell increased. The maximum deflections are also obtained for further design requirements.

## 5.5. Finite Element Method

Finite element method (FEM) is the most commonly used method in structural design and is extremely effective, when used correctly. However, if the user is not aware of its limitations, the results could be detrimental. In addition, designs which require an in-depth mathematical understanding should generally avoid using FEM, and the designer should rather consider a different approach in solving the problem.

Bathe & Chapelle (2011) provide an in-depth guide on how to analyse thin shelled structures using finite element analysis. The thin nature and complexity of the curve makes these structures difficult to model. Even though FEM is widely used, it was initially designed to solve thin shells, as first principle methods were too complex (Argyris, 1954).

When modelling complex structures, such as thin shells, there are a number of ‘rules’ that need to be followed. Subjects such as element size, element type, type of analysis, constraints, etc. need to be carefully selected. The curves and geometry of thin shells are the main aspects that make them very difficult to model.

There are a few points to take into consideration when modelling thin shells to ensure that the results achieved are accurate. These include:

- Sharp changes in geometry cause major discrepancies in the results. The elements need to be smooth and continuous (Talocchino, 2005).
- The shape should never be modelled using linear elements, but rather quadrilateral or triangular. If quadrilateral elements are to be used, they need to be either eight or nine node to improve accuracy.
- All elements need to be orientated in the correct direction i.e. all elements are created in a clockwise direction so that all the same faces face outwards.
- Use as many elements as possible when meshing the model. This improves the accuracy, as the elements are smaller. It also minimises the number of linear, rigid sections as there are more points allowing for smoother changes in geometry.
- When modelling symmetrical objects, only small segments need be modelled and not the entire object as long as the correct constraints are applied.

The assumptions made and process followed in designing this vault will be discussed at a later stage.

# 6. Structural Analysis and Design of Catenary Vaults

## 6.1. Introduction

In this chapter, the segmental equilibrium method will be applied to design the catenary vaults of the prototype structure. All analysis will be performed as well as an investigation into a case study situated in South Africa. This section will focus on the roof structure and the adequacy of this method in structural design. The shape of the structure, as discussed in Chapter 3, is a square structure with two vaulted sections acting simultaneously as the roof and upper storey.

The loading is designed in accordance with SABS 0160 (2009). All finite element analysis done for both the case study and actual design are carried out in LISA version 7.7.1, a finite element programme. The results of the FEA analysis and equilibrium method are compared to check the accuracy of the results.

## 6.2. Case study: Bapong

### 6.2.1. Introduction

Bapong is a township situated just off the R556 en route to Sun City in North-West province, South Africa. The case study consists of a series of vaulted structures that have been abandoned, located on the end of a school property. They are unique in shape and have made use of the catenary vault in its design (Figures 6-1 to 6-3).




**Figure 6-1: Bapong case study location: image obtained off Google Earth**



**Figure 6-2: Bapong township, a set of abandoned structures**



**Figure 6-3: The abandoned structures are in impeccable condition even with no maintenance**

A site visit was arranged to inspect these structures and assess their condition as well as to highlight any major problems with their design and construction. These structures have proved to be extremely durable and structurally efficient. They are estimated to be approximately 20 years old with no apparent maintenance over the years.

The structures showed minimal deterioration and minor cracking. However, along the apex, or high point of the vaults, a crack had occurred, as seen in Figure 6-4. This was recurring in all the roof structures and no certain cause for the cracking was identified. Thus, a detailed finite element analysis was carried out to establish what has caused the recurring cracking.



**Figure 6-4: A crack occurs at the centre, or high point, of all the roof structures**

In the structures, both buttresses and steel ties were present. It is not clear whether the buttresses had a structural or aesthetic purpose. However, the steel ties are structural elements used to restrain the horizontal thrust force exerted by the vault (Figure 6-5).



**Figure 6-5: Steel ties are present in the structure to restrain the thrust force**

The shape of the roof is a catenary, and because of its shape the shell is in excellent condition. This is a valuable case study which highlights the high level of sustainability and durability of vault structures.

### 6.2.2. Finite Element Results

A finite element analysis was carried out to investigate the cause of the cracking in the vaults. Various loading conditions were investigated. The shape was modelled in LISA, a finite element programme. The elements used are nine noded shell quadrilaterals. The end conditions are applied at the relevant nodes. It is essential that these end conditions are accurate, as they will create major discrepancies in the results if modelled incorrectly. The edges of the roof are connected to the end walls and therefore pinned along the edges. It was also noted, at the site visit, that the edges of the vault were tied in to the wall. This meant that all edges of the vault were restrained, and thus all edges must be modelled as pinned connections (Figure 6-6).

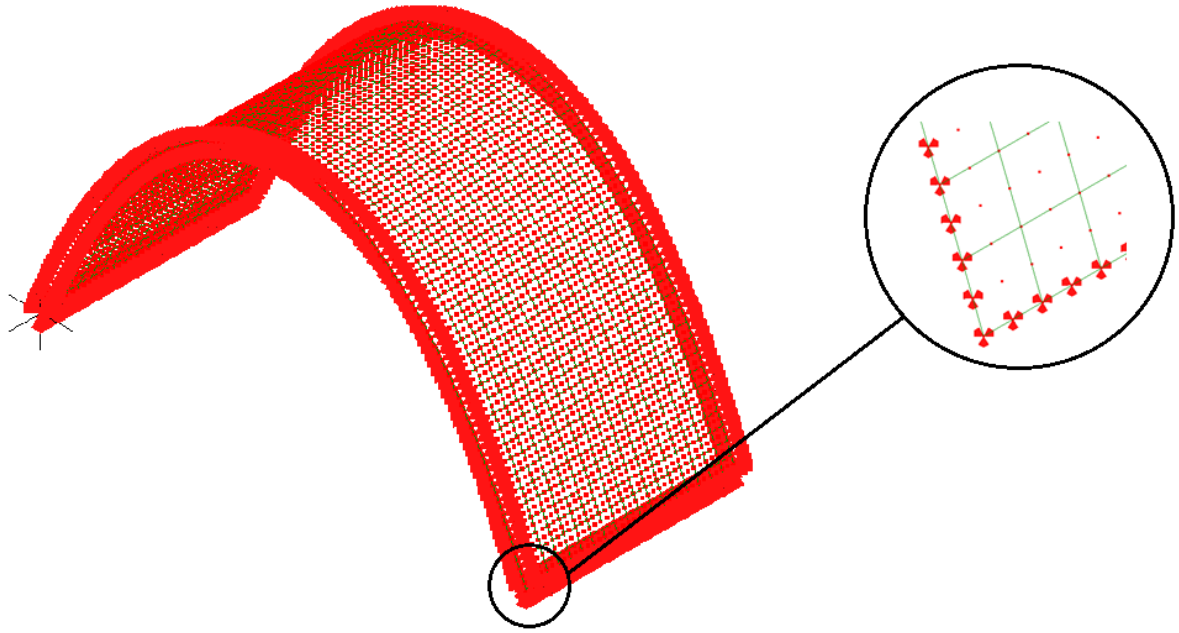


**Figure 6-6: All the edges of the vault must be restrained in all directions (i.e. pinned connection) due to its direct connection to the surrounding wall**

The vault is subjected to live loads, wind loads and temperature loads.

The analysis was performed and it was found that temperature loading caused considerable changes in stresses along the apex of the structure. This is due to the vault being unable to expand or contract, as no expansion joint is present between the vault and wall. This causes the structure to crack when it expands or shrinks as it is unable to move freely, thus resulting in extremely high stresses at the edges. Figures 6-7 and 6-8 are results of the analysis of two different loading combinations,

both including temperature changes, which show the distribution of stresses along the vault. At the centre it is clear that there is a sudden change in stresses from compressive to tensile, causing cracking in the vaults.

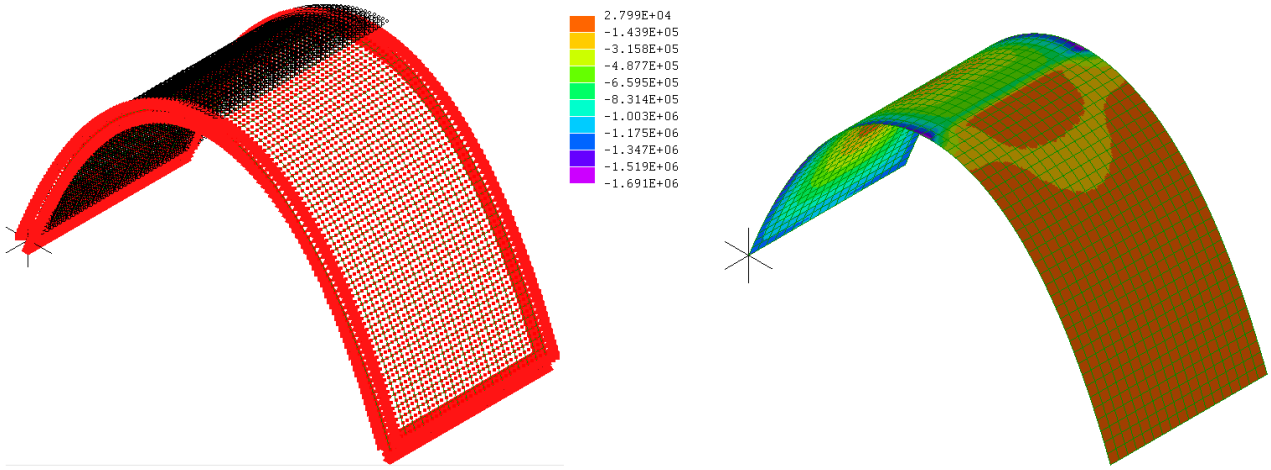



**Figure 6-7: Results of the load case whereby the structure has a temperature loading along the left side of the vault**

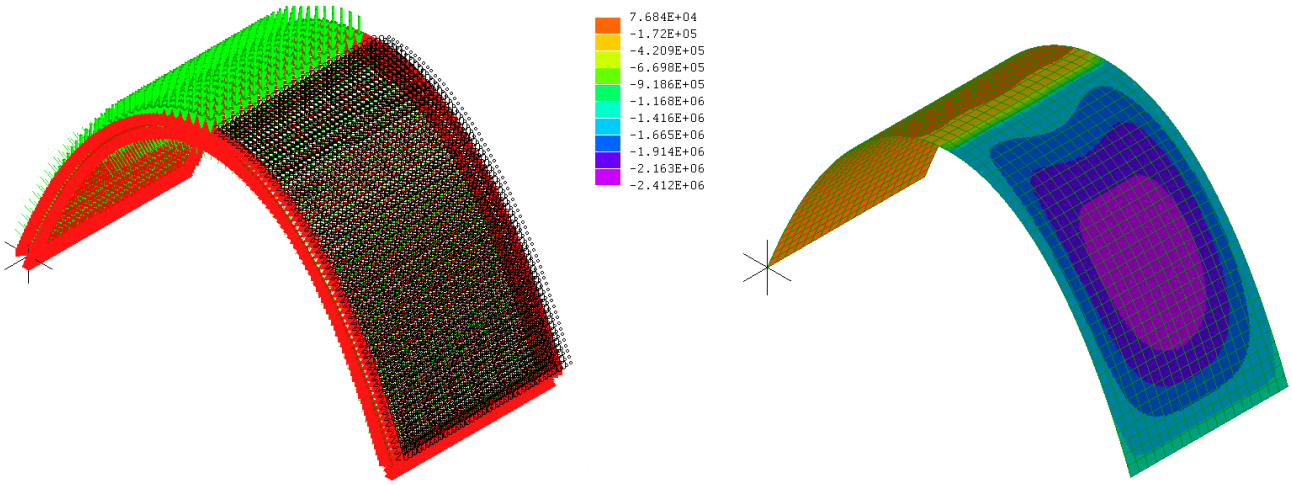



**Figure 6-8: Results of a load case whereby the structure has a full wind load, temperature loading along the right side of the vault and a live loading along the left side of the vault**

Note that positive values are tensile and negative values are compressive. Due to the restraining of the edges of the vault, considerable tensile forces formed at the apex, which caused cracking. Figure 6-7 shows that a tensile patch forms at the top of the structure when it is under dead and temperature loads. Figure 6-8 shows a clear change from compressive to tensile stresses along the apex of the vault. The cracking of the vault can also be explained in conjunction with Figure 6-9. Figure 6-9

shows how a vault under dead loading will experience certain compressive forces, never exceeding the materials capacity and the minimum compressive force at the apex. However, when a thermal load is applied to a restrained structure, the vault cannot move freely, thus creating additional tensile forces within the material. When the forces reach the apex, as seen in Figure 6-9, the amount of tension exceeds the maximum allowable tensile stress within the material, resulting in cracking.

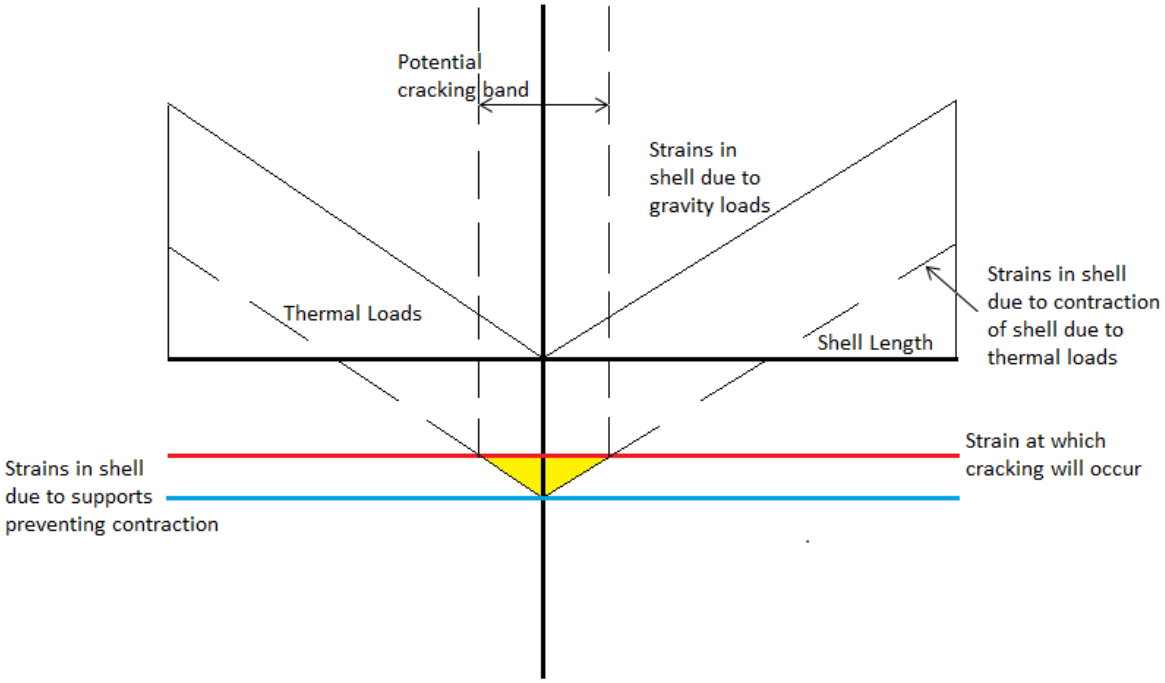



**Figure 6-9: A graphical explanation of cracking in a restrained vault after thermal loads are applied**

Thus, we can conclude that it is evident that an expansion joint must be incorporated where the vault meets the wall, to allow the roof to expand and contract without being restrained. This will reduce, if not eliminate, these drastic changes in stresses along the centre of the vault and in turn, eliminate cracking. The form is clearly unique, extremely efficient and durable. The design of the vault is instrumental in ensuring a sustainable structure is constructed.

## 6.3. Loading

The loading for a catenary vault is complex and requires investigation into a number of various pattern loadings. The segmental equilibrium method incorporates dead,

live and wind loading. Temperature loading is usually analysed in finite elements, as it is too complex to incorporate into the computerised equilibrium method.

- *Dead Load/Self-weight*

  The self-weight of the structure is the force exerted by the weight of the vault materials, i.e. the loading that the structure is permanently supporting.

  The dead load in this design consists of the materials within the structure. Therefore, the material properties of the blocks, mortar, plaster, etc. are included as dead loads. The load is calculated as a uniformly distributed load (UDL) over the surface of the structure. The calculation of the dead load for the vaulted roof is as follows:

  $$Dead\ Load = \ Block\ self\ weight + plaster\ self\ weight$$

  The self-weight of both the block and plaster is calculated as follows:

  $$Self\ weight = Density\ \times Gravitational\ constant\ \times thickness$$

  Thus the dead load exerted on the structure is:

  $$DL = (1950 \times 0.115 \times 9.81) + (2300 \times 0.03 \times 9.81) = 2.88kN/m^2$$

- *Live loading*

  The live load is obtained from the loading code SABS 0160-2 (2009), and applied in a number of pattern loading combinations on the structure.

  The live loading selected in the design of the roof structure is for maintenance and repair, i.e. an inaccessible roof load. The loading provided is a horizontal UDL of *0.25kN/m²,* or a concentrated point load of *0.9kN* applied over an area of *1m².*

- *Wind loading*

  The wind loading was done in accordance with SABS 0160-3 (2009). It is calculated as a surface pressure over the different sections of the structure and applied accordingly.

  Considerable research has demonstrated that curved structures resist wind loads extremely well. There is no official wind loading guide for catenary

curves; however, SABS 0160-3 (2009) addresses vaulted roofs and domes and this method was applied to this project. In some instances, when the vaults are extremely high, it is recommended to apply the same theory as you would for a pitch roof (Blackmore & Tsokri, 2006). Thus, by combining both theories, wind loading values are calculated and applied to the vaulted roof.

The construction of this structure is to occur in Johannesburg. The aim is to apply this project as a low-cost housing solution, thus the structure will be located in townships or other densely inhabited areas. The following wind loading values are selected:

$$v = 40m/s \ (wind\ speed\ for\ Johanneeburg\ area)$$
$$Class\ B$$
$$Category\ 3$$
$$k_p = 0.5 \ (a\ constant\ for\ specified\ altitudes)$$
$$Height\ of\ structure = 2.65m + \sim 3.4m \cong 6m$$

Note: *Class B* is to determine forces on structural members as well as resultant forces and overturning moments for structures which do not exceed 50m in any dimension. *Category 3* is selected for closely spaced obstructions, generally the size of domestic housing (i.e. fully or substantially developed suburbs, industrial areas and towns).

Once these initial values are set, the steps as outlined in SABS 0160-3 (2009) are followed so that all wind pressures applied over the structure are calculated. In order to calculate an accurate wind pressure over the structure, the wind speed multiplier, $k_z$, will need to be adjusted to suit a 6m height. This is done simply by interpolating the existing values in the 5-10m range.
A $k_z$ value of 0.654 is obtained and the wind pressure is calculated as follows:

$$q_z = k_p[v(k_z)]^2 \quad (6\text{-}1)$$

$$q_z = 0.5[40(0.654)]^2$$
$$= 342\ N/m^2$$

The external pressure coefficients, $C_{pe}$, are obtained from Figure 14 in SABS 0160-3 (2009, p37). The pressure distribution over a vaulted roof is summarised as follows:

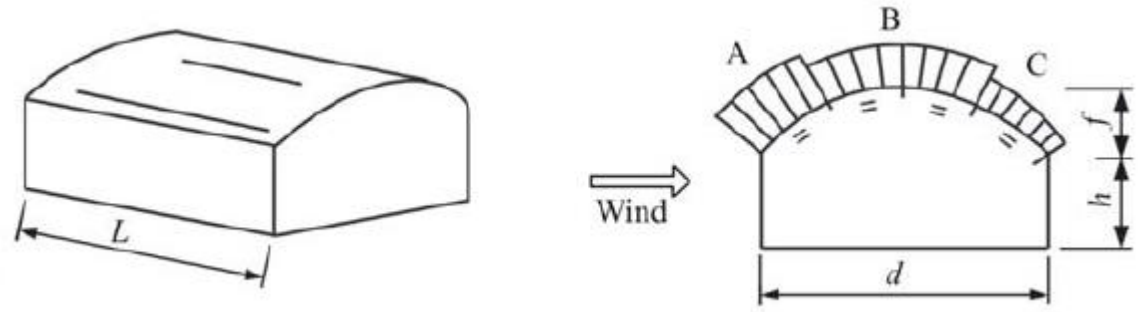



**Figure 6-10: Wind distribution over a vaulted roof with a rectangular base (SABS 0160-3, 2009, p37)**

The pressure over the surface of the vault is separated into quarters where the first quarter has a pressure *A*, the second and third a pressure *B* and the fourth a pressure *C*. It is important to note that Figure 6-10 represents positive pressure values acting downward. Thus, all negative values are applied in the opposite direction, i.e. acting upwards. The first vault's $C_{pe}$ values are calculated as explained above. However, for the second vault, the values and distribution changes slightly as stated by the multi-span roof wind theory in Figure 13c, SABS 0160-3 (2009, p36).

The external pressure coefficients for the structure, for wind angles of 0° and 180°, are summarised in Figure 6-11.

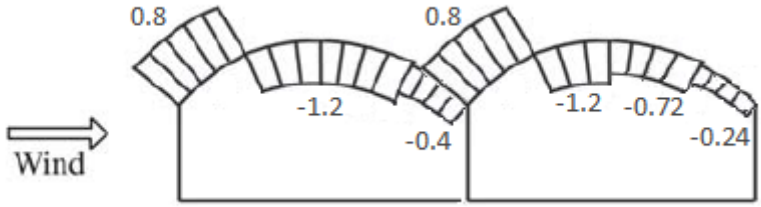



**Figure 6-11: External pressure coefficients for a multi-span vaulted roof**

If the direction of the wind changes to 90°, two different pressure space configurations are assessed.

If the vaults are assumed to behave in a similar manner as a duo-pitched roof, a pressure distribution as described in SABS 0160-3 (2009) is applied as follows (Figure 6-12):

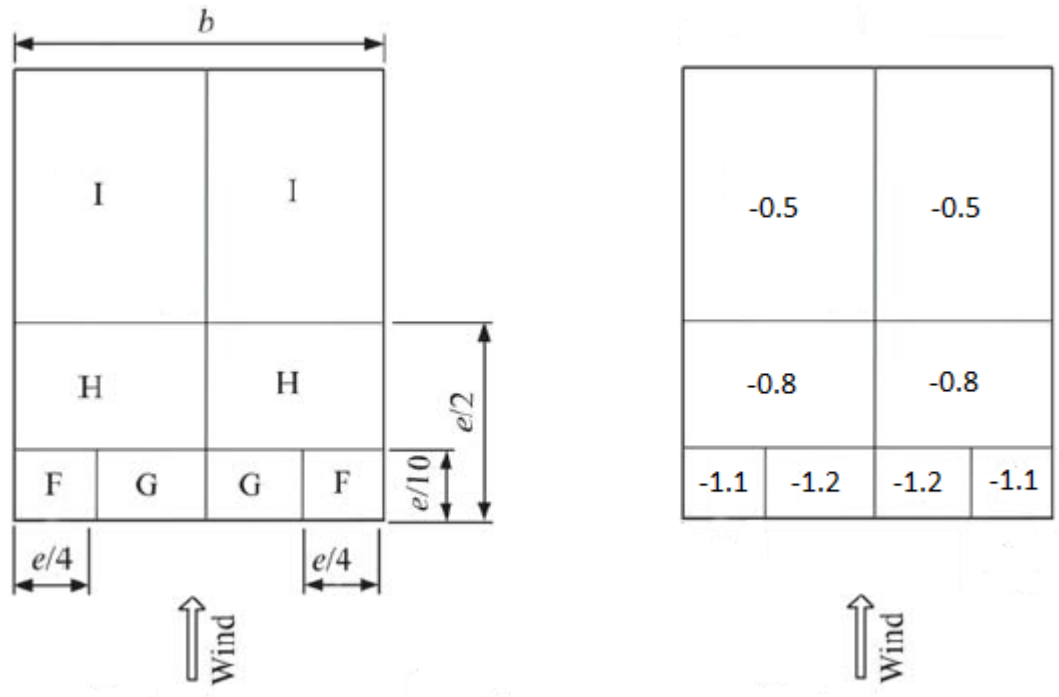



**Figure 6-12: *Left* - Wind pressure distribution as seen in SABS 0160-3 (2009, p 31); *Right*-The final external pressure values applied in the prototype as per code**

The external pressure coefficients distribution for a curved roof, according to Blackmore & Tsokri (2006), is presented in Figure 6-13. These curves do not consider catenary vaults, but can be applied as a possible loading pattern.

There are no published codes or literature describing the exact wind distribution on the surface of a catenary vault and therefore these various scenarios are analysed to ensure the worst loading pattern is accounted for.

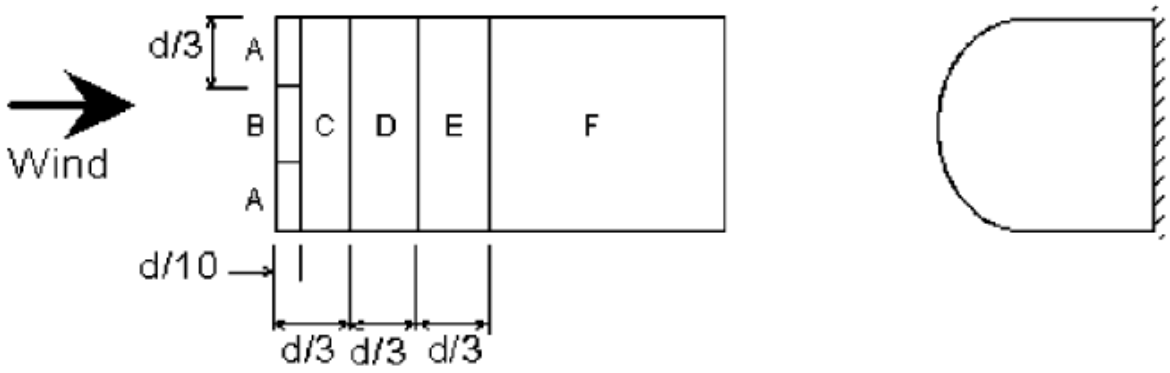



**Figure 6-13: External pressure coefficient distribution over a curved roof (Blackmore & Tsokri, 2006, p 837)**

When values of A to F are calculated, they are found to have the same values found in Figure 6-12, following an almost identical distribution.

In order to calculate the final wind pressure values applied onto the vaulted roof, a simple calculation must be applied to each of the sections for both wind directions of θ=0°/180° and 90°.

$$Wind\ Pressure = (C_{pe} - C_{pi}) \times q_z \quad (6\text{-}2)$$

$C_{pi}$ values of 0 and -0.2 are investigated and all wind pressures are calculated and applied to the vaults. Table 6-1 summarises the wind pressure configurations applied to the vaults during analysis.

**Table 6-1: Wind pressure distribution (N/m$^2$) values on the catenary roof**

| Wind Angle | Section | Wind Pressure *(N/m²)* | | Wind Pressure *(N/m²)* | |
|---|---|---|---|---|---|
| | | $C_{pi}$=0 | | $C_{pi}$=-0.2 | |
| | | *1st Vault* | *2nd Vault* | *1st Vault* | *2nd Vault* |
| *Θ=0° and 180°* | *A* | 273.6 | 273.6 | 342 | 342 |
| | *B (1st half)* | -410.4 | -410.4 | -342 | -342 |
| | *B (2nd half)* | -410.4 | -246.2 | -342 | -177.8 |
| | *C* | -136.8 | -82.1 | -68.4 | -13.7 |
| *Θ=90°* | *F* | -376.2 | | -307.8 | |
| | *G* | -410.4 | | -342 | |
| | *H* | -273.6 | | -205.2 | |
| | *I* | -171 | | -102.6 | |

- *Temperature loading*

  Temperature loads have been found to cause significant cracking, and yet they are very often overlooked. This load varies according to the environment in which the structure is situated (i.e. some places experience temperature changes of 5°C throughout the day while others can range by as much as 30°C). In Johannesburg, a temperature difference of 20°C is normally assumed.

## 6.4. Loading Combinations and Patterns

A number of loading combinations and patterns were investigated in both the Excel and the finite element analysis of design, as per SABS 0160 (2009). The following loading ultimate limit state combinations were assessed:

- 1.5 x Dead Load
- 1.2 x Dead Load + 1.6 x Live Load
- 1.2 x Dead Load + 0.5 x Live Load + 1.3 x Wind Load
- 0.9 x Dead Load + 1.3 x Wind Load

The following service limit state combinations were investigated as well:

- 1.0 x Dead Load
- 1.1 x Dead Load + 1.0 x Live Load
- 1.1 x Dead Load + 0.3 x Live Load + 0.6 x Wind Load
- 1.0 x Dead Load + 0.6 x Wind Load

Once the safety factors are established and the loading combinations applied, it is important to explore various pattern loadings. This is done to ensure that all possible loading patterns have been taken into account when the structures final design is established, and is therefore designed for the 'worst case' scenario. In the current analysis, the only loads that are applied in various patterns are that of live loads and temperature loads. The wind loading, although different for various designs, is a set pressure over the surface, as identified in Table 6-1. The dead load is constant.

A finite element analysis was performed to identify the most severe live loading patterns. The final loading patterns that are investigated are shown in Figure 6-14. Each of these loading patterns were applied individually, resulting in six live loading combinations. They include: a horizontal projectile load over the full length (Figure 6-14a) and the two separate halves (Figures 6-14b and c), a point load at the centre (Figure 6-14d), at a quarter length (Figure 6-14e) and at three quarters length (Figure 6-14e).

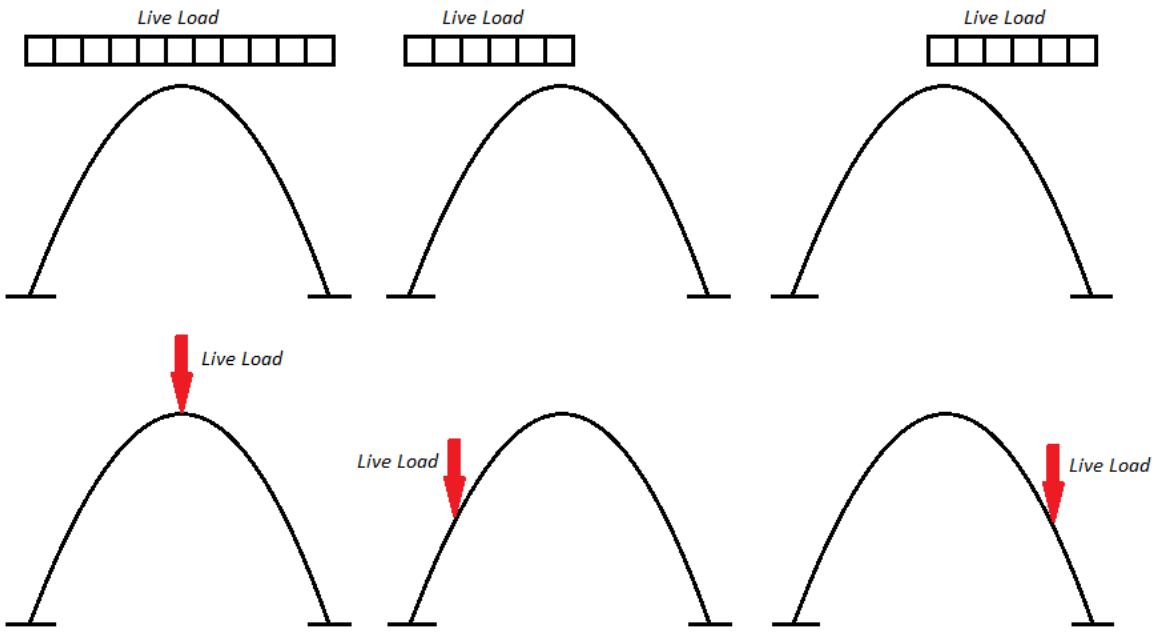



**Figure 6-14: Loading patterns for the applied live loads: (a) Full horizontal projection, (b) half load over the left half, (c) half load over the right half, (d) point load at the centre, (e) point load at a quarter length, (f) point load at three quarters.**

The temperature loading was assessed and selected in a similar manner to the live loading. The key loading patterns are summarised in Figure 6-15. Positive and negative temperature changes, resulting in shrinkage and expansion, were investigated.

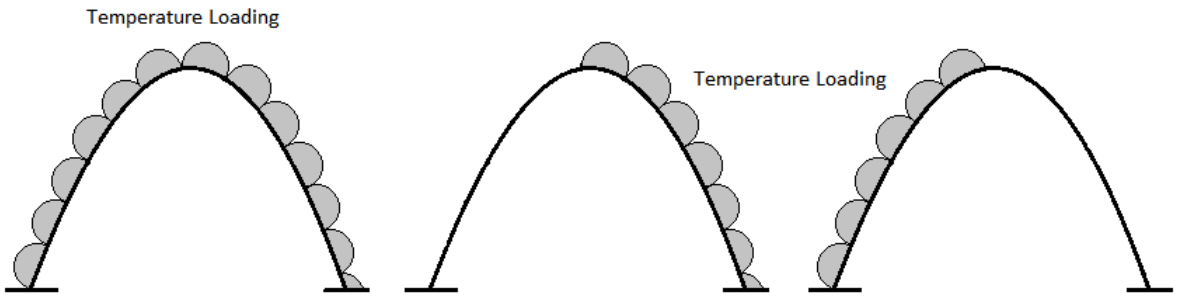



**Figure 6-15: Investigated loading patterns for temperature loads: (a) temperature loading over the entire structure, (b) temperature loading over the right half of the structure, (c) temperature loading over the left half of the structure**

## 6.5. Design Process using the Segmental Equilibrium Method

Chapter 5 discussed the process by which a catenary curve is designed using the segmental equilibrium method. In this section, the process of designing the roof structure of the prototype will be discussed in detail.

### 6.5.1. Dead Load Design

The first step is to establish the geometry of the curve. The user has a general idea of the dimensions of the curve, i.e. its length and height. All the designs are done to a metre length vault section. Gravity loading determines the dimensions of the vault; however, the lateral forces determine the required thickness of the shell. All final calculations were done in Excel spread sheets (Appendix A). The steps presented below can be followed in the spread sheet on page 99. The process is as follows:

1. Input all the material properties:
    - Density = 1950kg/m$^3$
    - Young's Modulus = 3500MPa
2. Add the initial vault dimensions. These are important when you are iterating to ensure that the curve spans the required vault size. These values are the initially assumed dimensions as discussed in Chapter 3.
    - Height = 3.5m
    - Length = 3.4m
3. Select an initial segment size. The segment height chosen was 130mm. This height was selected to allow for higher accuracy in shorter heights but with more number of segments spanning the length of the curve. The length of the segment will vary with each load case. It was roughly estimated that 63 segments were to be used. This number is a random estimate; however, the more segments you have the higher the accuracy.
4. An initial angle of 80° is selected as the vault is predominantly vertical. This value will also change with each load case in the iterative approach.
5. The various loads are now incorporated into the spread sheet and all factors are applied. In this example, only the gravity loads will be discussed. These loads are transformed into point loads that are applied at the centre of each segment (Table 6-2 and 6-3). These point loads are calculated according to

the length of the segment, thus with a differing segment height, the value of the point load will also vary.

**Table 6-2: Dead Loads applied to the vault**

| **Loads** | | |
|---|---|---|
| *Dead Load* | | Units |
| Bricks/Masonry weight per block | 2.88 | $kN/m^2$ |
| Weight of each segment as a point load | 0.37 | kN |

**Table 6-3: Loading combinations applied in analysis of vault**

| Load combinations | | |
|---|---|---|
| | *ULS* | DL (kN) |
| LC1 | 1.5DL | 0.56 |
| | *SLS* | DL (kN) |
| LC1 | 1.0DL | 0.37 |

6. The spread sheet is now set up as demonstrated in point 9 of section 5.5.4. The thrust line under gravitational forces can now be calculated. In this section, we are only discussing the dead load applied to the structure which will be constant at each segment; thus, the value in the *weight* column is identical for each segment. All the previously chosen values are inputted into the spread sheet. These include initial segment height, angle and number of segments. The first row of calculation is the most unique and complex as values may need to be manually inputted or calculated in a separate spreadsheet. The remaining rows of calculation follow a continuous pattern generated from the previous rows of results. All steps can be followed in the spread sheet presented on page 99 (Figure 6-16).
7. The first calculation includes establishing the exact value of the left thrust force, which is also the reaction force at the left end of the curve. Since the loading is symmetrical over the structure, a simple equilibrium calculation can be done to establish the vertical component of this force, i.e. $\sum Fy=0$. The left

and right reaction forces are identical and thus the total dead load is calculated and halved.

$$Left\ Thrust\ Force\ (y) = \frac{0.559 \times 63}{2} = 17.63kN$$

8. *Left Thrust x* and ***Left Thrust Resultant*** are calculated using trigonometry as follows:

$$Left\ Thrust = \frac{Left\ Thrust\ (y)}{sin\theta} = \frac{17.63}{\sin(80)} = 17.90kN$$

$$Left\ Thrust\ (x) = Left\ Thrust\ \times cos\theta = 17.90\ \times \cos(80) = 3.11kN$$

Note: The chosen sign notation indicates that any forces to the right and up are positive.

9. The remaining steps will follow a continuous pattern throughout the spread sheet. *Right thrust x* and *right thrust y* are calculated through equilibrium equations, i.e. ∑Fy=0 and ∑Fx=0. This is done at the centre of the segment, where equilibrium is calculated around that point incorporating all the various loading. In this case, there are no horizontal loads applied to the structure, only a vertical dead load. Thus, the *right thrust x* is identical in magnitude but opposite in direction to *left thrust x*.

$$Left\ Thrust\ x + Right\ Thrust\ x = 0$$

$$Right\ Thrust\ x = -Left\ Thrust\ x = -3.11kN$$

The *right thrust y* has to account for the reaction force from the left as well as any external vertical forces.

$$Left\ Thrust\ y + Right\ thrust\ y + Dead\ Load = 0$$

$$Right\ Thrusy\ y = -Left\ Thrust\ y - Dead\ Load = -17.63 - (-0.559)$$

$$= -17.07kN$$

The ***Right Thrust Resultant*** force can now be calculated using Pythagoras theorems:

$$Right\ Thrust = \sqrt{17.07^2 + 3.11^2} = 17.35kN$$

10. The new angle is calculated. This is done using the newly calculated right side forces and trigonometry.

$$\theta = \tan^{-1}\left(\frac{Right\ Thrust\ y}{Right\ Thrust\ x}\right) = \tan^{-1}\left(\frac{17.07}{3.11}\right) = 79.68°$$

11. Finally, the co-ordinates of the centre of the first segment are calculated. This is the start of the thrust line. The co-ordinates are calculated using trigonometry as follows.

$$x = Length\ of\ block\ \times \cos(\theta) = 130\ \times \cos(80) = 22.57mm$$

$$y = Length\ of\ block\ \times \sin(\theta) = 130\ \times \sin(80) = 128.03mm$$

Note that the angle used is the old angle and not the new one calculated in point 10. These points represent the centre of the segment and therefore do not start at (0,0). Thus, each succeeding co-ordinate will be calculated as before, using trig, but simultaneously added to the preceding co-ordinate. This is covered in point 14.

12. The first row of calculation is now complete. The second row needs to be set up accordingly and all the succeeding rows of calculation follow the same formulae as row 2. The Excel spread (see page 99) sheet highlights in green the values that are carried over from the previous row, i.e. the ***Right Thrust Resultant*** Force becomes the ***Left Thrust Resultant*** Force in the succeeding row and the newly calculated right angle becomes the left angle on the succeeding row. Now that the ***left thrust*** force is calculated, the *left thrust x* and *left thrust y* are calculated using trig in conjunction with the new angle.

$$Left\ Thrust\ y = 17.347\ \times \sin(79.69) = 17.07kN$$

13. The right thrust values and new angle are calculated in the same manner as in step 9 and 10.
14. The new co-ordinate is calculated in the same way as point 11; however, it is added to the preceding co-ordinate.

$$x_2 = x_1 + Height\ of\ segment \times \cos(\theta) = 22.57 + 130 \times \cos(79.68) = 45.86mm$$

$$y_2 = y_1 + Height\ of\ segment \times \cos(\theta) = 128.03 + 130 \times \cos(79.68) = 255.92mm$$

15. Steps 12 to 14 are repeated for all of the remaining segments, resulting in a final thrust line.
16. As mentioned previously, each co-ordinate represents the centre of the segment. Thus, the first half and last half of the segment (i.e. height) are not incorporated into the calculation. In order to complete the curve, (0,0) is inputted as the first co-ordinate to ease calculations, and the final co-ordinate is calculated very simply. The values to be added in the x and y co-ordinates are given as the difference between the first and second co-ordinate. Since the first co-ordinate is (0,0) the value of the second is the difference, and need only be added to the final point.

$$x_{final} = 3518.11 + 22.57 = 3540.69mm$$

$$y_{final} = 128.03 - 128.03 = 0mm$$

The final dimensions of the curve, with the assumed initial inputs, were too high and exceeded the intended height of the shell. Thus, the above process was repeated, in an iterative approach, by varying the initial angle and the segment height until a more satisfactory set of dimensions was achieved.

The final initial angle is 80.5° and a segment height of 128.2mm. This provided us with a final curve with a vault height of 3482.85mm and a width of 3383.37mm. The final spread sheet for the calculation of the thrust line under dead load, and essential the final geometry, can be found in Appendix A.

| Segment no. | Height of Segment | Weight | Left Angle | Left Thrust x | Left Thrust y | **Left Thrust Resultant** | Right Thrust x | Right Thrust y | **Right Thrust Resultant** | Right angle | Co-ordinates X | Co-ordinates Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 130 | 0.56 | 80.00 | 3.11 | 17.63 | 17.90 | -3.11 | -17.07 | 17.35 | 79.68 | 0.00 | 0.00 |
| 2 | 130 | 0.56 | 79.68 | 3.11 | 17.07 | 17.35 | -3.11 | -16.51 | 16.80 | 79.34 | 22.57 | 128.03 |
| 3 | 130 | 0.56 | 79.34 | 3.11 | 16.51 | 16.80 | -3.11 | -15.95 | 16.25 | 78.97 | 45.87 | 255.92 |
| [illegible] | [illegible] | [illegible] | 78.97 | 3.11 | [illegible] | [illegible] | -3.11 | -15.39 | [illegible] | [illegible] | [illegible] | 383.68 |
| [illegible] | [illegible] | [illegible] | 78.58 | 3.11 | 14.83 | 15.15 | -3.11 | -14.83 | [illegible] | [illegible] | 94.79 | 511.28 |
| [illegible] | [illegible] | [illegible] | 78.16 | 3.11 | [illegible] | [illegible] | -3.11 | -14.27 | [illegible] | [illegible] | [illegible] | 638.70 |
| 7 | 130 | 0.56 | 77.71 | 3.11 | 14.27 | 14.60 | -3.11 | -13.71 | [illegible] | [illegible] | [illegible] | 765.94 |
| 8 | 130 | 0.56 | [illegible] | [illegible] | 13.71 | 14.06 | -3.11 | -13.15 | [illegible] | [illegible] | [illegible] | 892.96 |
| 9 | 130 | 0.56 | [illegible] | [illegible] | 13.15 | 13.51 | -3.11 | -12.59 | 12.97 | 76.13 | 203.60 | 1019.74 |
| 10 | 130 | 0.56 | 76.13 | 3.11 | 12.59 | 12.95 | -3.11 | -12.03 | 12.43 | 75.51 | 233.50 | 1146.26 |
| 11 | 130 | 0.56 | 75.51 | 3.11 | 12.03 | 12.47 | -3.11 | -11.47 | 11.88 | 74.84 | 264.66 | 1272.47 |
| 12 | 130 | 0.56 | 74.84 | 3.11 | 11.47 | 11.88 | -3.11 | -10.91 | 11.34 | 74.10 | 297.18 | 1398.34 |
| 13 | 130 | 0.56 | 74.10 | 3.11 | 10.91 | 11.34 | -3.11 | -10.35 | 10.81 | 73.29 | 331.17 | 1523.81 |
| 14 | 130 | 0.56 | 73.29 | 3.11 | 10.35 | 10.81 | -3.11 | -9.79 | 10.27 | 72.39 | 366.79 | 1648.84 |
| [illegible] | [illegible] | [illegible] | 72.39 | 3.11 | 9.79 | 10.27 | -3.11 | -9.23 | 9.74 | 71.40 | 404.17 | 1773.35 |
| [illegible] | [illegible] | [illegible] | 71.40 | 3.11 | 9.23 | 9.74 | -3.11 | -8.67 | 9.21 | [illegible] | [illegible] | 1897.26 |
| [illegible] | [illegible] | [illegible] | 70.29 | 3.11 | 8.67 | 9.21 | -3.11 | -8.11 | 8.69 | [illegible] | [illegible] | 2020.46 |
| 57 | 130 | 0.56 | -77.23 | 3.11 | -13.71 | 14.06 | -3.11 | 14.27 | 14.60 | -77.71 | 3337.08 | 1019.74 |
| 58 | 130 | 0.56 | -78.16 | 3.11 | -14.27 | 14.60 | -3.11 | 14.83 | 15.15 | -78.16 | 3365.83 | 892.96 |
| 59 | 130 | 0.56 | -78.58 | 3.11 | -14.83 | 15.15 | -3.11 | 15.39 | 15.70 | -78.58 | 3393.49 | 765.94 |
| 60 | 130 | 0.56 | -78.58 | 3.11 | -15.39 | 15.70 | -3.11 | 15.95 | 16.25 | -78.97 | 3420.16 | 638.70 |
| 61 | 130 | 0.56 | -78.97 | 3.11 | -15.95 | 16.25 | -3.11 | 16.51 | 16.80 | -79.34 | 3445.90 | 511.28 |
| 62 | 130 | 0.56 | -79.34 | 3.11 | -16.51 | 16.80 | -3.11 | 17.07 | 17.35 | -79.68 | 3470.77 | 383.68 |
| 63 | 130 | 0.56 | -79.68 | 3.11 | -17.07 | 17.35 | -3.11 | 17.63 | 17.90 | -80.00 | 3494.82 | 255.92 |
| | | | | | | | | | | | 3518.11 | 128.03 |
| | | | | | | | | | | | 3540.69 | 0.00 |

An initial assumed brick length of 130mm is applied

The initially assumed angle is inputted

63 bricks are used, as chosen in step 3

A constant dead load is applied to all the bricks

Left Reaction Force of the curve

Left Thrust (line 2) = Right Thrust (Line 1)

Left angle (line 2) = Right angle (Line 1)

Insert co-ordinate (0,0) as a starting point

Each co-ordinate represent the centre point for the brick

Calculate the final co-ordinate, thus taking into account the remainder of the brick

**Figure 6-16: An Excel spread sheet showing the design process of a catenary curve subject to dead loading**

Once the thrust line under dead load is calculated, the geometry of the curve is set. From here, the thickness of the segment and the middle third parameters can be drawn in (Figure 6-17). This is important so as to ensure that the thrust lines fall within the middle third of the shell thickness and to identify areas of weakness or areas susceptible to tensile stresses.

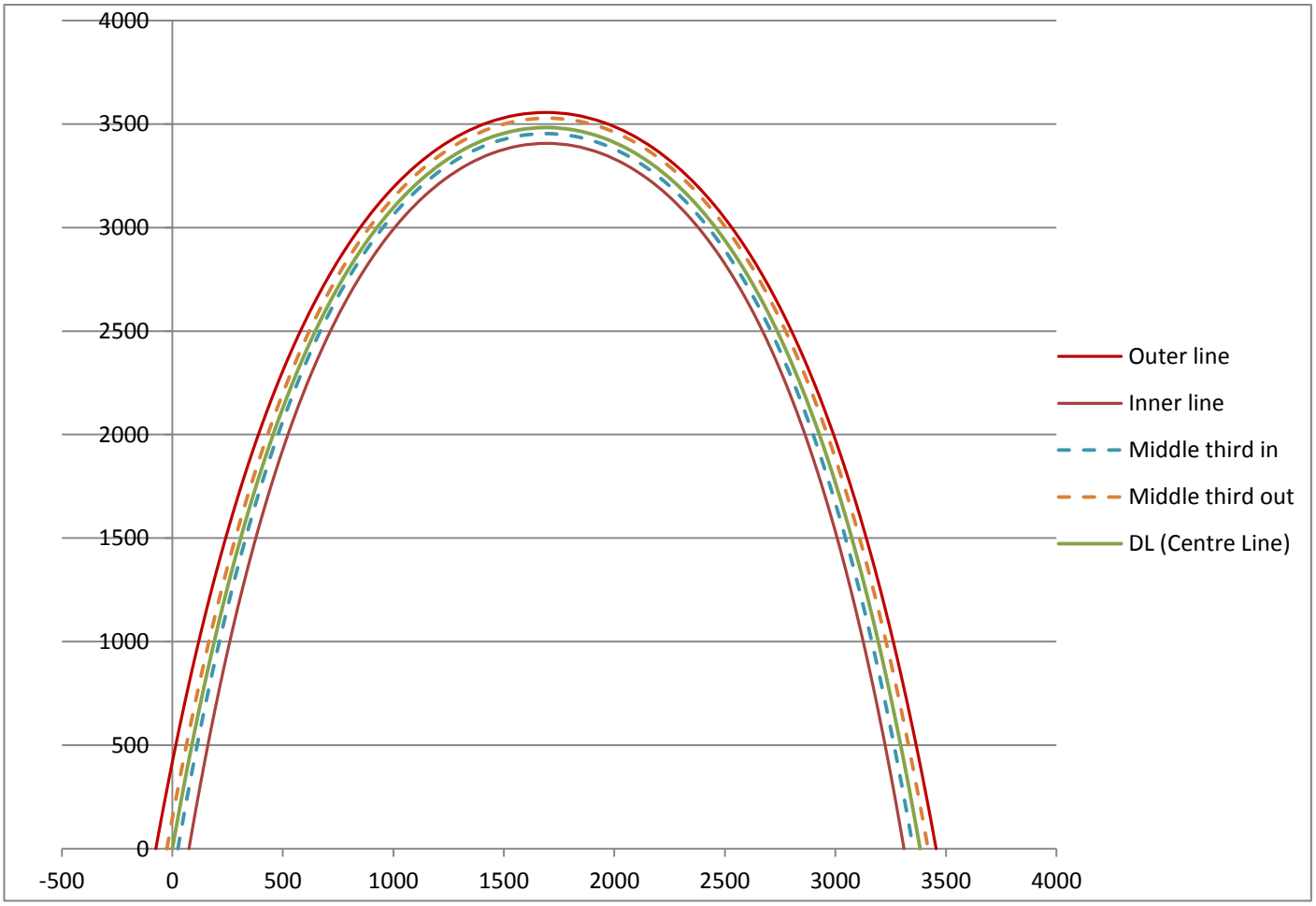



**Figure 6-17: A graph representing the final geometry of the vaulted roof**

### 6.5.2. Dead Load, Live Load and Wind Load Analysis

The geometry of the curve is now set, providing a platform from which the remaining loading analysis can commence. The segment height and initial angle will vary with each load case, but only marginally, and therefore less iteration's are necessary to solve for the required geometry. Each thrust line is unique for each load case and

the aim is to get it as close as possible to the original (dead load) thrust line, therefore keeping it in the middle third of the segment thickness.

Thrust Line Analysis with only dead loads is relatively simple. The process becomes considerably more complex when a lateral force is applied; such as wind loading. In this section, a detailed step by step design process will be discussed which will cover a number of varying loads. The curve will be subject to a wind load, live load and dead load. The live load is a horizontal projection over all or a portion of the curve, as described in figure 6-5, and the wind load has a $C_{pi}$ value of -0.2. No different to the dead load calculation, the analysis phase begins with an assumed initial angle and segment height. These values are varied to achieve the required geometry for the specific thrust line. In this step, the final values achieved in the dead load calculation are used as the initial guess and then follow an iterative process to calculate the actual angle and segment height. Unlike section 6.6.1, the *final* calculations steps will be covered with the correct angle and segment height value for that specific thrust line.

1. The material properties are as before (refer to step 1 in section 6.6.1) and the thrust line should fit within the middle third, as seen in figure 6-15.
2. The segment height and angle, for the final thrust line, are 133mm and 83.3° respectively. This has been obtained through an iterative process.
3. The load cases are now incorporated into the spread sheet (Table 6-4, 6-5 and 6-6). These loads include live loads, wind loads and dead loads. As before, these loads are transformed from loads and surface loads into point loads, and applied at the centre of each segment.

   The dead load is calculated as a vertical force:

**Table 6-4: Dead loads applied to vaulted roof**

| **Loads** | | |
|---|---|---|
| *Dead Load* | | Units |
| Bricks/Masonry weight per block | 2.88 | $kN/m^2$ |
| Weight of each segment as a point load | 0.37 | kN |

The live load is not a UDL over the surface of the structure, as is the dead load, but rather a horizontal projection over the structure and therefore the value of the live load applied is different for each segment. This value depends on the angle at which the segment is situated, i.e. for a steeper section the live load will be less as it covers less of a horizontal distance and vice versa for more horizontal sections (Figure 6-18).

**Table 6-5: The value of the live load applied on the vault, obtained from SABS 0160 (2009)**

| | | |
|---|---|---|
| *Live Load* | 0.25 | kN/m2 |

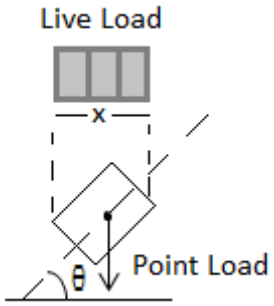



**Figure 6-18: A horizontal projection of the live load over a segment**

$$Point\ Load\ of\ LL\ per\ segment = Load\ Factor\ \times 0.25\ kN/m^2 \times\ x \qquad (6\text{-}3)$$

Where $x$ is the length of the live load exerted on that segment and is calculated as follows:

$$x = Height\ of\ segment\ \times \cos\ (angle\ of\ segment) \qquad (6\text{-}4)$$

The live load at the apex of the curve is calculated as follows:

$$PL = 0.5 \times 0.25 \times (128.2 \times \cos(5.42)) = 0.016kN$$

This point load is then added to the dead load value at the segment centroid. This value will vary at each segment, depending on the angle of the segment.

The calculation of the wind load is slightly more complex as it has a horizontal and vertical component. The wind load is a pressure over the surface of the vault. As with the other loads, the wind pressure is transformed into a point load and then separated into its relevant components and applied to the segments. It is assumed that the wind load is perpendicular to the segment and thus the components will vary according to the angle of the segment. In this load case, a wind pressure with a $C_{pi}$ value of -0.2 is used.

**Table 6-6: Wind Pressures values distributed over the vaulted roof (Refer to Figure 6-10)**

| *Wind Load (kN/m2)* | *Cpi=-0.2* | *Point Load (kN)* |
|---|---|---|
| 1st section (A) | 0.342 | 0.044 |
| 2nd and 3rd section (B) | -0.342 | -0.044 |
| 4th section (C) | -0.068 | -0.0089 |

To calculate the horizontal and vertical components at any given segment, the following steps are followed:

$$Wind\ Load\ H = Factor\ of\ Safety\ \times Wind\ Load \times \sin(Angle\ of\ the\ segment) \quad (6\text{-}5)$$

$$Wind\ Load\ V = Factor\ of\ Safety\ \times Wind\ Load \times \cos(Angle\ of\ the\ segment) \quad (6\text{-}6)$$

If a random segment is selected for analysis, in this case segment no 12, the wind load is calculated as follows:

- This segment falls within the 1st section, therefore Wind Load is 0.044kN.
- The load factor of the current load combination is 1.6
- The angle of the segment is obtained from the DL spread sheet so that the true angle of the segment is used. The angle is 75.58°

$$Wind\ Load\ H = 1.6 \times 0.044 \times \sin(75.58) = 0.055kN$$

$$Wind\ Load\ V = 1.6 \times 0.044 \times \cos(75.58) = 0.014kN$$

These values are reasonable as the segment is at a steep angle, therefore the load will predominantly have a horizontal component.

The loads are inputted into the relevant cells by the user. As noted in the spread sheet, the live loads are only applied from segment 32 onwards as the loading pattern comprises of a live load over the second half of the vault (Figure 6-14c). The wind load is adjusted at every quarter point, as indicated by SABS0160-3 (2009).

A summary of the loading combinations is presented in Table 6-7.

**Table 6-7: Loading combinations for the analysis of a catenary vault**

| | ***Load combinations*** | | | | | |
|---|---|---|---|---|---|---|
| | **ULS** | **DL (kN)** | **LL (kN/m²)** | **WL1 (kN)** | **WL2+3 (kN)** | **WL4 (kN)** |
| *LC1* | 1.5DL | 0.552 | 0 | 0 | 0 | 0 |
| *LC2* | 1.2DL+1.6LL | 0.441 | 0.400 | 0 | 0 | 0 |
| *LC3* | 1.2DL +0.5LL +1.3WL | 0.441 | 0.125 | 0.057 | -0.057 | -0.011 |
| *LC4* | 0.9DL+1.3WL | 0.331 | 0 | 0.057 | -0.057 | -0.011 |
| | | | | | | |
| | **SLS** | **DL (kN)** | **LL (kN/m²)** | **WL1 (kN)** | **WL2+3 (kN)** | **WL4 (kN)** |
| *LC1* | 1.0DL | 0.368 | 0 | 0 | 0 | 0 |
| *LC2* | 1.1DL+1.0LL | 0.405 | 0.250 | 0 | 0 | 0 |
| *LC3* | 1.1DL+0.3LL+0.6WL | 0.405 | 0.075 | 0.026 | -0.026 | -0.005 |
| *LC4* | 1.0DL+0.6WL | 0.368 | 0 | 0.026 | -0.026 | -0.005 |

4. Now that the loading columns are complete, the first row of calculations can be set up. The first step is to calculate the *left thrust y*. As discussed previously, this force is the reaction force of the vault on the left hand side. Unlike the previous example, the loading is not symmetrical and the reaction cannot be calculated by simply adding and halving the external loads. The

force can still be calculated through the use of equilibrium, but by utilising a slightly more complex method, i.e. ∑M=0. Each of the external loads are totalled and transformed into a single point load with a corresponding distance to the edge. The dead and live loads are simply multiplied by the length of the load and applied as point loads. The wind loads are transformed in their corresponding sections and applied as point loads in the centroid of each section. It is important to obtain the correct distance to the edge of the vault, as well as angle at which the load is orientated. The loads are separated as presented in figure 6-19.

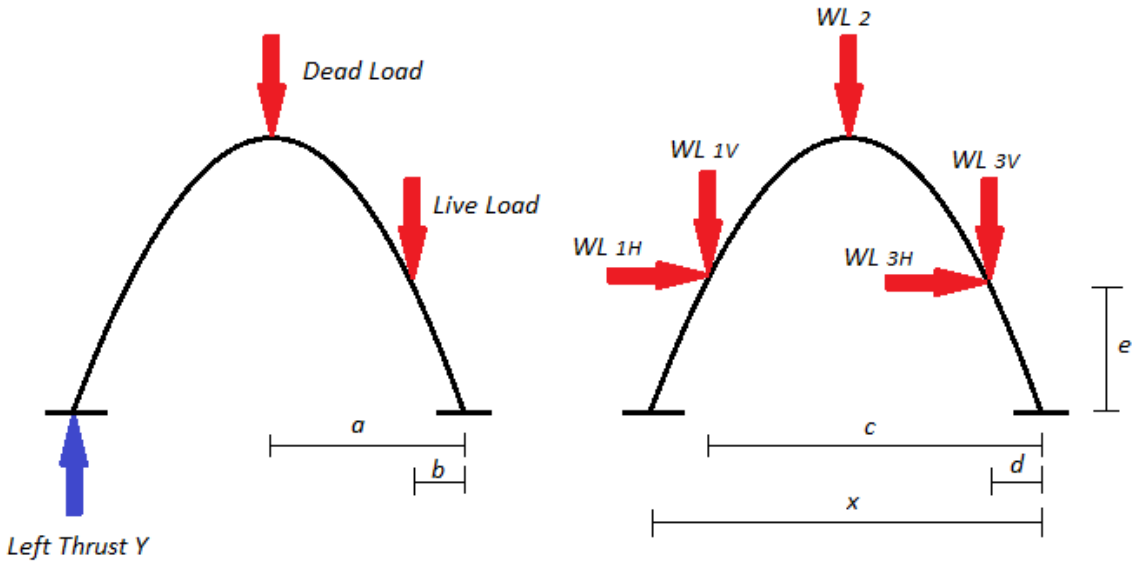



**Figure 6-19: A summary of all of the collapsed loads and their distances to edge - *Left:* Dead and Live Loads; *Right:* Wind Loads**

The left thrust force is calculated as follows:

$$LT\ Y = \left((DL + WL_2) \times a + LL \times b + WL_{1V} \times c + WL_{3V} \times d - (WL_{1H} + WL_{3H}) \times e\right)/x \quad (6\text{-}7)$$

Thus, the value of the *Left Thrust Y* for this load case has a value of 13.24kN.

5. The *Left thrust x* and ***Left Thrust*** are calculated as before:

$$Left\ Thrust = \frac{Left\ Thrust\ (y)}{sin\theta} = \frac{13.24}{\sin(83.3)} = 13.33kN$$

$$Left\ Thrust\ (x) = Left\ Thrust\ \times cos\theta = 13.33\ \times \cos(83.3) = 1.56kN$$

6. The remainder of the steps follow a similar procedure as in section 6.6.1. Previously, when calculating the *Right Thrust x,* it was merely equal to the *Left Thrust x*. However, in this load case, there is an external horizontal force exerted by the wind load that needs to be considered in the calculation. Thus, the *Right Thrust x,* is calculated as follows:

$$Left\ Thrust\ x + Right\ Thrust\ x + Wind\ Load\ (H) = 0 \qquad (6\text{-}8)$$

$$Right\ Thrust\ x = \ -Left\ Thrust\ x - Wind\ Load\ (H) = \ -1.56 - 0.056 = -1.61kN$$

The *Right Thrust Y* is calculated, as before, by taking into account all the vertical forces exerted on that particular segment.

$$Left\ Thrust\ y + Right\ thrust\ y + Dead\ Load + Live\ Load + Wind\ Load\ (V) = 0 \qquad (6\text{-}9)$$

$$Right\ Thrusy\ y = -Left\ Thrust\ y - Dead\ Load - Live\ Load - Wind\ Load\ (V)$$
$$= \ -13.24 - (-0.441) - 0 - (-0.009) = -12.79kN$$

In this load case, the live load is equal to zero for the first calculation and the following 30 as the load only falls over the second half of the vault.

The ***Right Thrust*** is calculated as follows:

$$Right\ Thrust = \ \sqrt{12.79^2 + 1.61^2} = 12.89kN$$

7. The new angle is calculated:

$$\theta = \tan^{-1}\left(\frac{Right\ Thrust\ y}{Right\ Thrust\ x}\right) = \tan^{-1}\left(\frac{12.79}{1.61}\right) = 82.82°$$

8. Lastly, the co-ordinates of the centre of the first segment are calculated as in section 6.6.1.

$$x = Length\ of\ block\ \times \cos(\theta) = 133\ \times \cos(83.3) = 15.52mm$$
$$y = Length\ of\ block\ \times \sin(\theta) = 133\ \times \sin(83.3) = 132.09mm$$

9. The remaining rows of calculation follow a constant formula. The ***right thrust*** and its components, as well as the new angle are calculated as discussed previously. It is important to note that:
    - ***Right Thrust*** *(Row 1) =* ***Left Thrust*** *(Row 2)*
    - *New Angle (Row 1) = Old Angle (Row 2)*
10. The left thrust components are calculated using trigonometry. Steps 6 to 9 are repeated for each succeeding row.
11. The co-ordinates are calculated in the same manner as step 8; however, they are also added to the preceding co-ordinate.

$$x_2 = x_1 + \ Length\ of\ block\ \times \cos(\theta) = 15.52 + 133 \times \cos(82.82) = 32.14mm$$

$$y_2 = y_1 + Length\ of\ block \times \cos(\theta) = 132.09 + 133 \times \cos(82.82) = 264.05mm$$

All calculations can be followed on page 108.

| Segment no. | Height of Segment | DL + LL per block | Wind Load | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | **Left Thrust Resultant** | Right Thrust x | Right Thrust y | **Right Thrust Resultant** | Right angle | Co-ordinates X | Co-ordinates Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 133 | 0.4414 | 0.0570 | 0.0562 | 0.0094 | 83.30 | 1.556 | 13.242 | 13.333 | -1.612 | -12.791 | 12.892 | 82.82 | 0 | 0 |
| 2 | 133 | 0.4414 | 0.0570 | 0.0562 | 0.0097 | 82.82 | 1.612 | 12.791 | 12.892 | -1.668 | -12.340 | 12.452 | 82.30 | 15.52 | 132.09 |
| 3 | 133 | 0.4414 | 0.0570 | 0.0561 | 0.0100 | 82.30 | 1.669 | 12.340 | 12.452 | -1.724 | -11.888 | 12.013 | 81.75 | 32.14 | 264.05 |
| 4 | 133 | 0.4414 | 0.0570 | 0.0560 | 0.0104 | 81.75 | 1.724 | 11.888 | 12.013 | -1.780 | -11.436 | 11.585 | 81.15 | 49.96 | 395.85 |
| 5 | 133 | 0.4414 | 0.0570 | 0.0560 | 0.0107 | 81.15 | 1.780 | 11.436 | 11.585 | -1.836 | -10.985 | 11.137 | 80.51 | 69.05 | 527.47 |
| 6 | 133 | 0.4414 | 0.0570 | 0.0559 | 0.0111 | 80.51 | 1.836 | 10.985 | 11.137 | -1.892 | -10.532 | 10.701 | 79.82 | 89.41 | 658.89 |
| 7 | 133 | 0.4414 | 0.0570 | 0.0558 | 0.0115 | 79.82 | 1.892 | 10.532 | 10.701 | -1.948 | -10.079 | 10.266 | 79.07 | 110.07 | 790.07 |
| | | | | | | | | ... | | | | | | | |
| 15 | 133 | 0.4414 | 0.0570 | 0.0546 | 0.0164 | 71.29 | 2.335 | 6.894 | 7.278 | -2.390 | -6.426 | 6.825 | 69.63 | 357.42 | 1824.36 |
| 16 | 133 | 0.4414 | 0.0570 | 0.0543 | 0.0173 | 69.63 | 2.390 | 6.436 | 6.865 | -2.444 | -5.968 | 6.446 | 67.76 | 400.09 | 1950.33 |
| 17 | 133 | 0.4414 | -0.0570 | -0.0540 | -0.0184 | 67.76 | 2.444 | 5.977 | 6.457 | -2.390 | -5.554 | 6.046 | 66.72 | 446.38 | 2075.01 |
| 18 | 133 | 0.4414 | -0.0570 | -0.0536 | -0.0195 | 66.72 | 2.390 | 5.554 | 6.046 | -2.336 | -5.132 | 5.639 | 65.52 | 496.72 | 2198.12 |
| 19 | 133 | 0.4414 | -0.0570 | -0.0531 | -0.0207 | 65.52 | 2.336 | 5.132 | 5.639 | -2.283 | -4.711 | 5.235 | 64.14 | 549.29 | 2320.29 |
| | | | | | | | | ... | | | | | | | |
| 30 | 133 | 0.4414 | -0.0570 | -0.0244 | -0.0515 | 18.87 | 1.829 | 0.625 | 1.933 | -1.805 | -0.235 | 1.820 | 7.42 | 1423.54 | 3457.15 |
| 31 | 133 | 0.4414 | -0.0570 | -0.0156 | -0.0548 | 7.42 | 1.805 | 0.235 | 1.820 | -1.789 | 0.151 | 1.796 | -4.84 | 1549.39 | 3500.16 |
| 32 | 133 | 0.4574 | -0.0570 | -0.0054 | -0.0567 | -4.84 | 1.789 | -0.151 | 1.796 | -1.784 | 0.552 | 1.867 | -17.20 | 1681.28 | 3517.34 |
| 33 | 133 | 0.4574 | -0.0570 | 0.0054 | -0.0567 | -17.20 | 1.784 | -0.552 | 1.867 | -1.789 | 0.953 | 2.027 | -28.04 | 1813.80 | 3506.12 |
| 34 | 133 | 0.4568 | -0.0570 | 0.0156 | -0.0548 | -28.04 | 1.789 | -0.953 | 2.027 | -1.805 | 1.355 | 2.257 | -36.89 | 1940.86 | 3466.79 |
| | | | | | | | | ... | | | | | | | |
| 46 | 133 | 0.4473 | -0.0570 | 0.0531 | -0.0207 | -68.97 | 2.283 | -5.938 | 6.361 | -2.336 | 6.364 | 6.779 | -69.84 | 2843.61 | 2194.26 |
| 47 | 133 | 0.4469 | -0.0570 | 0.0536 | -0.0195 | -69.84 | 2.336 | -6.364 | 6.779 | -2.390 | 6.791 | 7.200 | -70.61 | 2891.35 | 2070.12 |
| 48 | 133 | 0.4466 | -0.0114 | 0.0108 | -0.0037 | -70.61 | 2.390 | -6.791 | 7.200 | -2.401 | 7.234 | 7.622 | -71.64 | 2937.19 | 1945.27 |
| 49 | 133 | 0.4463 | -0.0114 | 0.0109 | -0.0035 | -71.64 | 2.401 | -7.234 | 7.622 | -2.412 | 7.677 | 8.047 | -72.56 | 2981.34 | 1819.81 |
| 50 | 133 | 0.4460 | -0.0114 | 0.0109 | -0.0033 | -72.56 | 2.412 | -7.677 | 8.047 | -2.423 | 8.120 | 8.474 | -73.39 | 3023.23 | 1693.58 |
| | | | | | | | | ... | | | | | | | |
| 61 | 133 | 0.4443 | -0.0114 | 0.0112 | -0.0021 | -78.58 | 2.533 | -12.545 | 12.798 | -2.545 | 12.987 | 13.234 | -78.91 | 3327.82 | 536.45 |
| 62 | 133 | 0.4442 | -0.0114 | 0.0112 | -0.0020 | -78.91 | 2.545 | -12.987 | 13.234 | -2.556 | 13.429 | 13.670 | -79.22 | 3355.82 | 406.43 |
| 63 | 133 | 0.4442 | -0.0114 | 0.0112 | -0.0019 | -79.22 | 2.556 | -13.429 | 13.670 | -2.567 | 13.871 | 14.107 | -79.52 | 3382.96 | 276.23 |
| | | | | | | | | | | | | | | 3409.29 | 145.86 |
| | | | | | | | | | | | | | | 3434.86 | 0.00 |

Dead Load only

Change in wind pressure at this brick

DL+LL: Live Load is over 2nd half of curve

WL H = WL*sin(orig angle)
WL V = WL*cos(orig angle)

Calculated by using static equilibrum: ΣM=0

Insert co-ord as starting point

Right Thrust (Line 1) = Left Thrust (Line 2)

Right angle (Line 1) = Left Angle (Line 2)

**Figure 6-20: An Excel spread sheet showing the design process of a catenary curve subject to vertical and lateral loading**

The final thrust line obtained for this load case is shown in figure 6-21.

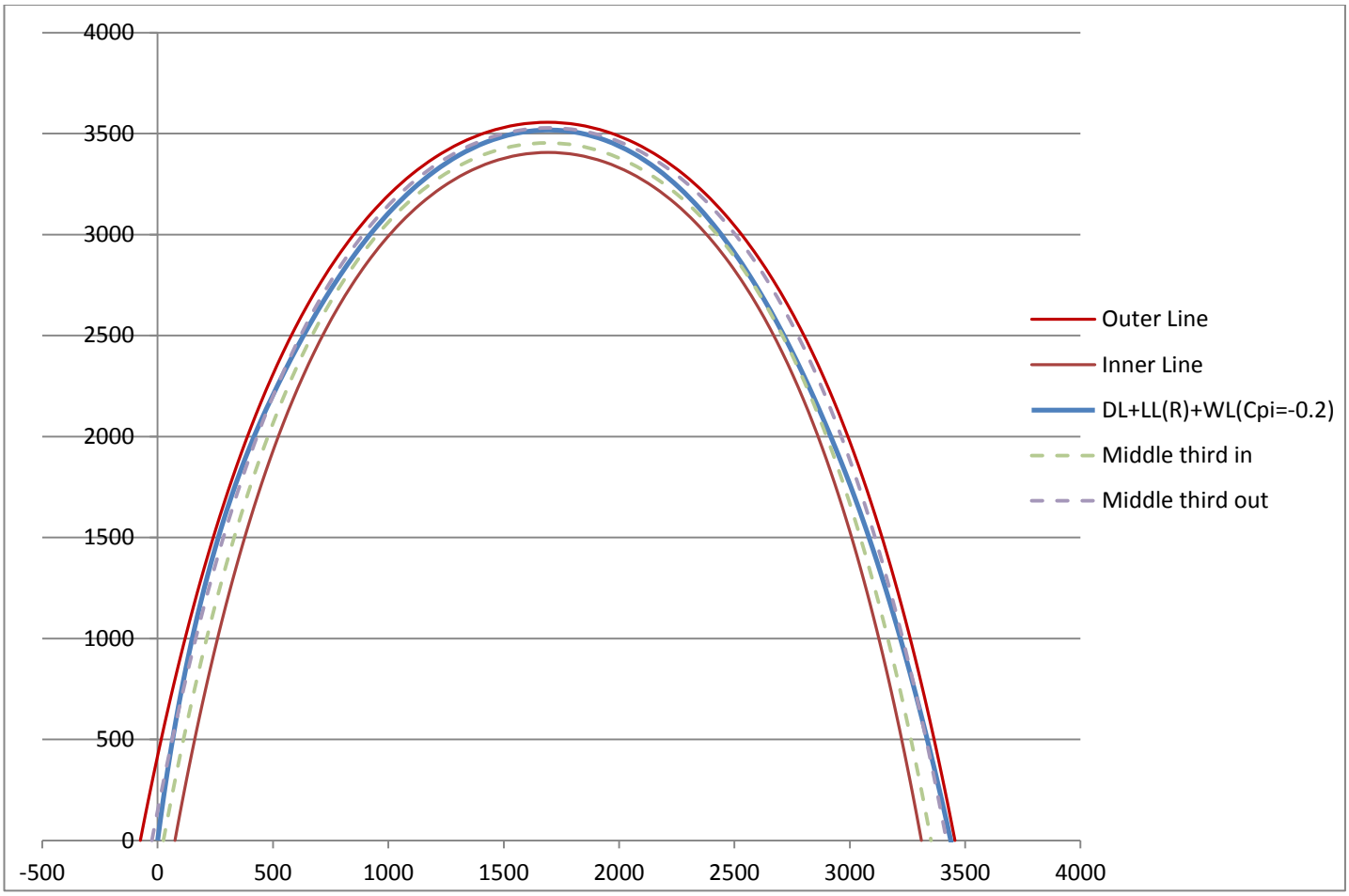



**Figure 6-21: The final thrust line obtained for the load case of: *DL+LL(R)+WL(Cpi=-0.2)***

## 6.6. Finite Element Analysis

Finite Element Analysis is an important aspect in the design phase. Finite Element was used to verify the accuracy of the equilibrium method and to analyse temperature loading on the structure. LISA version 7.7.1, a finite element analysis programme, was used in the analysis of this project.

### 6.6.1. Verification Phase

The first step of analysis was done to compare the results obtained from the FEA programme to the segmental equilibrium method. This was done by comparing the reactions and the thrust lines obtained in the two methods. Furthermore, all of the

load cases were modelled in the programme and a selected set of critical cases evaluated.

A summary of the reactions obtained are compared and presented in Table 6-8 below. The errors obtained in Table 6-8 are minor and verify that the equilibrium method is correct and is a viable method for the design of catenary curves. The errors obtained for the vertical reactions range between 2.8 and 6.1 percent. The vertical reactions are significantly larger than the horizontal reactions. The horizontal reactions are smaller in magnitude with greater percentage errors, as they are more sensitive to smaller variations in value. The horizontal reaction errors are in the range of 0 and 8.9 percent.

**Table 6-8: Load reactions comparison of the results obtained from Finite element Analysis and the Segmental Equilibrium Method**

| *Load Case* | *Excel ∑H (kN)* | *LISA ∑H (kN)* | *Error* | *Excel ∑V (kN)* | *LISA ∑V (kN)* | *Error* |
|---|---|---|---|---|---|---|
| Dead Load, Live Load (Full) | 0 | 0 | 0% | 29.588 | 30.413 | 2.8% |
| Dead Load, Live Load (Left half) | 0 | 0 | 0% | 28.529 | 29.684 | 4.7% |
| Dead Load, Wind Load Cpi=-0.2 | -1.012 | -1.093 | 8% | 19.936 | 20.924 | 5% |
| Dead Load, Live Load (full), Wind Load Cpi=-0.2 | -1.016 | -1.093 | 7.6% | 27.322 | 28.462 | 4.2% |
| Dead Load, Live Load (Left half), Wind Load Cpi=0 | -1.000 | -0.911 | 8.9% | 26.814 | 28.463 | 6.1% |
| Dead Load, Live Load (Right half), Wind Load Cpi=-0.2 | -1.012 | -1.093 | 8% | 27.113 | 28.238 | 4.2% |

The second phase of verification consists of comparing the thrust lines obtained from the two methods. Figures 6-22 to 6-25 compares the thrust lines obtained from finite element and the segmental equilibrium method. The thrust lines are similar and

verify the viability of the segmental equilibrium method. Lateral loads create a greater discrepancy in the thrust lines, than vertical loading. Discrepancies in the thrust lines are due to the approximate nature of the finite element method as a means of designing catenary curves. The discrepancies can also be attributed to the fact that the number of segments and sizes differ, and therefore the plots will vary with accuracy.

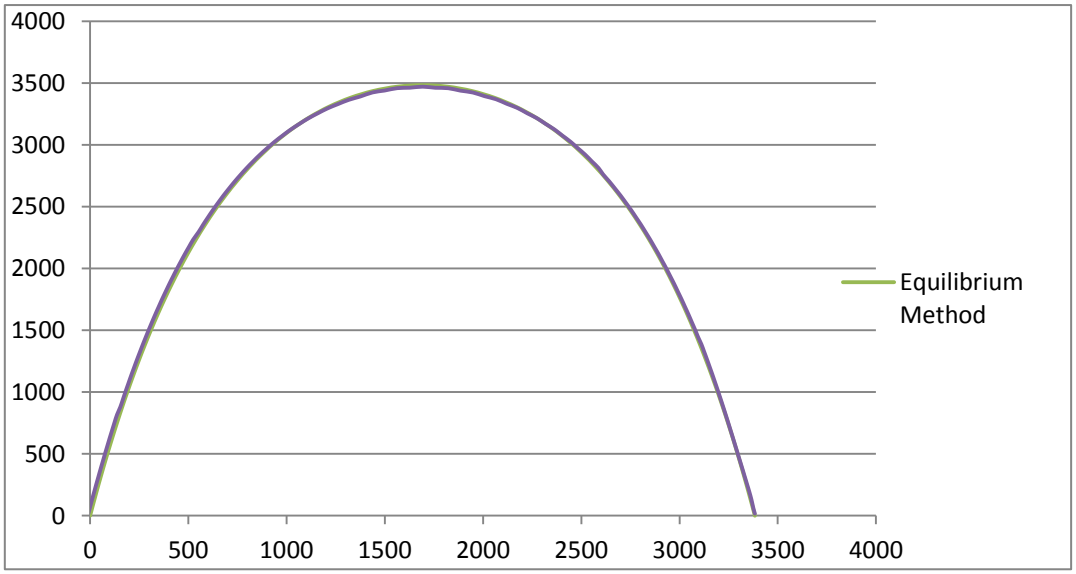



**Figure 6-22: A comparison of the Segmental Equilibrium Method and Finite element method when subject to dead loads**

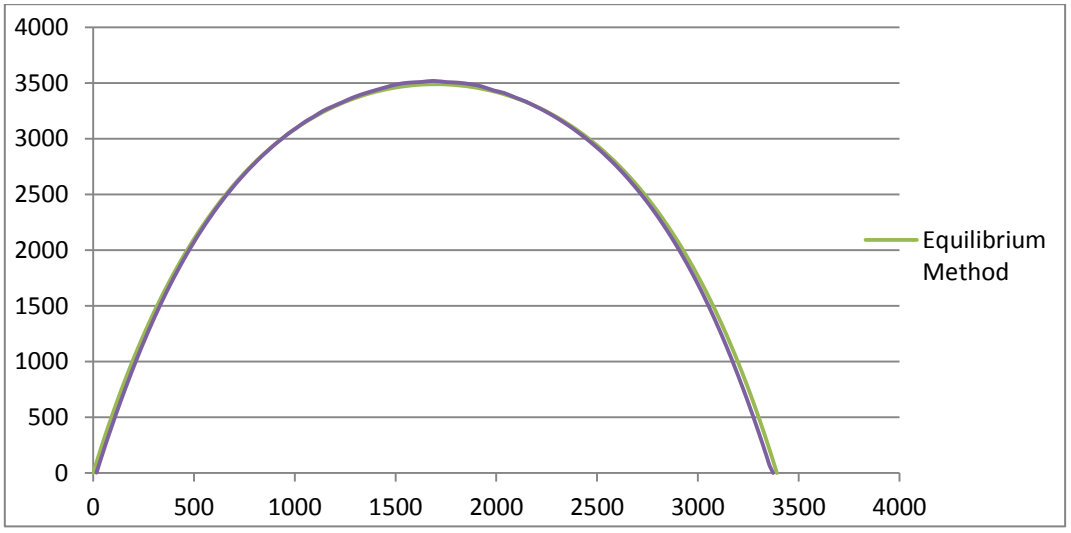



**Figure 6-23: A comparison of the Segmental Equilibrium Method and Finite element method when subject to dead and live loads**

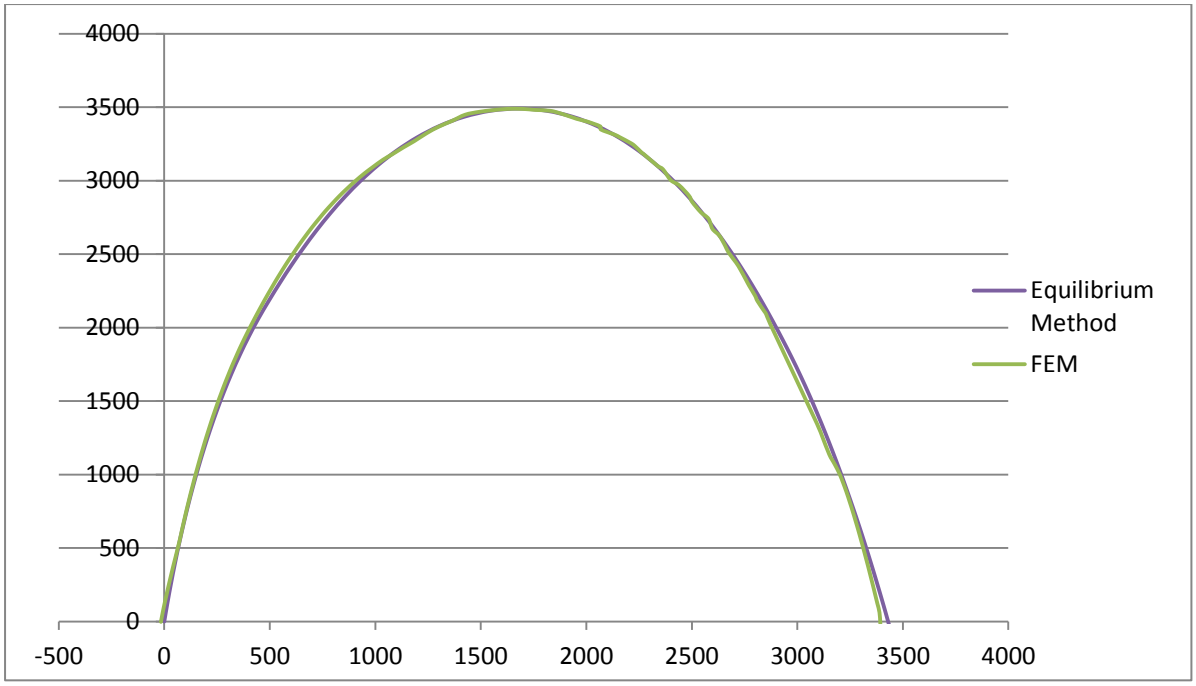



**Figure 6-24: A comparison of the Segmental Equilibrium Method and Finite element method when subject to dead, full live and wind loads (Cpi=-0.2)**

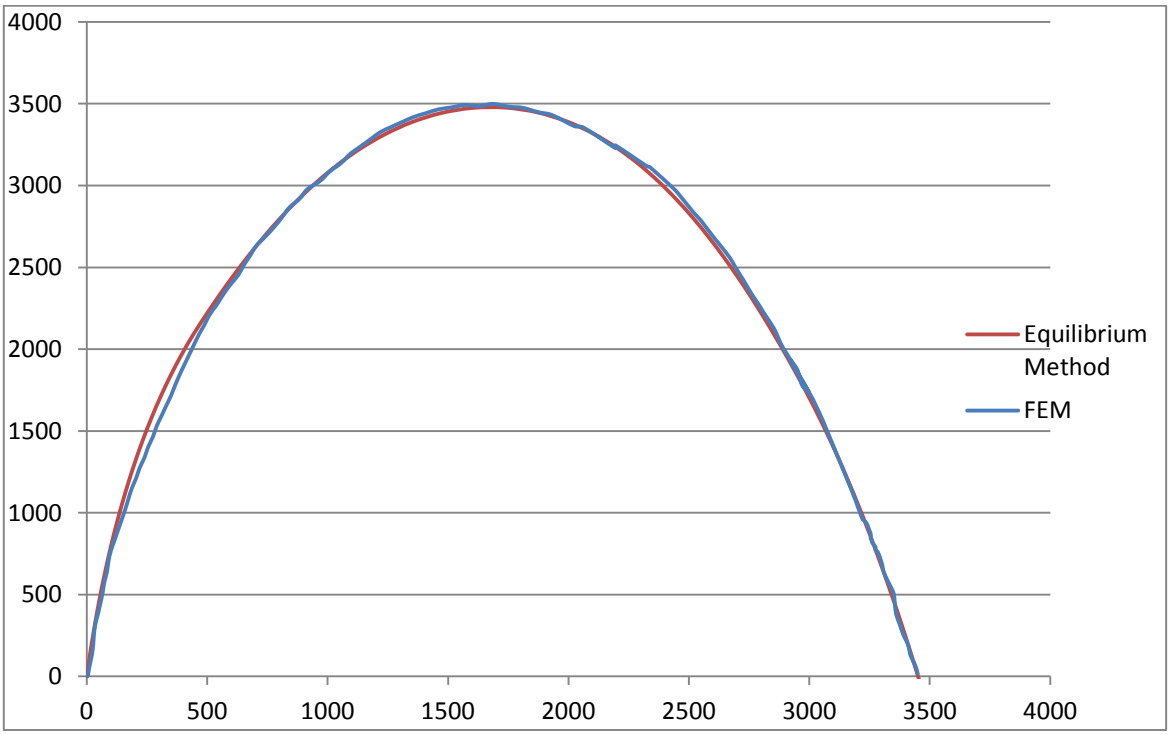



**Figure 6-25: A comparison of the Segmental Equilibrium Method and Finite element method when subject to dead and wind loads (Cpi=-0.2)**

### 6.6.2. Analysis of Temperature Loading

Finite Element was used to analyse temperature loading on the structure. A temperature difference of 20°, in expansion and contraction, was analysed when applied to the full and half surface of the structure.

All loading combinations and patterns were investigated in combination with temperature loading. All the finite element results from the loading cases can be found in Appendix B. Here, we will discuss the worst loading case which created the highest stresses within the vault.

The analysis showed that the structure was subject to the highest tensile stresses during temperature changes (±20°) combined with wind action, i.e. Dead Load + Wind Load ($C_{pi}$ = 0) + Temperature Load (±20°). These tensile stresses are predominantly found at the base of the structure and sometimes in small clusters close to the apex. Figures 6-26 to 6-29 demonstrate the distribution of tensile and compressive forces throughout the structure under the worst loading case. Note that the edges of the vault in this project are not restrained in any way, and are therefore allowed to expand and contract naturally.

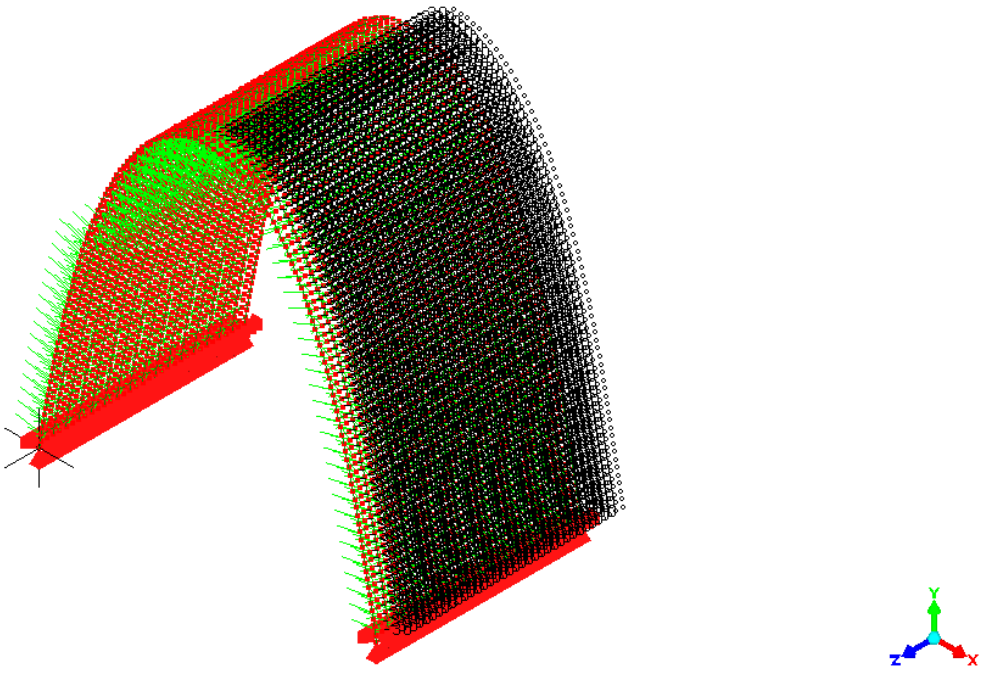



**Figure 6-26: A model of the worst load case inputted to LISA 7.7.1: *DL+WL+TL***

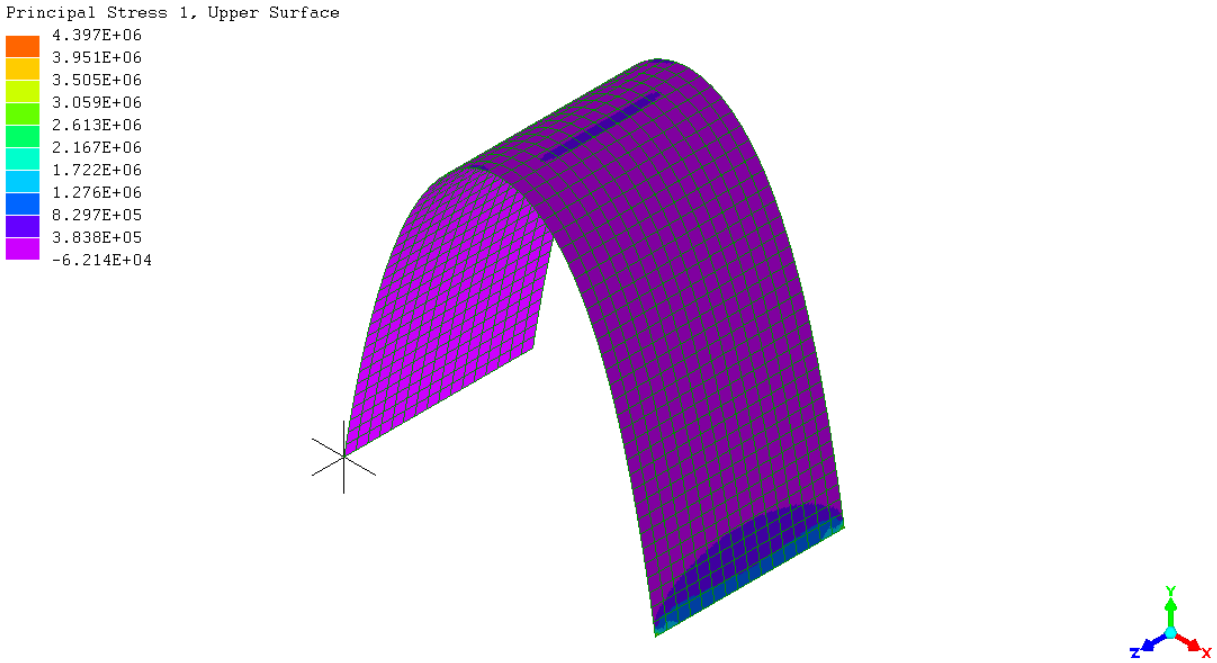



**Figure 6-27: The dominant principal stress distribution on the upper surface of the vault under the most severe loading case**

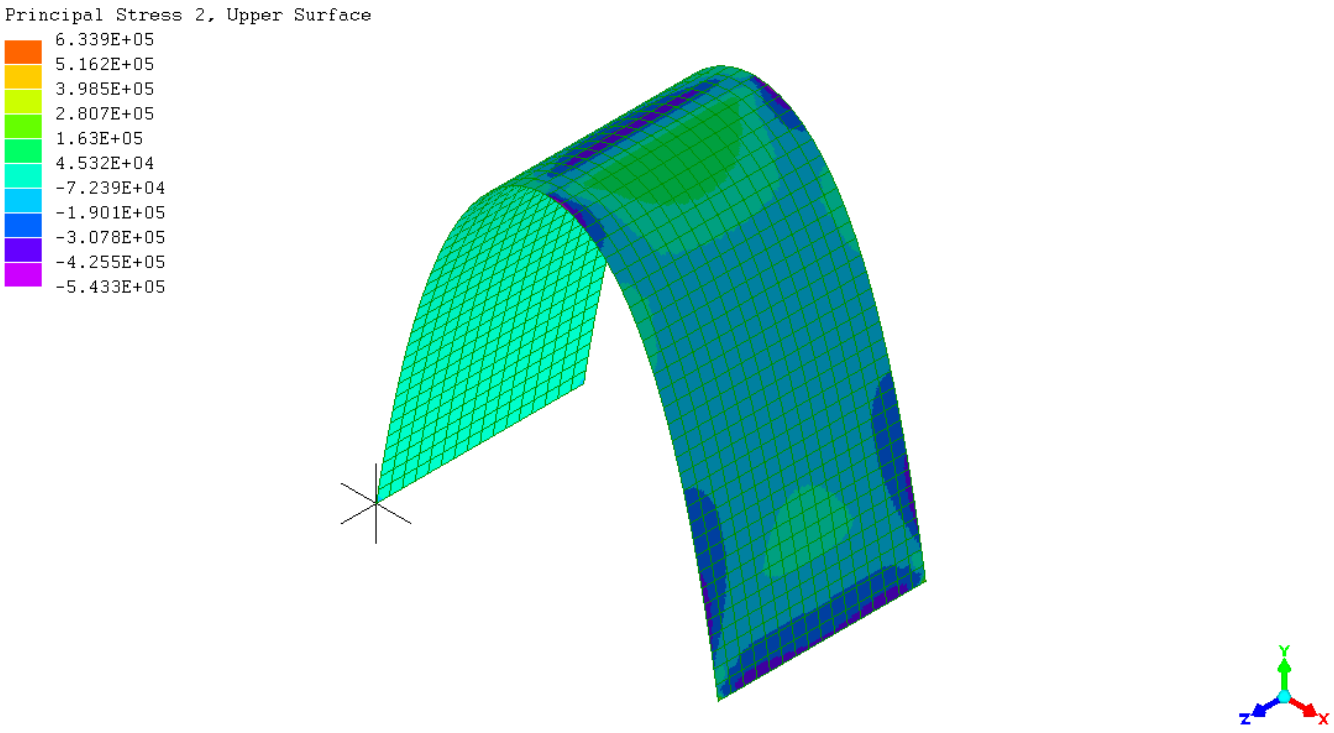



**Figure 6-28: The minor principal stress distributions on the upper surface of the vault under the most severe loading case**

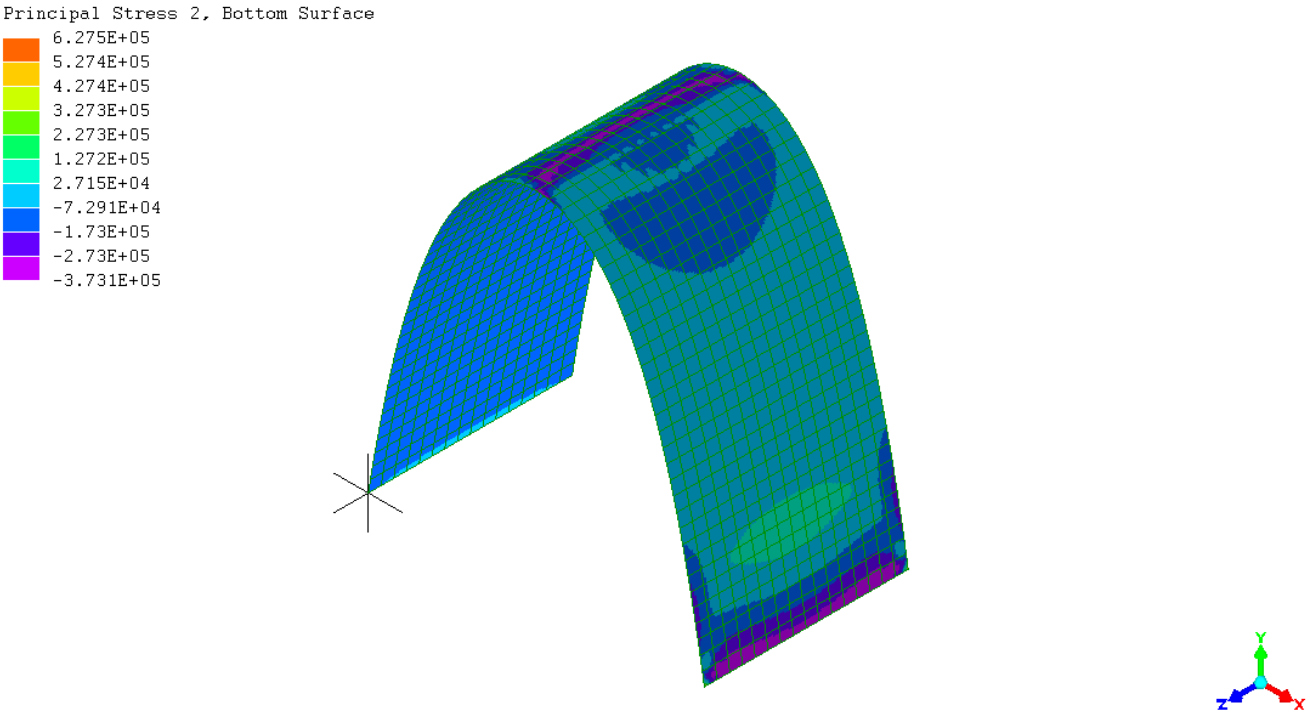



**Figure 6-29: The dominant principal stress distribution on the bottom surface of the vault under the most severe loading case**

Note: All negative values represent compressive stresses and positive values represent tensile stresses. The analysis displays what occurs on the upper and bottom surfaces of the material with major and minor stresses. From the above figures, it is clear the tensile stress are very concentrated to specific areas, i.e. Figure 6-27 – dark blue, Figure 6-28 – bright green, Figure 6-29 – light green.

## 6.7. Discussion of Results

### 6.7.1. Thrust Line Analysis

All loading combinations and patterns were investigated and plotted to identify areas of weakness and further investigation. Figures 6-30 to 6-36 display the thrust lines obtained from all the investigated loading combinations. Figure 6-30 shows the loading patterns which are only loaded with wind loads, Figures 6-31 to 6-33 represent only UDL live loads and Figures 6-34 to 6-36 are loaded with a point live load. Areas which require further investigation are ones where the thrust line falls outside of the middle third.

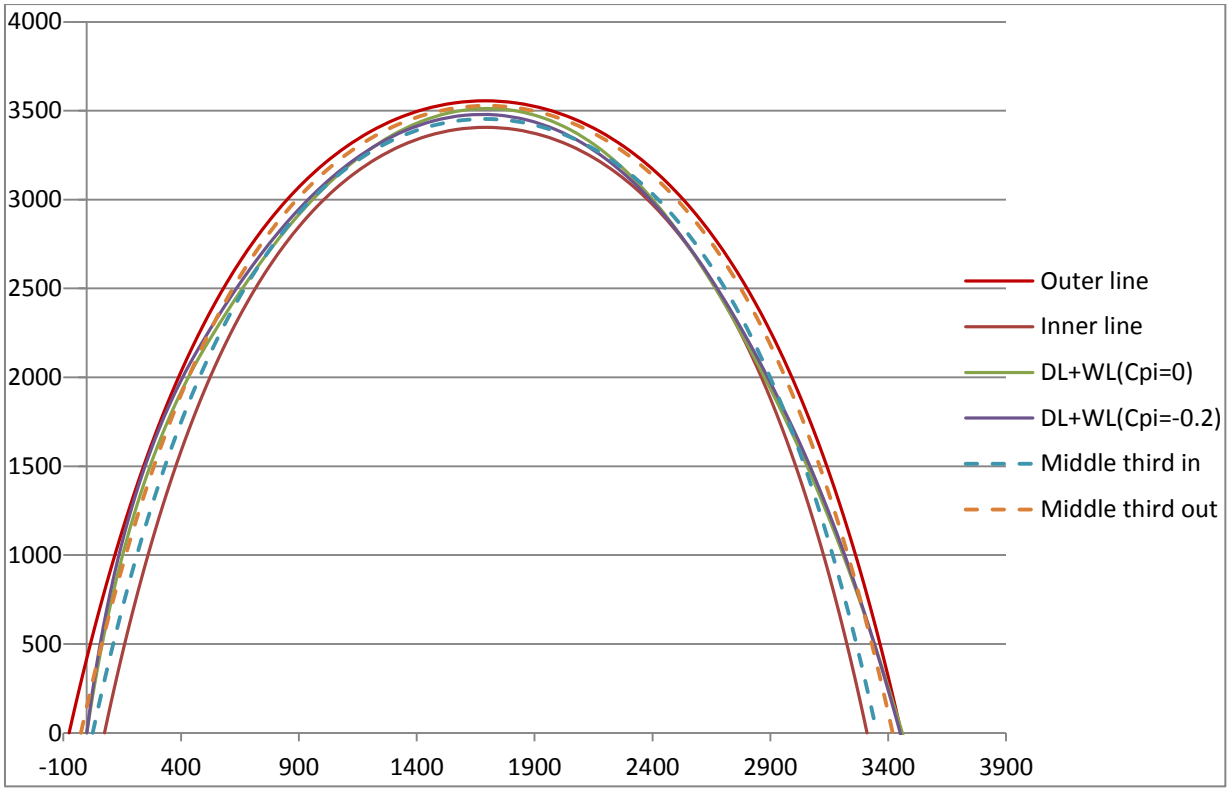



**Figure 6-30: A graph representing the thrust lines obtained from only wind and dead load combinations**

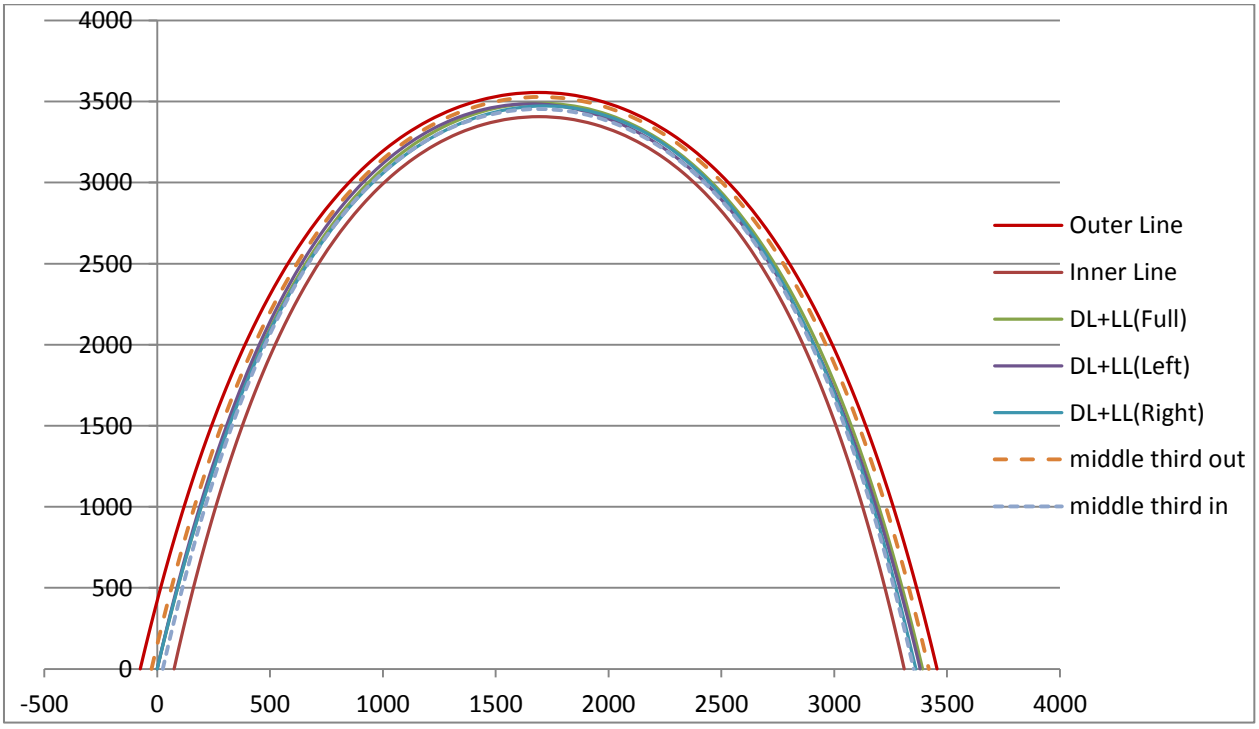



**Figure 6-31: A graph representing the thrust lines obtained from only live (udl) and dead load combinations**

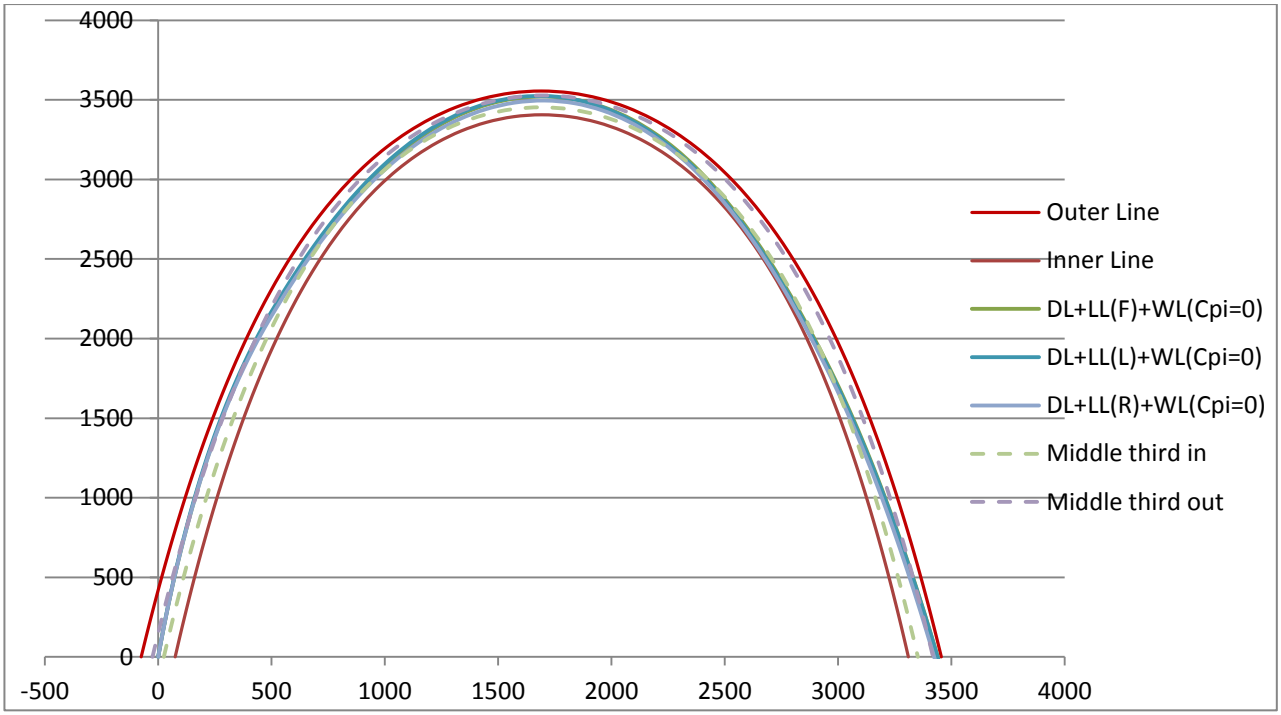



**Figure 6-32: A graph representing the thrust lines obtained from wind (cpi=0), live (udl) and dead load combinations**

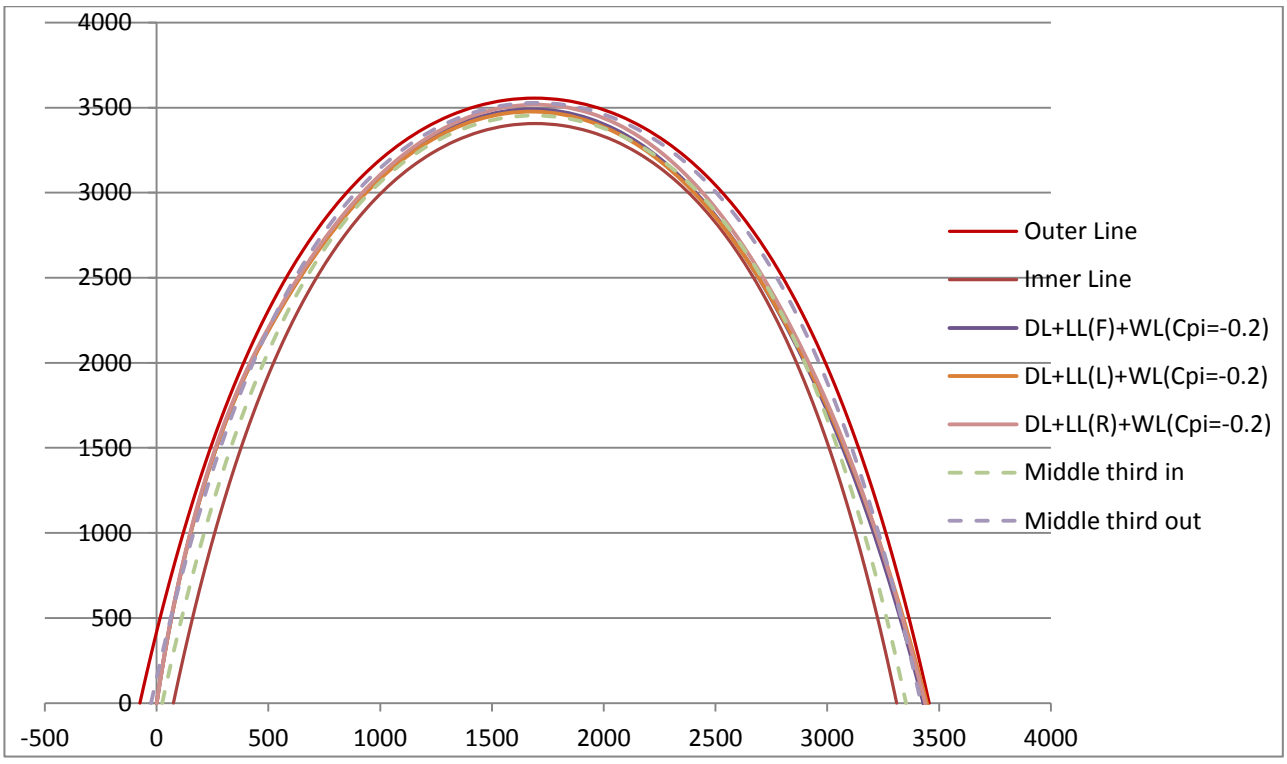



**Figure 6-33: A graph representing the thrust lines obtained from wind (cpi=-0.2), live (udl) and dead load combinations**

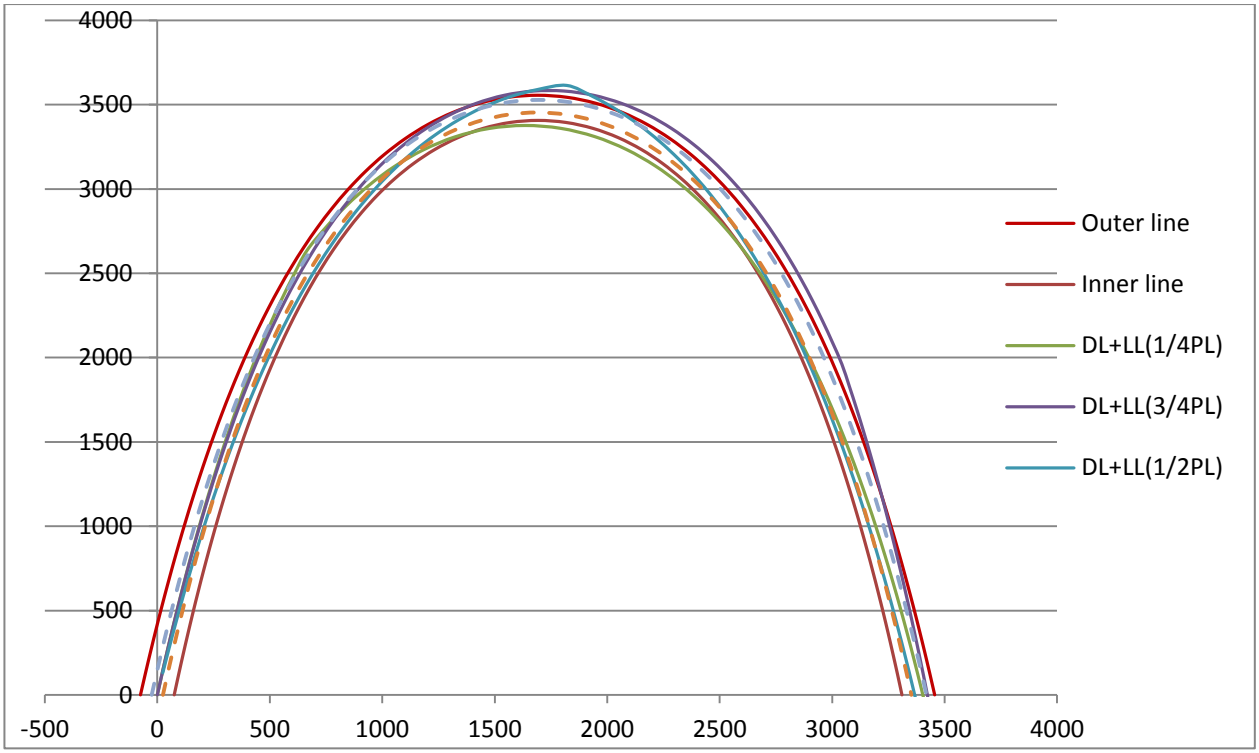



**Figure 6-34: A graph representing the thrust lines obtained from only live (point) and dead load combinations**

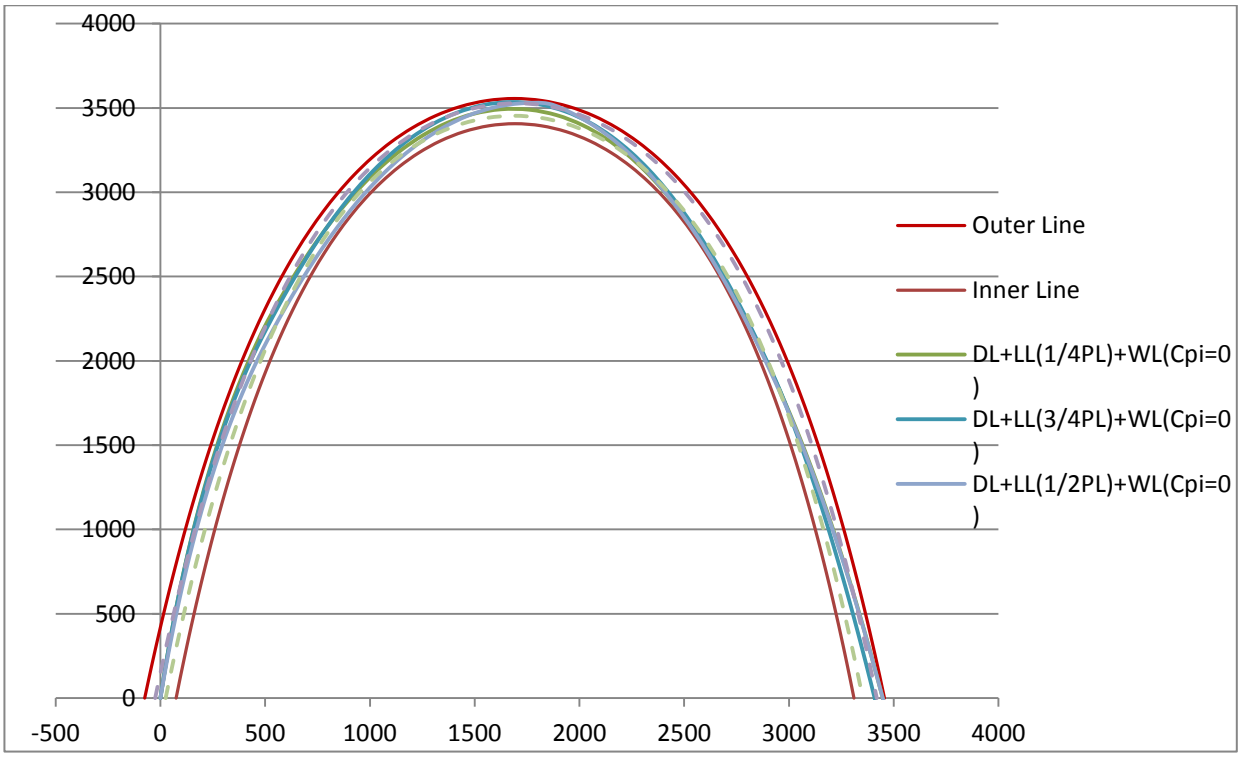



**Figure 6-35: A graph representing the thrust lines obtained from wind (cpi=0), live (point) and dead load combinations**

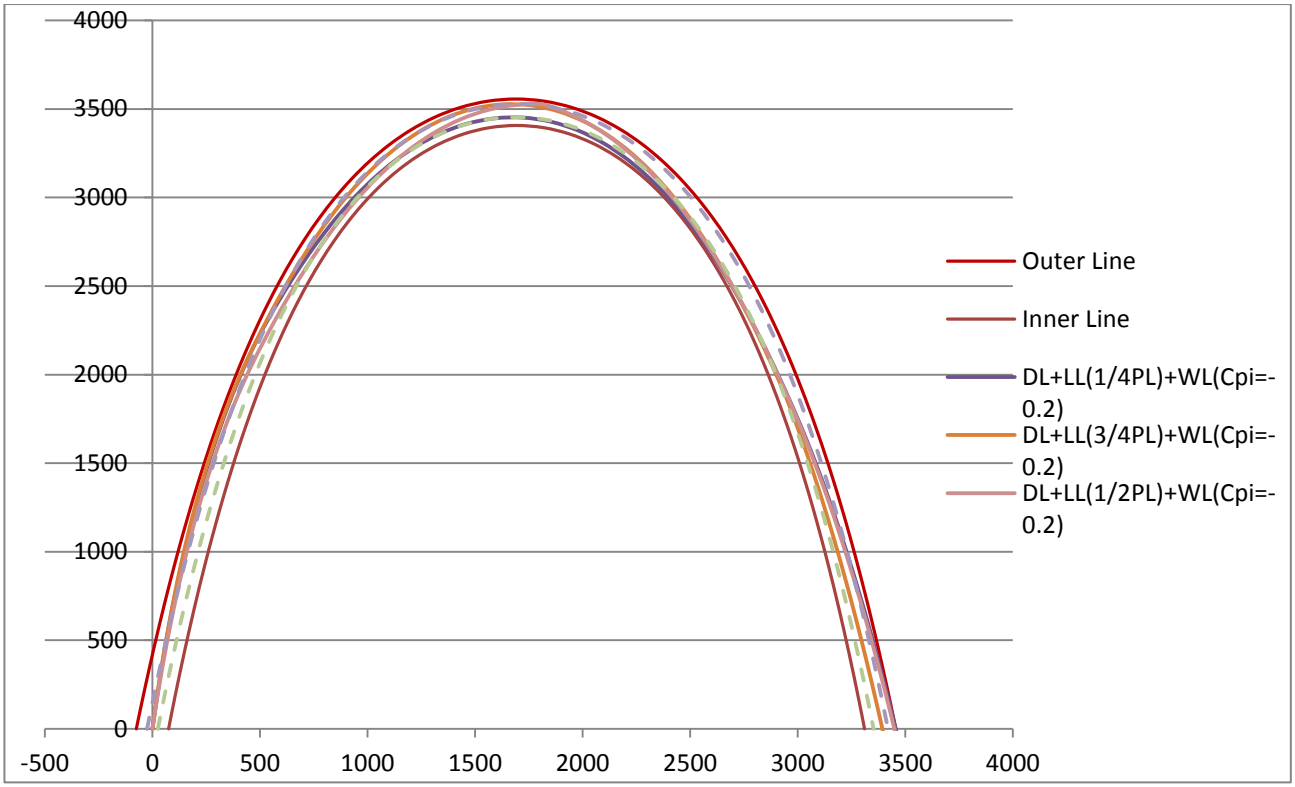



**Figure 6-36: A graph representing the thrust lines obtained from wind (cpi=-0.2), live (point) and dead load combinations**

Point loading on the vault structure is the most likely concern in causing structural instability and failure. Figure 6-34 to 6-36 show the results obtained when the structure is subject to a point load at various points, i.e. at a ¼ length, ¾ lengths and at the centre of the structure. When this load is applied in combination with a wind load, all thrust lines fall within the thickness of the vault. However, when the structure is subjected to point loads, the thrust lines far exceed the thickness of the vault. This is a clear warning sign and reiterates the fact that catenary's are not robust in supporting point loads; however, this is the case with all shell structures (Wilson, 2005). Thus, it is very important that the structure is not subjected to point loads so as to avoid any complications or structurally instability in the roof. If the roof is to be accessed for maintenance or other such needs, it is strongly advised that supports, scaffolding or other such alternatives are used for safety purposes.

It can be seen that load cases which include wind loads can cause areas of weakness. Figures 6-30 and 6-32 show that two dominant areas fall outside of the middle third. However, they do remain within the thickness of the material. The

tensile forces in these areas are obtained from the finite element analysis and compared to the tensile strength of the material. The maximum tensile forces are minor and fall within the tensile limit of 1.1N/mm² (refer to Chapter 4). All tensile stresses obtained are within a range of 0.11-0.95N/mm².

### 6.7.2. Finite Element Analysis

Finite Element was carried out to assess the effects of temperature loading on the structure. Temperature loading was found to be the most severe loading case, creating the largest tensile and compressive stresses. As discussed previously, there is a change in stresses on the centre line of the curve. However, in this case the change is gradual and not abrupt as is the case for Bapong. Therefore this does not create concern in terms of cracking. All compressive stresses are below the compressive strength of the material. It is advised that the stresses do not exceed a third of the strength (rule of thumb). The maximum compressive stress obtained is 1.02N/mm², where the strength of the masonry is 3.75N/mm². The maximum tensile stresses are of magnitude 0.99N/mm². This value is quite close to the tensile strength of the material and it is advised that additional precautionary measures should be taken once construction is complete.

## 6.8. Conclusion

It is concluded that all load cases are within the required limits. Thus, the above curve is the finalised design of the roof structure. However, it was decided that a layer of a very lightly coloured form of waterproofing, paint or fabric would be placed over the roof to minimise the temperature loading on the structure. This in turn would minimise the chance of cracking within the roof structure.

# 7. Structural Member Design

The design of all the members in this chapter were carried out in accordance with the reinforced and pre-stressed concrete codes SABS 0100-1 (2000) and BS8100-1 (1997), as well as the masonry codes BS 5628-1(1992) and ENV1996-1-1 (1996). A number of elements were selected prior to design and the capacity was checked to ensure that the elements were sufficient to support the exerted loading. In this chapter, the design process and detail of all members are discussed. All the members are designed to capacity, finalising the design of the prototype structure before construction can commence.

## 7.1. Slab

### 7.1.1. Introduction

The design of the slab was conducted by Spancon, a local distributor of slab systems. A rib and block slab was decided on to minimise the quantity of concrete used, which is approximately 30% less than normal slabs. It is also the most cost effective solution for slab flooring. This is highlighted particularly in the installation process. The slab is very easy to install, and thus less labour is needed in shorter periods. The slab merely utilises lintels as the ribs and hollow precast blocks (void formers) which are placed between the lintels, thus eliminating the need for formwork or scaffolding. A ready mix of concrete is used and minimal steel reinforcing is required. A rib and block slab has also proved to have excellent insulation properties (Spancon, 2013). This is particularly important when designing for a low-cost house.

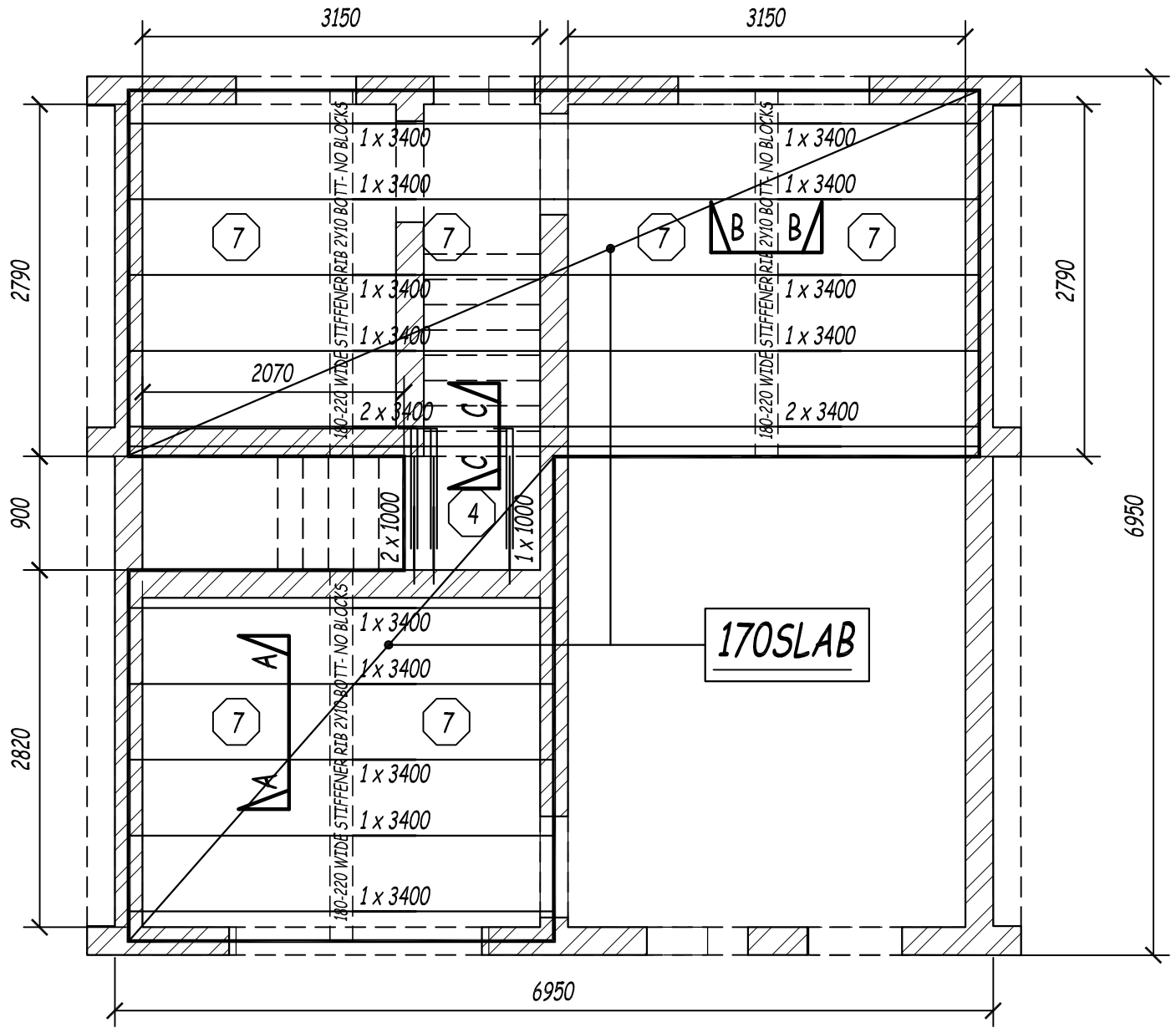
### 7.1.2. Design

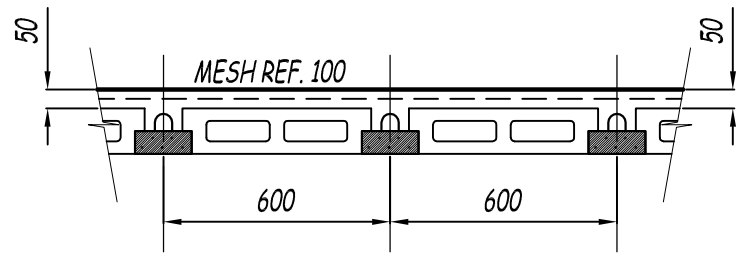
All slab specifications and designs are supplied by Spancon (Table 7-1, Figure 7-1).

**Table 7-1: Properties of materials used in the slab**

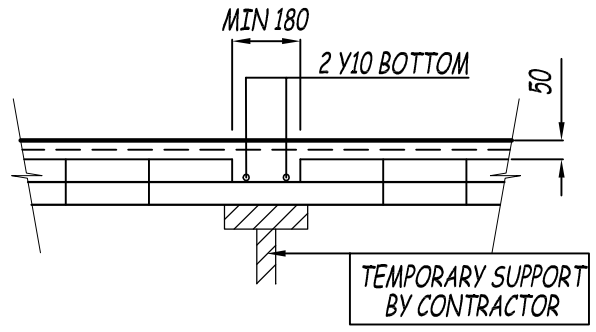
| | |
|---|---|
| Loading | 1.5kN/m² |
| Reinforcing steel | Y10 |
| Ready mix concrete quantity | 3m³ |
| Ready mix concrete strength | 25MPa |
| Floor area | 28m² |
| Thickness of slab | 170mm |
| Thickness of concrete above rib and block system | 50mm |

NOTE:
NO SITE MIX CONCRETES ARE PERMITTED - VIBRATION OF CONCRETE IS MANDATORY
NO CONCRETE MAY BE POURED WITHOUT INSPECTION AND APPROVAL BY SUPERVISING ENGINEER - NO INSPECTION NO CERTIFICATE

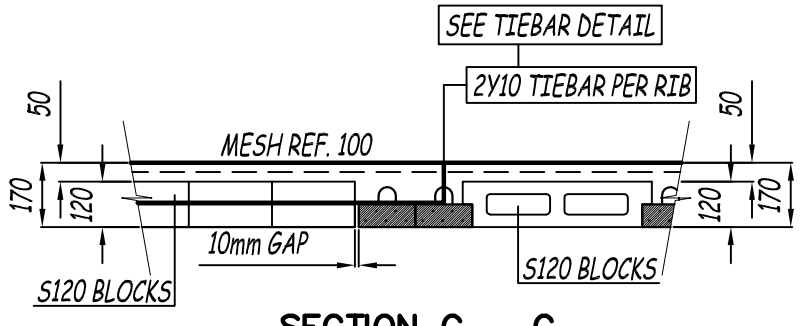


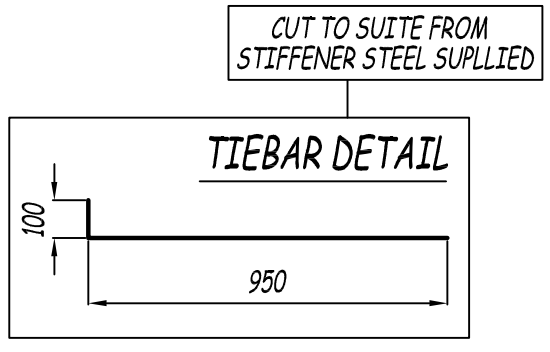

SECTION A – A




SECTION B – B




SECTION C – C




PLAN ON 170 DEEP FIRSTFLOOR SLAB
(UNLESS OTHERWISE SHOWN)
SCALE 1 : 50

| LEGEND | | |
|---|---|---|
| SYMBOL | BLOCK TYPE | DIMENSIONS (WxLxH) |
| | | |
| | | |
| ○ | S120 BLOCK | 440x220x120 |
| □ | S150 BLOCK | 440x220x150 |
| ◇ | S205 BLOCK | 440x220x205 |
| | | |
| ⬡ | S290 BLOCK | 440x220x290 |
| | LOADBEARING BRICKWORK | |
| | BEAM STRIPS | |
| | BEAMS | |
| | STEPPED BLOCK | |
| | S TRAY (PIPE SERVICES) | |
| | SOLID SECTION | |
| 1,5kPa | DESIGN LIVE LOAD | |

NOTES
GENERAL
1. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL OTHER RELEVANT DRAWINGS & SPECIFICATIONS.
2. ALL DIMENSIONS TO VERIFIED ON SITE & ANY DISCREPANCIES TO BE REPORTED TO THE ENGINEER.
3. REFER TO ARCHITECTS DETAIL FOR ALL SETTING OUT DIMENSIONS.

CONCRETE
1. ALL CONCRETE WORK TO BE EXECUTED IN ACCORDANCE WITH SABS 1200 G.
2. CONCRETE STRENGTHS AS FOLLOWS :
   FOUNDATIONS - 20 MPa
   COLUMNS - 25 MPa
   SLABS - 25 MPa
3. 6 CUBE TESTS TO BE TAKEN WITH EACH CONCRETE POUR AND TO BE TESTED AS FOLLOWS : - 3 CUBE TESTS @ 7 DAYS
   - 3 CUBE TESTS @ 28 DAYS.
4. ALL STRUCTURAL CONCRETE TO BE CURED FOR 7 DAYS UNLESS OTHERWISE INSTRUCTED.
5. SLIP JOINTS TO BE PROVIDED ON ALL LOAD BEARING WALLS AS PER THE DETAIL.
6. SLAB LEVELS TO ARCHITECTS DETAIL.
7. NO BRICKWORK IS TO BE BUILT ONTO A PROPPED SLAB UNLESS DIRECTLY ABOVE A LOAD BEARING WALL.
8. IT REMAINS THE ERECTION CONTRACTORS RESPONSIBILITY TO ENSURE THAT THE TEMPORARY SUPPORTWORK TO SLABS IS ADEQUATE.

REINFORCEMENT
1. ALL REINFORCEMENT FIXING TO BE INSPECTED & APPROVED BY THE ENGINEER PRIOR TO CONCRETING.
2. ENGINEER TO BE GIVEN AT LEAST 24 HOURS NOTICE OF REQUIRED INSPECTION. ALL PREPARATORY WORK TO BE COMPLETED PRIOR TO INSPECTION.
3. COVER TO REINFORCING :
   SLAB SOFFIT - 20 mm
   TOP OF SLAB - 20 mm
   COLUMNS - 30 mm
   BEAMS - 30 mm
   FOUNDATIONS - 50 mm
4. ALL REINFORCEMENT TO COMPLY WITH THE REQUIREMENTS OF SABS 1200 G.

BRICKWORK
1. ALL BRICKWORK TO BE EXECUTED IN ACCORDANCE WITH SABS 0164.
2. LINTELS TO BE PROVIDED OVER ALL OPENINGS IN WALLS. INSITU LINTELS FOR LARGER SPANS AS PER THE DETAIL.
3. MORTAR CLASS II - 5 MPa
4. BRICK COMPRESSIVE STRENGTH - 14 MPa.

FOUNDATIONS
1. ALL FOUNDATION EXCAVATIONS TO BE MECHANICALLY COMPACTED TO 95 % MOD AASHTO.
2. ALL FOUNDATION EXCAVATIONS TO BE INSPECTED & APPROVED BY THE ENGINEER PRIOR TO CONCRETING.
3. FOUNDATIONS TO LOAD BEARING WALLS 700 x 250 U.O.N.

ROOF DRAINAGE
1. ROOF DRAINAGE, SCREEDING & WATERPROOFING TO ARCHITECTS DETAIL.

| REV | DATE | REVISION DESCRIPTION | BY |
|---|---|---|---|
| | | | |

TITLE
FIRST FLOOR SLAB LAYOUT

PROJECT
UNIVERSITY OF WITWATERS RAND
LOW-COST HOUSING PROTOTYPE

| DATE | DESIGNED BY | |
|---|---|---|
| 17/09/13 | DRAWN BY | BeckEr |
| | CHECKED BY | |
| APPROVED BY CLIENT | DRAWING No. | Q13466 |

## 7.2. Masonry wall design

### 7.2.1. Introduction

The design of the wall is done in accordance with BS 5628-1 (1992) and ENV 1996-1-1 (1996). The method adopted is that of a simple masonry design where the total loads is compared to the resistance of the material and its capacity to support it. The buckling of the wall is also checked during design. The walls that require analysis are the load carrying walls. All of the walls in the prototype are of the same height, and thus only the wall with the highest applied load need be checked.

### 7.2.2. Loading

The load carried by the walls is simply vertical. This is due to the fact that the lintels and ties (as explained in more detail in section 7.3) resist the horizontal loading. Therefore the walls only need to be checked for buckling and its compressive strength capacity.

Figure 7-2 illustrates which of the walls are load bearing as well as the wall with the highest load. The central wall is the highest load carrier and is therefore selected for design. A metre length section of the wall is designed.

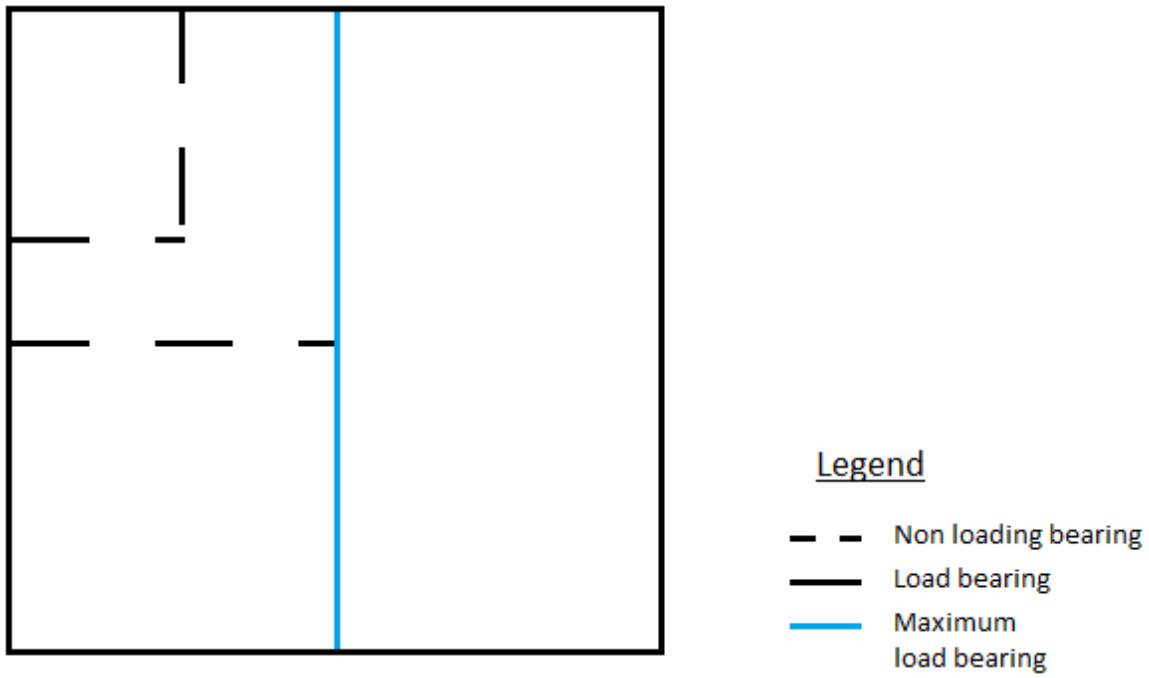



**Figure 7-2: Layout of the wall system highlighting the function of each wall as well as the wall with the greatest applied load**

The loading exerted on the central wall is summarised as follows:

- *Dead Load*
    - Self-weight of wall = 11.15kN/m
    - Vaults = 12.08kN/m per vault. However, there are two vaults being exerted on the central wall, thus a total load of 24.16kN/m is used
    - Slab = 13.75kN/m
- *Live Load*
    - For dwellings =1.5kN/$m^2$ x 1.5 = 2.25kN/m

The total load exerted on the wall is 51.31kN/m.

### 7.2.3. Design

There are two methods that can be employed in the design of a masonry wall. The first method is to calculate the characteristic compressive strength needed to resist the applied load and compare it to the compressive strength of the materials. The second method calculates the stresses exerted by the loading and compares it to the ultimate stress allowed. Both methods were applied and found the design to be satisfactory.

However, the first method also checks for buckling. Thus, method one will be applied and the results are presented below.

When designing a wall, the β value is critical. This value is the capacity reduction factors and is dependent on the slenderness of the wall. It also highlights and combats the likelihood of the wall buckling. In order to obtain the β value, the eccentricity of the loading needs to be calculated. The layout of the loading is described in Figure 7-3 and the eccentricity can calculated as described below.

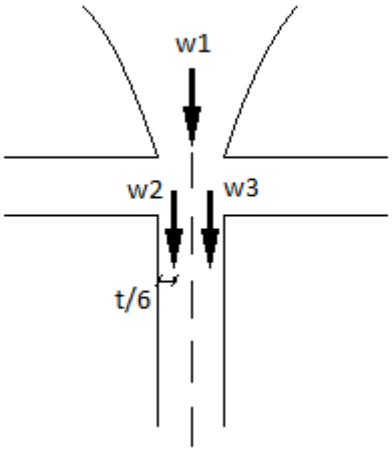



**Figure 7-3: The loading and eccentricity as applied to the wall**

Where *w1* = Vault loads and self-weight of wall

*w2* = Load from the full slab

*w3* = Load from sectioned slab

*t* = thickness of the wall (220mm)

In this case, a β value of 1 was obtained. This indicates that the wall is not susceptible to buckling. The design compressive strength is now calculated.

The design strength is calculated using the following equation:

$$Design\ Strength = \frac{\beta t f_k}{\gamma_m} \quad (7\text{-}1)$$

Where $\beta$ is the capacity reduction factor

$t$ is the thickness of the section

$f_k$ is the characteristic compressive strength

$\gamma_m$ is the material safety factor (3.5)

The compressive strength required, under the stipulated loading, was found to be 1.24MPa. The compressive strength of the material is 10MPa. This value has not been reduced, as it usually would be in combination with mortar, as the wall is dry stack. The wall is clearly suitable in supporting the above loads.

## 7.3. Thrust Force Structural Components Design

### 7.3.1. Introduction

The design of the lintels in this project varies slightly to the standard use of lintels. Lintels are generally used to support sections of walls above windows and doors. They act as composite beams, which comprise of concrete lintels and masonry. However, in this project, there is a need for a structural member to counteract the outward thrust of the vaults. Since the masonry walls cannot support these horizontal thrusts, particularly when dry stacked, a new innovative approach is required. A simple, but effective method was established. The solution is a simple combination of lintels, steel tubes and reinforcing bars. As demonstrated in Figure 7-4, the lintels are simply placed within the steel tubes which are then welded to the ties (reinforcing bars). The ties contain the outward thrust force exerted by the vaults.

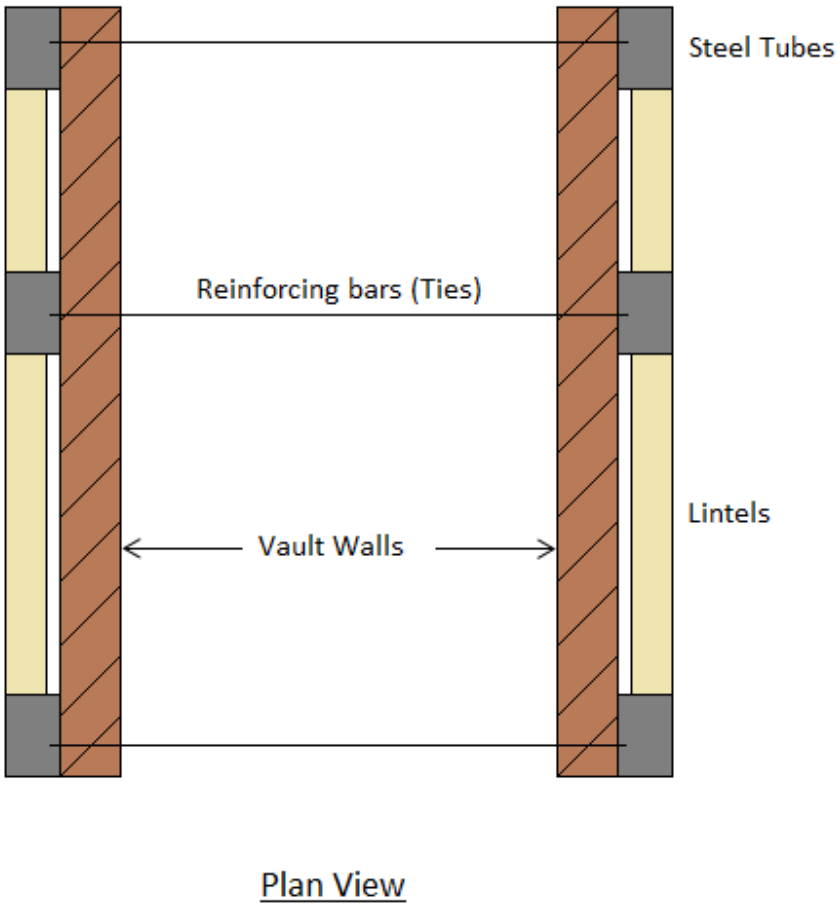



**Figure 7-4: A layout describing the manner in which the system is set out to contain the thrust force**

### 7.3.2. Lintel Design

#### *7.3.2.1. Introduction*

This design is done in accordance with SABS 0100-1 (2000) and BS 8110-1 (1997). It is designed as a pre-stressed concrete section, satisfying all the relevant checks. The lintel is designed as a 1 metre length section. All material properties are obtained from *Lintel Supplier,* a local supplier of lintels in South Africa. The lintels were precast and pre-tensioned in a plant and shipped to site. It is important to note that lintels are able to resist horizontal forces. The same method of design is used with the sections rotated 90°, as described in Figure 7-5.

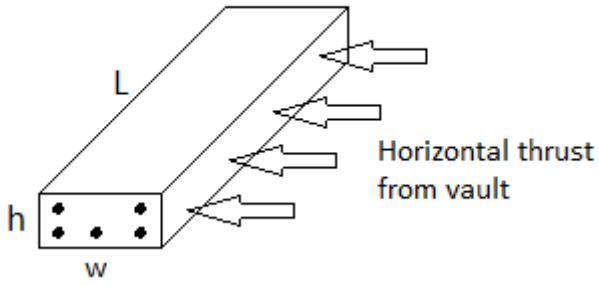



**Figure 7-5: The manner in which the lintels are loaded by the horizontal thrust exerted by the vault**

It is important to note that the ties attached to the lintels need to be cast within the concrete slab to limit corrosion. To reach the necessary height whereby the ties are covered, two lintels are placed on top of one another and mortared together to act as a single beam. The configuration is illustrated in Figure 7-6.

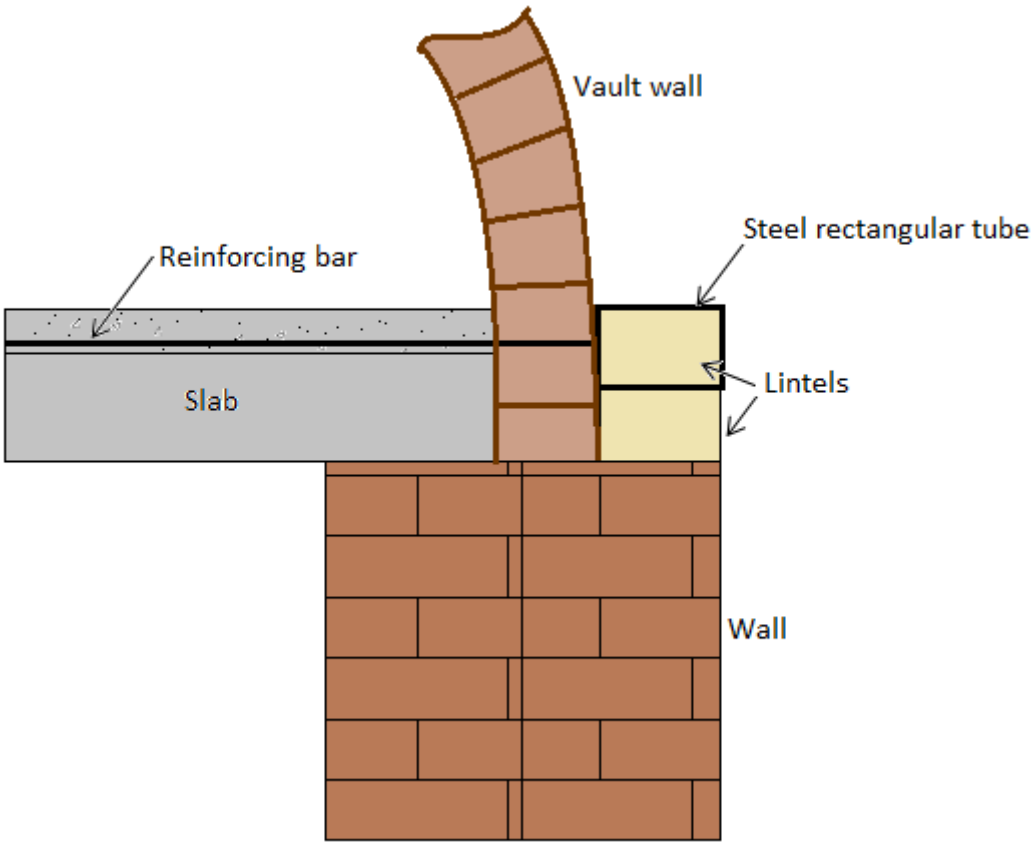



**Figure 7-6: Two lintels are placed on top of one another to ensure the ties fall within the concrete section and are therefore covered**

#### *7.3.2.2. Loading*

The loading exerted on the lintels is the horizontal thrust force exerted by the vaulted roof. This value is obtained from either the segmental equilibrium method or the finite element analysis. All load cases are analysed and the greatest reaction forces are used in the design of the lintels.

The greatest horizontal reaction, exerted by the vaults, is 2kN per metre length. This value is obtained when only a dead load and temperature load (20°C change) are exerted on the vault. This value is applied to the lintels, as demonstrated in Figure 7-5.

#### *7.3.2.3. Design*

In the design phase, a pre-stressed concrete analysis was carried out to ensure that the lintels can resist the loading. The properties and dimensions of the lintels are fixed and summarised in Table 7-2. It was decided that the lintels would be

orientated in such a way to ensure that the load is carried in the stiff, rigid direction, as can be seen in Figure 7-5.

**Table 7-2: A table summarising the material and section properties of the lintels**

| ***Concrete Properties*** | Value | Unit | Notes |
|---|---|---|---|
| Strength at 28days | 35 | MPa | |
| Strength at release | 12 | MPa | |
| Young's Modulus at 28 days | 30000 | MPa | |
| Young's Modulus at release | 18171 | MPa | |
| ***Section Properties*** | | | |
| Height per lintel | 70 | mm | Two lintels are used, thus a height of 140mm |
| Width | 135 | mm | |
| ***Strand Properties*** | | | |
| No of wires | 4 | | |
| Wire Diameter | 2.64 | mm | |
| Characteristic strength, $P_u$ | 9.31 | kN | Per lintel |
| Initial Jacking Force | 70 | % | |

(Lintel Suppliers, 2009)

The design process is followed in accordance with SABS 0100-1 (2000), pre-stressed concrete. The lintels were analysed and the results are given below:

- Service stresses at Transfer
    - Stress at Top = 5.22 MPa < 6MPa ok
    - Stress at Bottom = 1.79MPa < 6MPa ok
- Long term service Stresses
    - Stresses at Top = 8.19MPa < 11.55MPa ok
    - Stresses at Bottom = 1.35MPa < 11.55MPa ok
- Ultimate Moment of resistance = 11.05kNm > Moment under ultimate load = 2.08kNm ok

- Shear under ultimate load = 4.16 kNmm < 4.75 ok
- Shear under ultimate load = 4.16 kNmm < Shear capacity (uncracked section) = 17.25 kNmm ok
- Shear under ultimate load = 4.16 kNmm < Shear capacity (cracked section) = 9.22 kNmm ok
- Deflection at Camber transfer satisfied
- Long term deflection satisfied (l/300)

The analysis process ensured that all code checks are satisfied and thus the lintels are sufficient to carry the required load.

### 7.3.3. Steel Ties and Welds

#### *7.3.3.1. Introduction*

As previously discussed, one of the most important design aspects of this project is that of the ties required to support the horizontal forces exerted by the vaulted roof. Figure 7-4 and 7-6 illustrates the layout of the steel ties required in the prototype. These ties work in a way such that when the roof kicks outward, the ties (that are attached to the lintels) go into tension and restrain the structure from collapsing. Thus, it is necessary that the welds and ties are strong enough to resist the outward thrust force of 2kN per metre length of the vault.

The ties are to be welded to the steel tubes and therefore a R10 reinforcing bar is chosen to ensure a good quality weld is created and sufficient strength is provided in the section.

#### *7.3.3.2. Design*

A weld design is required to ensure that sufficient support is provided to the structure (Figure 7-7).

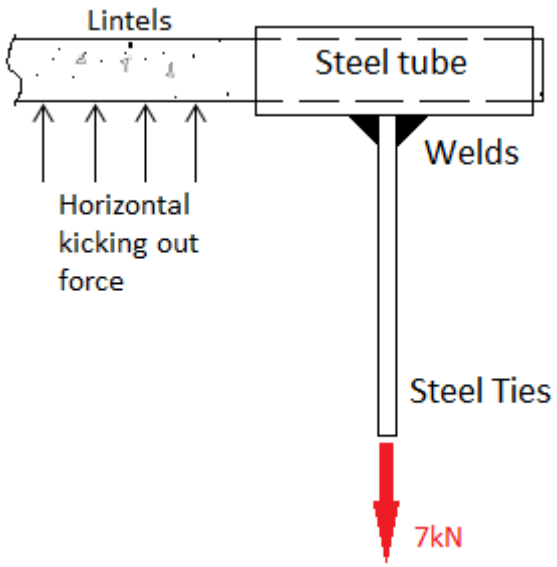



**Figure 7-7: The tube-weld-tie connection with an applied force in the tie**

A R10 bar, with yield strength ($f_y$) of 250MPa, is selected to act as the tie. An R8 bar is a round mild steel reinforcing bar, 10mm in diameter. An 'R' bar is selected because it is weldable on site. The weld size is designed as follows:

$$Area\ of\ bar = \pi r^2 = \pi(\frac{10}{2})^2 = 78.54mm^2 \qquad (7\text{-}2)$$

The vault, according to Figure 3-4, illustrates how the ties will each support a length of 3.5m thus the total force is:

$$Total\ load = 2\ x\ 3.5 = 7kN$$

Therefore, the stress in the bar can be calculated as follows:

$$Stress\ in\ bar = \frac{Load}{Area} = \frac{7}{78.54} = 89.13kN/mm^2 < \frac{250}{1.15} = 217.5MPa \qquad (7\text{-}3)$$

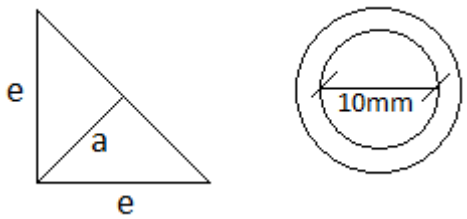



**Figure 7-8: Calculation of the weld size**

Where *'e'* is the leg length of the weld and '*a'* the throat thickness (Figure 7-8).

If we assume a minimum weld size of 4mm, we can thus calculate '*a',* and effectively determine whether the weld is suitable to carry the load.

$$a = 4 \times \cos(45) = 2.83mm$$

Thus, the unity throat welded area

$$2\pi(6) = 37.70mm$$

$$37.70 \times 2.83 = 106.69mm^2$$

The shear resistance of the steel and weld are compared. The shear resistance of the steel is calculated as follows:

$$V_r = 0.67\emptyset_w A_m f_u \quad (7\text{-}4)$$

$$V_r = 0.67 \times 0.67 \times 78.54 \times 250 = 8.8kN$$

The shear resistance of the weld is calculated as follows:

$$V_r = 0.67\emptyset_w A_w x_u(1 + 0.5sin^{1.5}\theta) \quad (7\text{-}5)$$

$$V_r = 0.67 \times 0.67 \times 106.69 \times 480 \times (1 + 0.5sin^{1.5}90) = 34kN > 8.8kN \qquad ok$$

The minimum weld size of 5mm is used for the prototype. An electrode of 480MPa is used; thus, the weld yield strength exceeds the yield strength of the steel, of 250MPa.

## 7.4. Foundation design

### 7.4.1. Introduction

The design of the foundations was done according to the South African concrete design code SABS 0100-1 (2000). The standard method of design takes into consideration sliding, overturning and bearing pressures. Due to the nature of the loading, i.e. vertical loading only, only bearing pressures and shears were calculated and compared, sliding and overturning forces were ignored.

The foundations were placed under the respective load bearing walls. This can be seen in Figure 7-9. The central internal wall is a load bearing wall and carries the load of the vaults and slab. However, the other internal walls are not load bearing and therefore do not require foundations, just slab thickening.

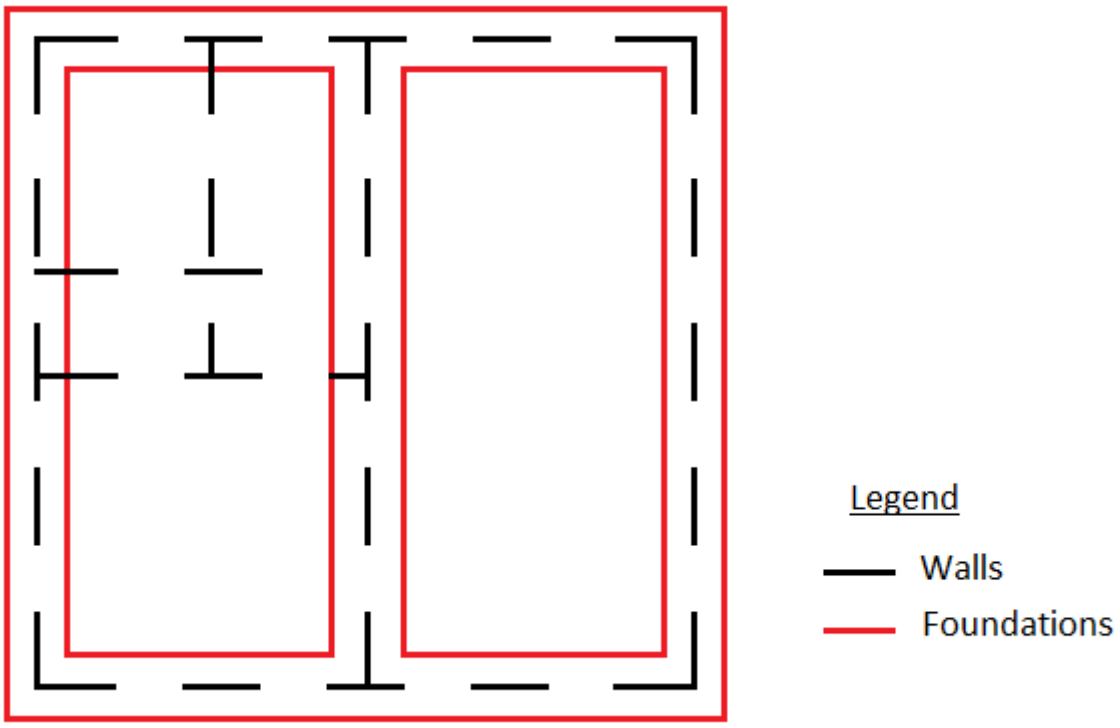



**Figure 7-9: A layout showing where the foundations are positioned**

The foundations were designed to optimise on materials. However, the foundation has been designed to be extremely stiff, to avoid any cracking that may be caused by differential settlement in the soil. The foundation acts as a stiff beam in the

vertical direction with a horizontal footing at the base to ensure that the bearing pressure is never exceeded.

### 7.4.2. Design

The dimensions of the foundation were selected and optimised in the design process. The final design dimensions and details are shown in Figure 7-10.

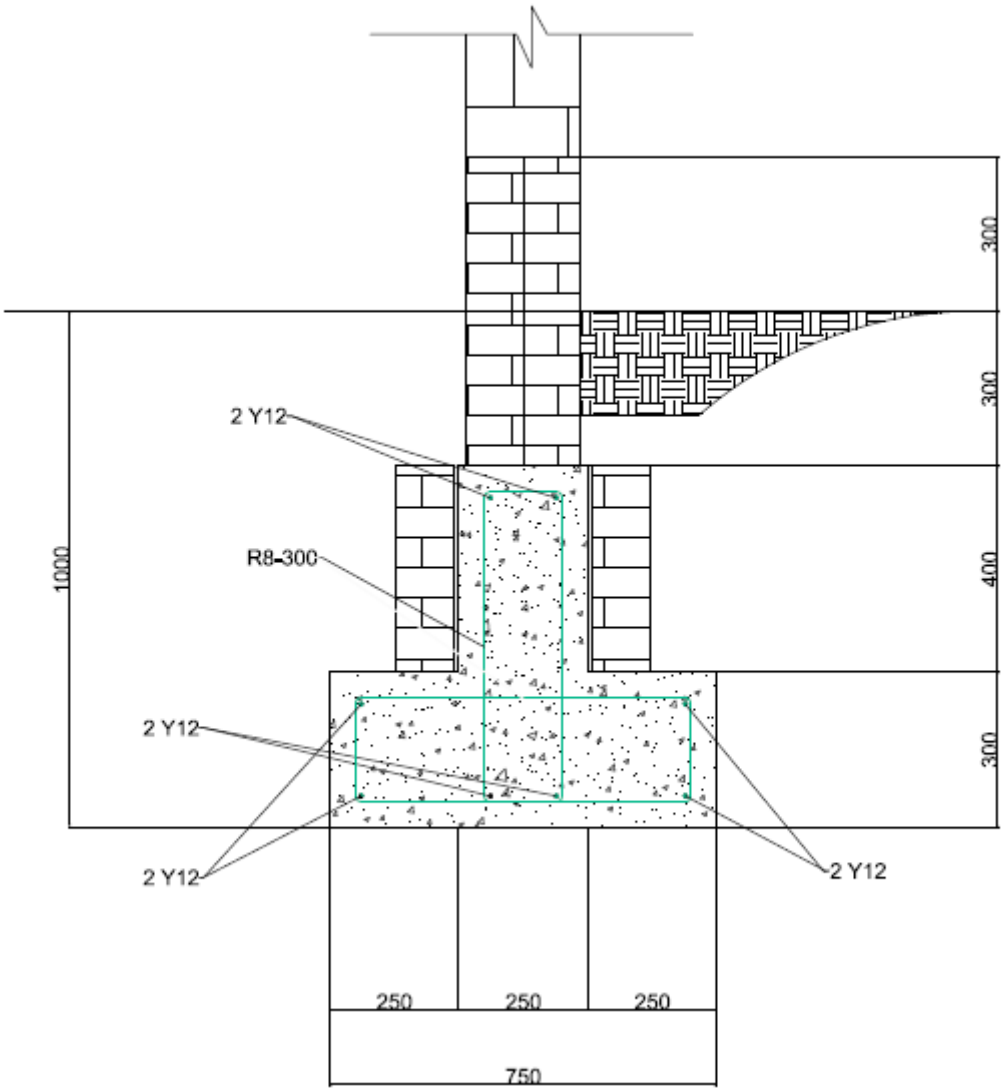



**Figure 7-10: Dimensions and detailing of the foundation**

### 7.4.3. Loading

A bearing pressure of 100kPa was selected to design a standard shape, since soil bearing capacities are rarely lower that this value within South Africa. The bearing pressure was compared to the loading to ensure that the foundation is sufficient in

supporting the building. The stress from the loading is calculated using the following equation:

$$\sigma = \frac{P_s}{ab} \tag{7-4}$$

Where $P_s$ is the total service load on the structure, and *ab* is the cross sectional area of the foundation. The equation is for vertical loads only.

The loading exerted on the foundation is a combination of dead loads and live loads. The bearing pressure was checked for dead load only, as well as a combination of dead and live loads. The dead load consists of the vault, slab, wall, brick shuttering, soil, surface bed, and self-weight of the foundation, totalling 68.86kN. The live load, as per SABS0100-1 (2000) is taken as 1.5kN/m$^2$. Once all these values have been calculated and added using the service safety factors, of 1.0DL+1.1LL, a total load of 71.11kN is exerted on the foundation. The bearing pressure was calculated and the results are as follows:

$$\sigma_{DL} = \frac{68.86(10^3)}{0.75(1)} = 91kN/m^2 < 100kPa \qquad Ok$$

$$\sigma_{DL+LL} = \frac{71.11(10^3)}{0.75(1)} = 95kN/m^2 < 100kPa \qquad Ok$$

Note: The soil bearing capacity at the site of the prototype is much greater then 100kPa, but the foundation was designed to be used at almost any location in South Africa.

### 7.4.4. Flexural steel

As discussed, it is important that the foundations do not move when differential settlement occurs. This, being the worst case scenario, was the basis of design. As a precaution, one metre section of soil was assumed to have settled, which is depicted in Figure 7-11.

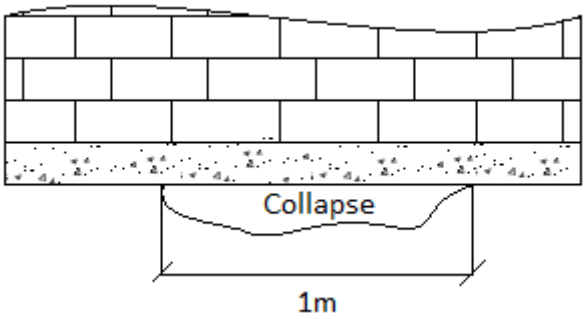



**Figure 7-11: An analysis of the foundation of a 1m section of soil collapses**

Table 7-3 summarises the steel requirements in the construction of this foundation. The detail of the foundation can be seen in Figure 7-10.

**Table 7-3: A table detailing the steel required in the foundation**

| | ***Top T section*** | ***Base of inverted T*** |
|---|---|---|
| *Top steel* | 2Y12 | 2Y12 |
| *Bottom steel* | 2Y12 | 2Y12 |
| *Shear steel* | R8 | R8 |
| *Shear steel spacing* | 300mm | 300mm |

Notes: 2Y12 – Two high yield reinforcing bars, 12mm in diameter

R8 – Mild steel reinforcing bars, 8mm in diameter

# 8. Construction

## 8.1. Introduction

The construction process is vital in ensuring that thin shells are favoured over the standard form of rectangular housing. Thin shells are very difficult and complex to construct and a variety of methods have been explored over the years. Some of these methods include using visual guides, balloon formworks ( Gohnert, 2011, Wilson, 2005), compacted soil forms (Wilson, 2005) and the like. The aim of this project is to explore innovative methods to simplify and speed up the process of construction. It is just as important that the method of construction is cheap, while maintaining a high level of accuracy. The vault will adopt an original method, which utilises a shifting formwork.

## 8.2. Site preparation

The site that we were provided with is situated on West Campus at the University of the Witwatersrand, South Africa. The site was previously used as a housing site and building material was strewn over the surface; thus, there is no vegetation that needed to be removed. Builders line was used to measure and layout the foundation before digging began.

## 8.3. Foundations

Construction commenced by digging the foundations to the required depth. Digging proved to be relatively quick and easy. However, since this is a previously built up site, there were sections that contained concrete members that needed to be demolished. This proved quite difficult and time consuming. Furthermore, approximately 400mm below ground level, a raft foundation was found. This raft foundation served as the foundation for the previous properties. The raft foundation takes up approximately two-thirds of the foundation area. The raft foundation is in excellent condition and it would be very expensive and time consuming to breakdown. It was decided that the raft would be utilised and incorporated into the structure. The section not containing the raft was dug to the required depth and the new foundation was built with ties into the existing raft foundations (Figure 8-1).



**Figure 8-1: The foundation is measured and set up using builder's line before it is dug to the required depth**

The foundation steel cages were assembled in the inverted "T" shape and dropped into the excavations (Figure 8-2). Holes were drilled into the existing raft foundation and rebar was used to connect the cage to the existing section (Figure 8-3).



**Figure 8-2: The steel sections are assembled into the inverted T shape and dropped into the foundations**



**Figure 8-3: Holes are drilled into the raft foundation so that the edges of the steel cages can be connected into the raft**

The concrete was then poured (Figure 8-4). Afrisam, a local concrete supplier in South Africa, sponsored the Readymix concrete, at a strength of 25MPa.



**Figure 8-4: Readymix Concrete is poured into the foundation**



**Figure 8-5: A 10mm layer is positioned over the entire foundation to bind the old and new concrete properly**

Once the foundations were complete (Figure 8-5); the next step was the construction of the walls.

## 8.4. Exterior Walls

It is essential that the exterior walls start at foundation level. Therefore this section forms an important part in the foundation construction process.

A double layer of single cement bricks were used to construct the wall from foundation level to 300mm above ground level (Figure 8-6). The sections around the brickwork were then backfilled with soil (Figure 8-7).



**Figure 8-6: Cement bricks are used to construct the base of the wall to 300mm above ground level**



**Figure 8-7: The cement bricks are built to 300mm before the dry-stack layers begin**

At this level, there is a change in the construction material used. Hydraform interlocking dry-stack blocks are to be used to construct the remainder of the external walls.

Durability is an important design consideration which is addressed in considerable detail in this project, particularly when working with earth materials. Therefore it is important to note the use of cement bricks for the first 300mm above ground level and then the change to earth bricks. There have been many durability problems in

many projects, in both South Africa and Algeria, where earth blocks are used at ground level. This is due to the collection of rainwater at the base and in turn, the rapid deterioration of these bricks. Soil blocks have been known to loose as much as 70% strength if submerged for long periods of time (Ipinge, 2012).

To ensure that no durability problems arise, to minimise maintenance needs, cement bricks are used to the required height, followed by a damp proof course (DPC) (Figure 8-8). The DPC layer (plastic sheeting) is placed before the first layer of dry stack blocks are placed. This ensures that no water passes through the DPC layer and absorbed by the CSEB. The first layer of blocks has to be mortared to the DPC layer. All succeeding layers are simply dry-stacked and interlocked, with no mortar required in the joints. Builder's line is used to ensure that the first layer of blocks is perfectly level. This is extremely important to ensure that the remainder of the blocks interlock properly. Uneven surfaces will cause openings in joints and interlocking will be difficult.



**Figure 8-8: A layer of DPC is placed between the cement bricks and earth blocks**

Dry stack interlocking blocks have many benefits, particularly ease and speed of construction. The blocks are designed in such a way to slide into one another without

requiring mortar. As demonstrated in Figure 8-9, the succeeding courses lock perfectly, with one another to create a strong and durable wall. The figure also demonstrates how each course is laid and locked in the opposite direction to the previous, i.e. one layer will be laid with the ‘front’ of the block facing the right and the following layer will face the opposite way, to the left (Hydraform, 2012).

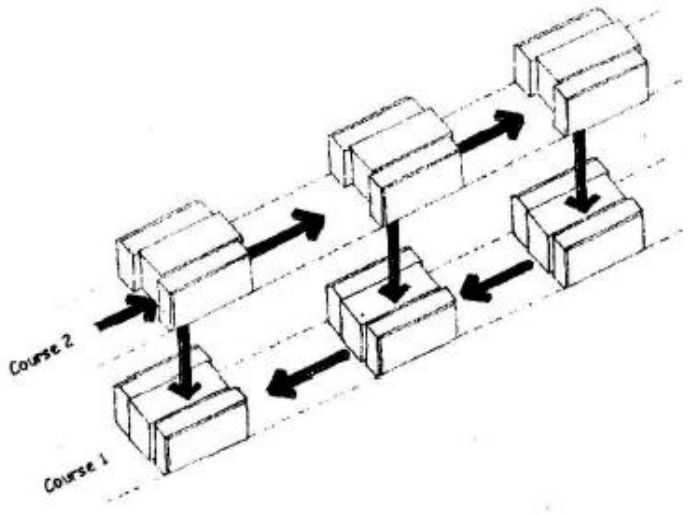



**Figure 8-9: The method of constructing two courses of dry stack interlocking blocks (Hydraform, 2012, p 55)**

When constructing with interlocking blocks, it is important to understand the exact method of construction to ensure that the blocks interlock properly. The corners are first built up and then constructed inwards towards the wall centre (Figure 8-10). The last block is cut to size to ensure it fits snuggly. The last block acts as a key, locking that specific layer of bricks. This is repeated until the wall is completed (Figure 8-11).



**Figure 8-10: Construction of the walls is done from the corners-inwards**



**Figure 8-11: A completed dry-stack wall**

Parts of the walls that contain openings are built in a similar manner. When openings for doors or windows need to be considered, the process is the same, except that blocks will need to be cut at the openings to ensure that the correct sized openings are created. Door frames are built directly into the wall, while openings are left for windows to be fitted at a later stage (Figure 8-12). Lintels are positioned above the

doors and windows and mortared in before the standard method of dry-stacking continues (Figure 8-13 and 8-14). It is also important that internal walls are accounted for and thus ties are placed to connect the internal and external walls at a later stage (Figure 8-15). The final layer of blocks is laid with mortar to seal the wall (Figure 8-16).



**Figure 8-12: The construction of the wall when openings for windows and doors are required**



**Figure 8-13: Lintels are positioned above the windows and doors to support the bricks above them**



**Figure 8-14: Lintels are positioned above all openings to support the bricks above it; the last layer of bricks is mortared in to *lock* the walls**



**Figure 8-15: Ties are placed in the wall to connect the exterior and interior walls at a later stage**



**Figure 8-16: The completed walls with the last layer of dry-stack mortared in to *lock* the walls**

The final two layers of the first floor walls are completed using cement bricks (Figure 8-17). This is done to 'lock' the wall before the slab is set up, as well as to minimise cracking caused during expansion. Cracking between the slab and the wall can occur if there is a large discrepancy in the material properties. Once the slab is set up, it will expand and shrink with varying temperature variations. By adding two layers of cement bricks, the expansion difference in the expansion of the wall and slab will be considerably less than if the slab is connected to the CSEB directly.



**Figure 8-17: The completed first level, where the last two layers of bricks are cement bricks**

## 8.5. Rib and Block Slab

A rib and block slab is a slab systematically made up of lintels as ribs, cement blocks (Figure 8-18), minimal steel meshing and a concrete covering. It is a very economical and quick method of constructing a slab.



**Figure 8-18: Cement Blocks used in the rib-and-block slab**

The ribs are positioned first at specified distances followed by the placing of the blocks perfectly between the ribs (Figure 8-19). This is done over the entire slab. The blocks are void former, to reduce the weight of the slab. The end product is a series of “T” beams, spanning opposite walls.



**Figure 8-19: Placing the blocks between the ribs**

Props are positioned underneath the slab for support until the concrete is poured and the slab is sealed (Figure 8-20). Reinforcing and meshing is placed on top of the rib and block system (Figure 8-21).



**Figure 8-20: Props are set up under the slab to support it until concrete is poured**



**Figure 8-21: Steel mesh and reinforcing is positioned on top of the slab**

Before the concrete pour can be done, the slab must be shuttered, but just around edges. Wood shuttering is placed around all openings, which is removed once the

slab has cured (Figure 8-22). Brick shuttering is used around the edges of the slab so as to allow for an easy continuation of the wall construction.



**Figure 8-22: Wood shuttering is used around the openings**

Prior to the concrete pour, the lintels and steel ties need to be positioned. This is discussed in detail in section 8.6. Once the ties are set in place, the concrete is poured and the slab is left to cure for 7-14 days (Figure 8-23) before the props are removed.



**Figure 8-23: The final concrete pour; the slab is no complete and left to cure**

## 8.6. Lintels and Steel Ties

The steel ties had to be positioned prior to the concrete pour of the slab. The ties, as discussed in Section 7.3, are essential in the construction of the vaulted roof as they prevent the structure from kicking out. The layout is simple. Lintels are placed at the required distance at the ends of the structure. Steel tubes, slightly bigger in size then the lintels, are placed over the lintels at the corresponding tie positions (Figure 8-25). The tubes were filled with grout and all the lintels mortared to one another. Three ties are required on either side of the structure and therefore six ties are welded to the six tubes (Figure 8-24). The corresponding ties are welded together in the middle of the structure to form a continuous tie from one end to the other. Once these ties are connected, the slab is poured and the ties are covered by the concrete. This is important to ensure that no ties are exposed and therefore no rusting occurs. The ties are effective in preventing the vault from kicking out and in turn, collapsing.



**Figure 8-24: The steel ties are welded to the tubes at the ends of the structure**



**Figure 8-25: The tubes are placed over the lintels and then filled with grout**

## 8.7. Vaulted roof

The vaulted roof proved to be the most difficult and time consuming section of the structure. The construction of the vault is a new experience and thus required a considerable amount of brain storming and decision making along the way. The vaults were constructed using the Hydraform Splitter-brick block.

It was decided that a formwork would need to be provided to ensure that the accuracy of the shape is achieved. A number of materials were considered and finally, a steel formwork was chosen. The main motivation for choosing this formwork was accuracy and price. A stencil of the formwork was created and flat bars were bent to the correct shape (Figure 8-26). Steel allowed us to achieve the best possible shape with minimal work involved in creating it.

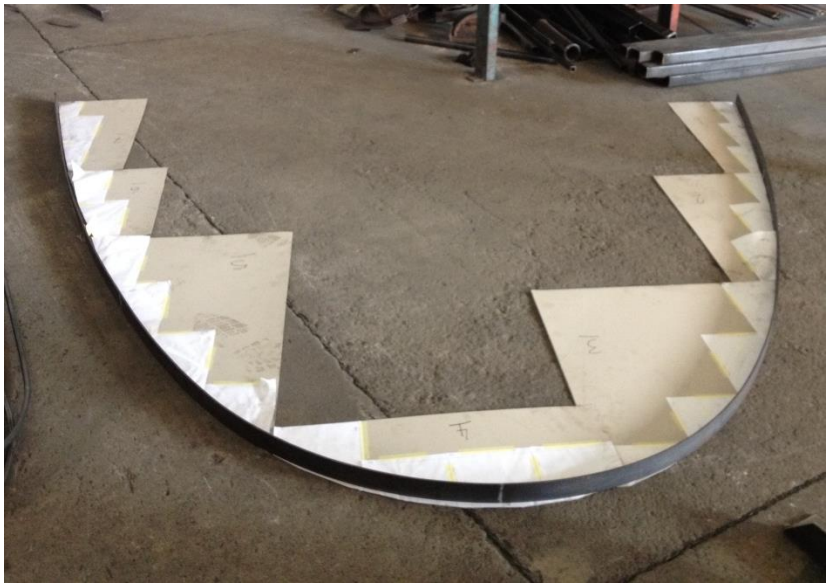


**Figure 8-26: A stencil is used to determine the shape and guide the bending of the flat bars**

The frames were then assembled and braced into a solid one metre length formwork section (Figure 8-27). Steel sheeting was then riveted onto the outside of the frame, completing the formwork. The formwork was designed and built to be one metre shorter in height than the actual vault to allow for easy dropping and shifting of the formwork. Two identical forms were created so that both vaults could be constructed simultaneously (Figure 8-28).



**Figure 8-27: The steel formworks used to construct the vaults**



**Figure 8-28: The two formworks at site, ready to be lifted and for construction to commence**

The form work was lifted onto the slab and propped up on bricks to reach the desired height, before construction commenced (Figure 8-29).



**Figure 8-29: The formwork is propped up onto bricks which can easily be pulled out**

The first layer of bricks was constructed prior to the pouring of the slab. This was essential for two key reasons:

1. The ties had to be attached to the first few layers of blocks to ensure that they worked effectively in case of any outward thrusts created by the structure at the base
2. The ties had to be covered within the slab to avoid any rusting

Thus, the start of the roof occurs at the slab surface and the remainder is built with the use of the constructed formwork (Figure 8-30).



**Figure 8-30: The first layer of bricks as at the same level as the slab**

The process of building the vaults is relatively difficult as the scaffolding needs to be set up adequately to allow for safe and accurate construction (Figure 8-31). Once the scaffolding is up, the construction went relatively quickly and accurately due to the effective formwork. A vault was constructed in metre length sections. Once each section is completed and allowed to dry, the formwork dropped and repositioned for the construction of subsequent sections.



**Figure 8-31: The start of the construction of the vaults**

The construction proved to be relatively difficult and slow. The manner in which the scaffolding was to be positioned, to ensure that the bricks could be laid efficiently, took considerable brain storming. A flexible and easily adjustable system needed to be set up as too much time was spent readjusting the formwork as the construction progressed. The first layer of construction was slow as the scaffolding proved to be a problem. A system was set up that incorporates scaffolding and steel lip channels. The lip channels span the entire length of the structure allowing the builders access between the two vaults.

The first layer of construction was a testing period for the formwork. At the base of the vault, where the forces are predominantly vertical, the formwork was found to work very effectively. Further up, where the angle changes to predominantly horizontal, the formwork began to warp. Certain areas contained insufficient bracing and the bricks sagged slightly. This was easily solved by propping either the bricks or the formwork at the warped point until the mortar had hardened. Additional bracing was added to the formwork once the first layer was completed to avoid continued warping within the vault. Throughout the construction process, a number of mistakes occurred (Figure 8-32). At times, layers of blocks had to be removed and rebuilt to rectify the mistakes.



**Figure 8-32: Inaccuracies in following the form during construction**

The construction, although slow, was extremely accurate (Figure 8-33). The first layer of construction was the learning curve and the next few layers were completed quickly.



**Figure 8-33: Accurate and efficient construction**

The two vaults are built simultaneously so that the thrust force is controlled by both structures. The vaults are built from either side to prevent distortions in the formwork and cause inaccuracies in the form (Figure 8-34).



**Figure 8-34: Constructing on each side to prevent swaying of the formwork under the weight of the vault**

Initially, the first length of the vault was constructed and the formwork was left in position allowing the mortar to set. However, after a day, a crack had formed at the apex of the vault (Figure 8-35). This crack is caused by the shrinking of the vault as the mortar dries. The formwork prevents the vault from contracting naturally, creating a crack along the apex of the vault. Therefore, the manner of drying had to be adjusted. The final layer of blocks was laid, as before, but the mortar was allowed an initial set before the formwork was dropped and the vault was allowed to dry unrestrained. This eliminated cracking at the apex and the remainder of the vaults were completed with precision and efficiency.



**Figure 8-35: Cracking occurred along the apex as the vault is restrained from contracting naturally**

Once the first layer was complete, the formwork was shifted, repositioned and construction could continue (Figure 8-36 to 8-37). This was repeated until the entire structure was completed (Figure).



**Figure 8-36: Completing the last few layers in the construction of the first section**



**Figure 8-37: The first length is complete: the most difficult section**



**Figure 8-38: The formwork is shifted and repositioned to continue construction of the vault**



**Figure 8-39: Construction of the second section is completed, the formwork is dropped and shifted and construction continues**



**Figure 8-40: The construction of the vaults continues**



**Figure 8-41: Construction of the first vault is almost complete**



**Figure 8-42: The second vault nearing completion**



**Figure 8-43: The completed vaulted roof**



**Figure 8-44: The completed catenary roof**

## 8.8. Top Floor Walls

The final step of the construction of the superstructure is the top floor walls (Figure 8-45 and 8-46). These walls close up the vaults, making it a habitable living space. The blocks used in the construction of these walls are the Hydraform dry-stack interlocking blocks. The method of construction followed a similar process as described in Section 8.4, where window openings had to be accounted for.



**Figure 8-45: The construction of the top floor walls**



**Figure 8-46: Completion of the top floor walls and thus the superstructure**

## 8.9. Interior Construction and Final Finishes

The final steps in the construction process comprised of the interior construction and finishes. The floor slabs were poured (Figure 8-47), followed by the construction of the internal walls and staircase. The internal walls were constructed using dry stack interlocking blocks (Figure 8-48) and followed the same process as discussed in Section 8.4. The stairs were constructed using lintels and blocks, followed by a layer

of mortar mix to stabilise and neaten up the stairs (Figure 8-49). Plaster work was done on the inside and outside walls to cover lintels, protect the steel tubes, cover the insides of the vaults and ceiling, and increase aesthetics (Figure 8-50). Lastly, windows and doors were installed and plastered and the structure was completed with the painting of all the plaster (Figure 8-51 and 8-52). The completed structure is demonstrated in Figures 8-53 to 8-55.



**Figure 8-47: The pouring of the floor slabs**



**Figure 8-48: The construction of the internal walls**



**Figure 8-49: Construction of the staircase using lintels, blocks and mortar**



**Figure 8-50: Plastering of the structure**



**Figure 8-51: The installation of the windows**



**Figure 8-52: The door is installed and painting of the plaster commences**



**Figure 8-53: The completion of the painting concludes the construction of the structure**



**Figure 8-54: The front view of the completed prototype**



**Figure 8-55: The back view of the completed prototype**

# 9. Cost Analysis

## 9.1. Introduction

The cost of constructing this project is vital in establishing whether it is a viable option for low-cost housing in South Africa. Considerable research has been done in comparing the costs of various housing solutions, e.g. Talocchino (2005).

When comparing the costs of different housing solutions, various aspects need to be considered. Some of these aspects include ease of construction, floor size, formwork required, labour availability, etc. It is essential that people are satisfied with the final product to ensure it is a success.

In this chapter, a cost breakdown is carried out. This cost is compared to various other projects, in the Section 10.5, to assess its viability.

This project was funded by a number of generous and interested parties. These include Hydraform, Spancon, Afrisam, Lintel Suppliers, WISPECO Aluminium, Macsteel and Robor. Majority of the materials were donated by these companies and the costing below is that of the actual costing has the materials not been donated (Table 9-1).

## 9.2. Breakdown

**Table 9-1: A cost breakdown of the materials required for the construction of the low-cost housing prototype**

| ***Cost Breakdown of Prototype*** | | | | |
|---|---|---|---|---|
| *Component* | *Quantity* | *Approximate (Rands)* | *Approximate (US Dollars)* | *Share of cost (%)* |
| ***Foundations*** | | **R20889.32** | **$2089** | 21.48% |
| Reinforcing Steel | 420kg (Y and R) | R3902.22 | $390 | |
| Ready-mix Concrete | 10.7m³ | R9497 | $950 | |
| Brickforce | 5 rolls | R213.75 | $21 | |

| | | | | |
|---|---|---|---|---|
| Bricks | 4000 | R5000 | $500 | |
| Cement | 10 bags | R774.50 | $78 | |
| Builders sand | 3m³ | R1466.25 | $147 | |
| DPC | 2 rolls | R35.60 | $4 | |
| ***Walls*** | | **R15121.10** | **$1512** | 16.55% |
| Hydraform Blocks | 2760 | R12420 | $1242 | |
| Lintels | 16 | R480 | $48 | |
| Cement | 3 bags | R232.35 | $23 | |
| Builders sand | 1m³ | R488.75 | $49 | |
| Bricks | 1200 | R1500 | $150 | |
| ***Slab*** | | **R11062.71** | **$1106** | 11.38% |
| Ribs | 28m² of slab area | R8400 | $840 | |
| Blocks | | | | |
| Reinforcing steel | | | | |
| Ready-mix Concrete | 3m³ | R2662.71 | $266 | |
| ***Structural Ties*** | | **R1600** | **$160** | 1.65% |
| Lintels | 12 | R990 | $99 | |
| Steel tubes | 33.164kg | R200 | $20 | |
| Steel Ties | 6 | R288 | $29 | |
| Cement | 1 bag | R77.45 | $8 | |
| Builders sand | 0.5m³ | R244.38 | $24 | |
| ***Vaulted Roof*** | | **R20167.55** | **$2017** | 20.74% |
| *Formwork* | | *R6362.05* | *$636* | |
| Steel frames | 4 | R1181.04 | $118 | |
| Bracing | Varies | R2000 | $200 | |
| Steel sheeting | 6 | R1844.81 | $185 | |
| Masonite boards | 8 | R720 | $72 | |
| Builders wood | 2 | R376.20 | $38 | |
| Gum poles | 4 | R240 | $24 | |
| *Materials* | | *R13805.50* | *$1381* | |

| | | | | |
|---|---|---|---|---|
| Hydraform Blocks | 3400 | R10200 | $1020 | |
| Builders sand | 5 | R2443.75 | $244 | |
| Cement | 15 | R1161.75 | $116 | |
| ***Internal Walls*** | | **R2655** | **$266** | 2.73% |
| Bricks | 590 | R2655 | $266 | |
| ***Staircase*** | | **R420** | **$42** | 0.43% |
| Lintels | 14 | R420 | $42 | |
| ***Surface Bed*** | | **R5850** | **$585** | 6.02% |
| Cement | 6.5m³ | R5850 | $585 | |
| ***Finishes*** | | **R17142** | **$1714** | 19.03% |
| Door frames | 5 | R4000 | $400 | |
| Interior Doors | 2 | R540 | $54 | |
| Exterior Doors | 2 | R1400 | $140 | |
| Aluminium Windows | 7 | R11202 | $1120 | |
| | | | | |
| ***TOTAL*** | | ***R94 907.50*** | ***$9 500*** | ***100%*** |

**Note**:

- The costing of the foundation is to the design, i.e. what would be required had the raft foundation not been found.
- The costs above do not include services in terms of electricity, plumbing, etc.
- The costs do not include labour costs, they are merely material costs

Majority of the costs went into the foundations and the roof structure. It is vital that there is no differential settlement in the foundation so that no cracking occurs in the vault. Because of this, the foundations were over-designed and costs could be reduced in this aspect.

In the breakdown, it can also be seen that approximately 30% of the vault cost is attributed to the formwork. However, the formwork is reusable and therefore this cost

will diminish significantly. To reduce these costs, other methods of construction need to be investigated. The prices stipulated are for a single building. These prices will change if a larger scale project is implemented. Specific areas where these costs will change include: formwork costs, brick making machines, foundations, finishes, etc. A more expensive, but economical formwork can be applied at a larger scale, i.e. an inflatable formwork (Gohnert, 2011, Wilson, 2005). This method may not be an affordable solution on a small scale, but other construction methods should be explored for larger scale developments.

In terms of brick costs, it is more affordable to purchase a block machine when constructing at a larger scale. This will minimise the costs and time of construction considerably, when materials are mass produced locally.

There are a number of ways in which the costs can be reduced more or kept at a minimum. One aspect, which is not covered in this report, is that of labour. The aim of this project is to involve the community and people who will be living in low-cost houses. Thus, it is expected that labour costs will be at a minimum due to the involvement of the residents in all aspects of the project.

# 10. Conclusions and Recommendations

## 10.1. The superior structural form and layout

A superior structure is not simply defined by its image or cost, but by a number of different criteria, such as energy efficiency, durability, social acceptance, etc. The prototype in this project considers a number of various criteria to ensure that the most efficient and comfortable home is produced, utilising a small budget. The orientation of the structure, in relation to the sun, to maximise solar power is vital in ensuring the residents have minimal electricity expenses. In addition, the internal layout of the home is essential. The internal layout of the house is selected to maximise on privacy and space, whilst simultaneously creating comfort and natural light.

A square form is selected for the bottom floor as the most optimal shape for maximising on space. Since most informal settlements are extremely dense and each resident has minimal floor area, the house is designed to be a double story house to maximise on space. Two catenary vaults are designed as the roof structure as well as the upper floor section. The very high vaults are designed to: 1.) utilise the upstairs area as a second bedroom and 2.) create a double volume area to provide natural light and reduce the feeling of confinement. The vaults are also incorporated to minimise on costs, while simultaneously maximising on thermal efficiency. The roof is designed as a natural, sustainable form which will require marginal maintenance due to its superior structural strength.

The most architecturally and structurally efficient structure, the catenary vault, is designed to maximise on space whilst minimising on costs in all areas (i.e. maintenance, costs, electricity, etc.) and providing a safe, durable and environmentally friendly solution for all.

## 10.2. Essential design considerations for catenary vaults

A method of design, The Segmental Equilibrium Method, was developed in this report to design catenary vaults. This method permits the accurate design of catenary vaults under both vertical and lateral loading. However, at present the

Segmental Equilibrium Method cannot analyse temperature loading, which is carried by using finite elements. The Segmental Equilibrium Method is particularly effective in allowing the user to design the most natural form under the stipulated loading, with an efficient and accurate method.

It would be substantially more time consuming and labour intensive to define the same curve in finite element, or using another form of design. The Segmental Equilibrium Method utilises simple equilibrium equations to define a natural and efficient curve to support the various loading criteria. The thrust lines under each loading combination or pattern can be plotted, and the various areas of weakness identified.

It was found that the loading case which generates the greatest tensile and compressive forces is that of dead load, wind load ($C_{pi}$=0) and a temperature drop of 20° over the right half of the structure. The form of loading is exaggerated as the temperature will vary along the structure. To simplify analysis and ensure that the structure is sufficiently designed a worst case temperature loading was investigated where the entire side was subject to the temperature change. However, this load does not exceed the strength capacity of the material and the design is therefore adequate.

The structure exhibits a considerable weakness, and possibly failure, under point loads. It is clear that two dimensional shells, such as vaults and arches, are not effective in supporting point loads. Thus, it is recommended that all maintenance is done from an adjacent support system which provides access to the roof. The design of the form also takes into consideration this weakness; therefore, a very steep form is selected where access without additional support is extremely difficult. However, point loads and shell systems do not mix and is a problem with all shell structures.

## 10.3. Material selection

The materials used in the construction of the prototype proved to be very effective in a number of ways. These blocks have excellent thermal properties, are easy to produce, require minimal energy input in the production phase and are cost effective. The dry stack interlocking blocks eased the construction process considerably and

saved costs in the form of mortar and speed of construction. The splitter-brick blocks were very effective in the construction of the vaults, as they provided the required thickness that ordinary bricks would not have. They also ensured that a strong joint was created in the grove, creating a *key* between each block.

The blocks exhibit excellent compressive and tensile strengths and are able to compete with ordinary cement bricks. During the analysis process, the forces exerted by the wall and vault do not exceed the capacity of the building materials. The blocks are satisfactory in the construction of double storey buildings as well as curved forms. However, due to the tensile forces created from the temperature loading, it is recommended that a waterproof layer or paint is applied onto the surface of the vaults to minimise the temperature differences in the material.

## 10.4. Methods of construction

A number of methods of construction were discussed in this report; however, the method of a sliding formwork was selected and utilised. This method proved to be very effective in ensuring the form was precise. However, it slowed the construction process down considerably. Due to the size of the vaults, it was difficult to determine the amount of bracing required to adequately support the bricks without overloading the formwork. These forms are heavy and therefore difficult to move, but if they are not sufficiently braced, warping occurs causing inaccuracies and thus delays in construction. The formwork must also be dropped after an initial set in the mortar to allow the vault to contract naturally as the mortar dries. This prevents the structure from being restrained so no cracks will form.

Even though the construction was accurate, different methods of formwork should be investigated. More costly methods of construction can also be considered if this project is applied at mass scale, as recycling the formwork could make it more efficient and cost effective

## 10.5. Costing analysis

The prototype form is an innovative and effective solution to low-cost housing. The cost of current RDP infrastructure programme in South Africa has been found to be ineffective (Blumenfeld, 1996). For smaller floor areas, the cost is only marginally

less i.e. costs approximately R1500/m² ($150/m²) (Mica, 2013). However, some literature suggests that costs can reach R2400/m² ($240/m²) for a RDP house (Mabeba, n.d.). This thesis presents a new solution to lost-cost housing which is approximately double in floor size to an RDP house and costs only in the range of 11% to 30% more. However, labour costs still need to be incorporated in the calculations and this could cause the costs to vary considerably depending on the community involvement. The costs provided above will also vary considerably if the project is applied at a larger scale as production and costs of bricks will be considerably less. Catenary vaults as a solution to low-cost housing is a viable and cost effective solution in South Africa.

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# Appendix A

| Segment no. | Height of Segment | Weight | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | X | Y |
| 1 | 128.20 | 0.55 | 80.50 | 2.91 | 17.38 | 17.62 | -2.91 | -16.83 | 17.08 | 80.19 | 0 | 0 |
| 2 | 128.20 | 0.55 | 80.19 | 2.91 | 16.83 | 17.08 | -2.91 | -16.28 | 16.54 | 79.87 | 21.16 | 126.44 |
| 3 | 128.20 | 0.55 | 79.87 | 2.91 | 16.28 | 16.54 | -2.91 | -15.73 | 15.99 | 79.52 | 42.99 | 252.76 |
| 4 | 128.20 | 0.55 | 79.52 | 2.91 | 15.73 | 15.99 | -2.91 | -15.17 | 15.45 | 79.15 | 65.54 | 378.96 |
| 5 | 128.20 | 0.55 | 79.15 | 2.91 | 15.17 | 15.45 | -2.91 | -14.62 | 14.91 | 78.75 | 88.86 | 505.02 |
| 6 | 128.20 | 0.55 | 78.75 | 2.91 | 14.62 | 14.91 | -2.91 | -14.07 | 14.37 | 78.32 | 112.99 | 630.93 |
| 7 | 128.20 | 0.55 | 78.32 | 2.91 | 14.07 | 14.37 | -2.91 | -13.52 | 13.83 | 77.86 | 138.00 | 756.66 |
| 8 | 128.20 | 0.55 | 77.86 | 2.91 | 13.52 | 13.83 | -2.91 | -12.97 | 13.29 | 77.36 | 163.95 | 882.20 |
| 9 | 128.20 | 0.55 | 77.36 | 2.91 | 12.97 | 13.29 | -2.91 | -12.42 | 12.75 | 76.81 | 190.92 | 1007.53 |
| 10 | 128.20 | 0.55 | 76.81 | 2.91 | 12.42 | 12.75 | -2.91 | -11.86 | 12.21 | 76.22 | 218.98 | 1132.62 |
| 11 | 128.20 | 0.55 | 76.22 | 2.91 | 11.86 | 12.21 | -2.91 | -11.31 | 11.68 | 75.58 | 248.22 | 1257.44 |
| 12 | 128.20 | 0.55 | 75.58 | 2.91 | 11.31 | 11.68 | -2.91 | -10.76 | 11.15 | 74.87 | 278.75 | 1381.95 |
| 13 | 128.20 | 0.55 | 74.87 | 2.91 | 10.76 | 11.15 | -2.91 | -10.21 | 10.61 | 74.10 | 310.67 | 1506.11 |
| 14 | 128.20 | 0.55 | 74.10 | 2.91 | 10.21 | 10.61 | -2.91 | -9.66 | 10.08 | 73.24 | 344.13 | 1629.86 |
| 15 | 128.20 | 0.55 | 73.24 | 2.91 | 9.66 | 10.08 | -2.91 | -9.10 | 9.56 | 72.28 | 379.26 | 1753.15 |
| 16 | 128.20 | 0.55 | 72.28 | 2.91 | 9.10 | 9.56 | -2.91 | -8.55 | 9.03 | 71.22 | 416.23 | 1875.90 |
| 17 | 128.20 | 0.55 | 71.22 | 2.91 | 8.55 | 9.03 | -2.91 | -8.00 | 8.51 | 70.02 | 455.24 | 1998.02 |
| 18 | 128.20 | 0.55 | 70.02 | 2.91 | 8.00 | 8.51 | -2.91 | -7.45 | 8.00 | 68.67 | 496.52 | 2119.39 |
| 19 | 128.20 | 0.55 | 68.67 | 2.91 | 7.45 | 8.00 | -2.91 | -6.90 | 7.49 | 67.13 | 540.32 | 2239.87 |
| 20 | 128.20 | 0.55 | 67.13 | 2.91 | 6.90 | 7.49 | -2.91 | -6.35 | 6.98 | 65.37 | 586.95 | 2359.29 |
| 21 | 128.20 | 0.55 | 65.37 | 2.91 | 6.35 | 6.98 | -2.91 | -5.79 | 6.48 | 63.34 | 636.76 | 2477.41 |
| 22 | 128.20 | 0.55 | 63.34 | 2.91 | 5.79 | 6.48 | -2.91 | -5.24 | 5.99 | 60.98 | 690.18 | 2593.95 |
| 23 | 128.20 | 0.55 | 60.98 | 2.91 | 5.24 | 5.99 | -2.91 | -4.69 | 5.52 | 58.19 | 747.70 | 2708.52 |
| 24 | 128.20 | 0.55 | 58.19 | 2.91 | 4.69 | 5.52 | -2.91 | -4.14 | 5.06 | 54.90 | 809.90 | 2820.62 |
| 25 | 128.20 | 0.55 | 54.90 | 2.91 | 4.14 | 5.06 | -2.91 | -3.59 | 4.62 | 50.96 | 877.46 | 2929.57 |
| 26 | 128.20 | 0.55 | 50.96 | 2.91 | 3.59 | 4.62 | -2.91 | -3.03 | 4.20 | 46.22 | 951.18 | 3034.45 |
| 27 | 128.20 | 0.55 | 46.22 | 2.91 | 3.03 | 4.20 | -2.91 | -2.48 | 3.82 | 40.49 | 1031.92 | 3134.02 |
| 28 | 128.20 | 0.55 | 40.49 | 2.91 | 2.48 | 3.82 | -2.91 | -1.93 | 3.49 | 33.58 | 1120.63 | 3226.57 |
| 29 | 128.20 | 0.55 | 33.58 | 2.91 | 1.93 | 3.49 | -2.91 | -1.38 | 3.22 | 25.37 | 1218.13 | 3309.81 |
| 30 | 128.20 | 0.55 | 25.37 | 2.91 | 1.38 | 3.22 | -2.91 | -0.83 | 3.02 | 15.88 | 1324.93 | 3380.72 |
| 31 | 128.20 | 0.55 | 15.88 | 2.91 | 0.83 | 3.02 | -2.91 | -0.28 | 2.92 | 5.42 | 1440.76 | 3435.65 |
| 32 | 128.20 | 0.55 | 5.42 | 2.91 | 0.28 | 2.92 | -2.91 | 0.28 | 2.92 | -5.42 | 1564.06 | 3470.74 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 128.20 | 0.55 | -5.42 | 2.91 | -0.28 | 2.92 | -2.91 | 0.83 | 3.02 | -15.88 | 1691.69 | 3482.85 |
| 34 | 128.20 | 0.55 | -15.88 | 2.91 | -0.83 | 3.02 | -2.91 | 1.38 | 3.22 | -25.37 | 1819.31 | 3470.74 |
| 35 | 128.20 | 0.55 | -25.37 | 2.91 | -1.38 | 3.22 | -2.91 | 1.93 | 3.49 | -33.58 | 1942.61 | 3435.65 |
| 36 | 128.20 | 0.55 | -33.58 | 2.91 | -1.93 | 3.49 | -2.91 | 2.48 | 3.82 | -40.49 | 2058.44 | 3380.72 |
| 37 | 128.20 | 0.55 | -40.49 | 2.91 | -2.48 | 3.82 | -2.91 | 3.03 | 4.20 | -46.22 | 2165.24 | 3309.81 |
| 38 | 128.20 | 0.55 | -46.22 | 2.91 | -3.03 | 4.20 | -2.91 | 3.59 | 4.62 | -50.96 | 2262.74 | 3226.57 |
| 39 | 128.20 | 0.55 | -50.96 | 2.91 | -3.59 | 4.62 | -2.91 | 4.14 | 5.06 | -54.90 | 2351.45 | 3134.02 |
| 40 | 128.20 | 0.55 | -54.90 | 2.91 | -4.14 | 5.06 | -2.91 | 4.69 | 5.52 | -58.19 | 2432.20 | 3034.45 |
| 41 | 128.20 | 0.55 | -58.19 | 2.91 | -4.69 | 5.52 | -2.91 | 5.24 | 5.99 | -60.98 | 2505.91 | 2929.57 |
| 42 | 128.20 | 0.55 | -60.98 | 2.91 | -5.24 | 5.99 | -2.91 | 5.79 | 6.48 | -63.34 | 2573.48 | 2820.62 |
| 43 | 128.20 | 0.55 | -63.34 | 2.91 | -5.79 | 6.48 | -2.91 | 6.35 | 6.98 | -65.37 | 2635.68 | 2708.52 |
| 44 | 128.20 | 0.55 | -65.37 | 2.91 | -6.35 | 6.98 | -2.91 | 6.90 | 7.49 | -67.13 | 2693.19 | 2593.95 |
| 45 | 128.20 | 0.55 | -67.13 | 2.91 | -6.90 | 7.49 | -2.91 | 7.45 | 8.00 | -68.67 | 2746.61 | 2477.41 |
| 46 | 128.20 | 0.55 | -68.67 | 2.91 | -7.45 | 8.00 | -2.91 | 8.00 | 8.51 | -70.02 | 2796.42 | 2359.29 |
| 47 | 128.20 | 0.55 | -70.02 | 2.91 | -8.00 | 8.51 | -2.91 | 8.55 | 9.03 | -71.22 | 2843.05 | 2239.87 |
| 48 | 128.20 | 0.55 | -71.22 | 2.91 | -8.55 | 9.03 | -2.91 | 9.10 | 9.56 | -72.28 | 2886.85 | 2119.39 |
| 49 | 128.20 | 0.55 | -72.28 | 2.91 | -9.10 | 9.56 | -2.91 | 9.66 | 10.08 | -73.24 | 2928.13 | 1998.02 |
| 50 | 128.20 | 0.55 | -73.24 | 2.91 | -9.66 | 10.08 | -2.91 | 10.21 | 10.61 | -74.10 | 2967.14 | 1875.90 |
| 51 | 128.20 | 0.55 | -74.10 | 2.91 | -10.21 | 10.61 | -2.91 | 10.76 | 11.15 | -74.87 | 3004.12 | 1753.15 |
| 52 | 128.20 | 0.55 | -74.87 | 2.91 | -10.76 | 11.15 | -2.91 | 11.31 | 11.68 | -75.58 | 3039.25 | 1629.86 |
| 53 | 128.20 | 0.55 | -75.58 | 2.91 | -11.31 | 11.68 | -2.91 | 11.86 | 12.21 | -76.22 | 3072.70 | 1506.11 |
| 54 | 128.20 | 0.55 | -76.22 | 2.91 | -11.86 | 12.21 | -2.91 | 12.42 | 12.75 | -76.81 | 3104.63 | 1381.95 |
| 55 | 128.20 | 0.55 | -76.81 | 2.91 | -12.42 | 12.75 | -2.91 | 12.97 | 13.29 | -77.36 | 3135.15 | 1257.44 |
| 56 | 128.20 | 0.55 | -77.36 | 2.91 | -12.97 | 13.29 | -2.91 | 13.52 | 13.83 | -77.86 | 3164.39 | 1132.62 |
| 57 | 128.20 | 0.55 | -77.86 | 2.91 | -13.52 | 13.83 | -2.91 | 14.07 | 14.37 | -78.32 | 3192.45 | 1007.53 |
| 58 | 128.20 | 0.55 | -78.32 | 2.91 | -14.07 | 14.37 | -2.91 | 14.62 | 14.91 | -78.75 | 3219.42 | 882.20 |
| 59 | 128.20 | 0.55 | -78.75 | 2.91 | -14.62 | 14.91 | -2.91 | 15.17 | 15.45 | -79.15 | 3245.37 | 756.66 |
| 60 | 128.20 | 0.55 | -79.15 | 2.91 | -15.17 | 15.45 | -2.91 | 15.73 | 15.99 | -79.52 | 3270.38 | 630.93 |
| 61 | 128.20 | 0.55 | -79.52 | 2.91 | -15.73 | 15.99 | -2.91 | 16.28 | 16.54 | -79.87 | 3294.51 | 505.02 |
| 62 | 128.20 | 0.55 | -79.87 | 2.91 | -16.28 | 16.54 | -2.91 | 16.83 | 17.08 | -80.19 | 3317.83 | 378.96 |
| 63 | 128.20 | 0.55 | -80.19 | 2.91 | -16.83 | 17.08 | -2.91 | 17.38 | 17.62 | -80.50 | 3340.38 | 252.76 |
| | | | | | | | | | | | 3362.21 | 126.44 |
| | | | | | | | | | | | 3383.37 | 0 |

| Segment no. | Height of Segment | DL+LL(F) | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | X | Y |
| 1 | 130 | 0.456 | 80.200 | 2.519 | 14.582 | 14.797 | -2.519 | -14.125 | 14.348 | 79.890 | 0 | 0 |
| 2 | 130 | 0.457 | 79.890 | 2.519 | 14.125 | 14.348 | -2.519 | -13.668 | 13.899 | 79.559 | 22.127 | 128.103 |
| 3 | 130 | 0.457 | 79.559 | 2.519 | 13.668 | 13.899 | -2.519 | -13.212 | 13.449 | 79.207 | 44.948 | 256.084 |
| 4 | 130 | 0.457 | 79.207 | 2.519 | 13.212 | 13.449 | -2.519 | -12.754 | 13.001 | 78.829 | 68.506 | 383.932 |
| 5 | 130 | 0.458 | 78.829 | 2.519 | 12.754 | 13.001 | -2.519 | -12.297 | 12.552 | 78.424 | 92.851 | 511.632 |
| 6 | 130 | 0.458 | 78.424 | 2.519 | 12.297 | 12.552 | -2.519 | -11.839 | 12.104 | 77.989 | 118.036 | 639.169 |
| 7 | 130 | 0.458 | 77.989 | 2.519 | 11.839 | 12.104 | -2.519 | -11.380 | 11.656 | 77.520 | 144.122 | 766.525 |
| 8 | 130 | 0.459 | 77.520 | 2.519 | 11.380 | 11.656 | -2.519 | -10.921 | 11.208 | 77.014 | 171.174 | 893.679 |
| 9 | 130 | 0.459 | 77.014 | 2.519 | 10.921 | 11.208 | -2.519 | -10.462 | 10.761 | 76.464 | 199.266 | 1020.608 |
| 10 | 130 | 0.460 | 76.464 | 2.519 | 10.462 | 10.761 | -2.519 | -10.002 | 10.314 | 75.866 | 228.480 | 1147.283 |
| 11 | 130 | 0.460 | 75.866 | 2.519 | 10.002 | 10.314 | -2.519 | -9.542 | 9.869 | 75.213 | 258.907 | 1273.672 |
| 12 | 130 | 0.461 | 75.213 | 2.519 | 9.542 | 9.869 | -2.519 | -9.081 | 9.424 | 74.498 | 290.652 | 1399.736 |
| 13 | 130 | 0.462 | 74.498 | 2.519 | 9.081 | 9.424 | -2.519 | -8.619 | 8.980 | 73.711 | 323.830 | 1525.431 |
| 14 | 130 | 0.462 | 73.711 | 2.519 | 8.619 | 8.980 | -2.519 | -8.157 | 8.537 | 72.840 | 358.576 | 1650.702 |
| 15 | 130 | 0.463 | 72.840 | 2.519 | 8.157 | 8.537 | -2.519 | -7.693 | 8.095 | 71.873 | 395.039 | 1775.483 |
| 16 | 130 | 0.464 | 71.873 | 2.519 | 7.693 | 8.095 | -2.519 | -7.229 | 7.655 | 70.792 | 433.395 | 1899.696 |
| 17 | 130 | 0.465 | 70.792 | 2.519 | 7.229 | 7.655 | -2.519 | -6.764 | 7.218 | 69.577 | 473.841 | 2023.244 |
| 18 | 130 | 0.466 | 69.577 | 2.519 | 6.764 | 7.218 | -2.519 | -6.298 | 6.783 | 68.202 | 516.612 | 2146.007 |
| 19 | 130 | 0.468 | 68.202 | 2.519 | 6.298 | 6.783 | -2.519 | -5.830 | 6.351 | 66.636 | 561.975 | 2267.835 |
| 20 | 130 | 0.469 | 66.636 | 2.519 | 5.830 | 6.351 | -2.519 | -5.361 | 5.923 | 64.836 | 610.248 | 2388.540 |
| 21 | 130 | 0.471 | 64.836 | 2.519 | 5.361 | 5.923 | -2.519 | -4.891 | 5.501 | 62.752 | 661.803 | 2507.881 |
| 22 | 130 | 0.473 | 62.752 | 2.519 | 4.891 | 5.501 | -2.519 | -4.418 | 5.086 | 60.314 | 717.079 | 2625.543 |
| 23 | 130 | 0.475 | 60.314 | 2.519 | 4.418 | 5.086 | -2.519 | -3.943 | 4.679 | 57.434 | 776.599 | 2741.117 |
| 24 | 130 | 0.477 | 57.434 | 2.519 | 3.943 | 4.679 | -2.519 | -3.466 | 4.285 | 53.998 | 840.982 | 2854.055 |
| 25 | 130 | 0.480 | 53.998 | 2.519 | 3.466 | 4.285 | -2.519 | -2.986 | 3.907 | 49.857 | 910.957 | 2963.615 |
| 26 | 130 | 0.483 | 49.857 | 2.519 | 2.986 | 3.907 | -2.519 | -2.503 | 3.551 | 44.825 | 987.373 | 3068.785 |
| 27 | 130 | 0.487 | 44.825 | 2.519 | 2.503 | 3.551 | -2.519 | -2.017 | 3.227 | 38.684 | 1071.184 | 3168.161 |
| 28 | 130 | 0.490 | 38.684 | 2.519 | 2.017 | 3.227 | -2.519 | -1.526 | 2.945 | 31.216 | 1163.388 | 3259.804 |
| 29 | 130 | 0.494 | 31.216 | 2.519 | 1.526 | 2.945 | -2.519 | -1.032 | 2.722 | 22.288 | 1264.866 | 3341.058 |
| 30 | 130 | 0.497 | 22.288 | 2.519 | 1.032 | 2.722 | -2.519 | -0.535 | 2.575 | 12.002 | 1376.044 | 3408.433 |
| 31 | 130 | 0.499 | 12.002 | 2.519 | 0.535 | 2.575 | -2.519 | -0.037 | 2.519 | 0.836 | 1496.332 | 3457.738 |
| 32 | 130 | 0.499 | 0.836 | 2.519 | 0.037 | 2.519 | -2.519 | 0.462 | 2.561 | -10.398 | 1623.490 | 3484.770 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 130 | 0.499 | -10.398 | 2.519 | -0.462 | 2.561 | -2.519 | 0.961 | 2.696 | -20.881 | 1753.476 | 3486.667 |
| 34 | 130 | 0.497 | -20.881 | 2.519 | -0.961 | 2.696 | -2.519 | 1.458 | 2.910 | -30.062 | 1881.342 | 3463.205 |
| 35 | 130 | 0.494 | -30.062 | 2.519 | -1.458 | 2.910 | -2.519 | 1.952 | 3.186 | -37.773 | 2002.803 | 3416.868 |
| 36 | 130 | 0.490 | -37.773 | 2.519 | -1.952 | 3.186 | -2.519 | 2.442 | 3.508 | -44.116 | 2115.316 | 3351.747 |
| 37 | 130 | 0.487 | -44.116 | 2.519 | -2.442 | 3.508 | -2.519 | 2.929 | 3.863 | -49.305 | 2218.074 | 3272.118 |
| 38 | 130 | 0.483 | -49.305 | 2.519 | -2.929 | 3.863 | -2.519 | 3.412 | 4.241 | -53.565 | 2311.406 | 3181.623 |
| 39 | 130 | 0.480 | -53.565 | 2.519 | -3.412 | 4.241 | -2.519 | 3.892 | 4.636 | -57.090 | 2396.170 | 3083.058 |
| 40 | 130 | 0.477 | -57.090 | 2.519 | -3.892 | 4.636 | -2.519 | 4.369 | 5.043 | -60.037 | 2473.379 | 2978.470 |
| 41 | 130 | 0.475 | -60.037 | 2.519 | -4.369 | 5.043 | -2.519 | 4.844 | 5.459 | -62.525 | 2544.010 | 2869.331 |
| 42 | 130 | 0.473 | -62.525 | 2.519 | -4.844 | 5.459 | -2.519 | 5.316 | 5.883 | -64.649 | 2608.938 | 2756.707 |
| 43 | 130 | 0.471 | -64.649 | 2.519 | -5.316 | 5.883 | -2.519 | 5.787 | 6.311 | -66.479 | 2668.915 | 2641.369 |
| 44 | 130 | 0.469 | -66.479 | 2.519 | -5.787 | 6.311 | -2.519 | 6.256 | 6.744 | -68.069 | 2724.575 | 2523.887 |
| 45 | 130 | 0.468 | -68.069 | 2.519 | -6.256 | 6.744 | -2.519 | 6.723 | 7.180 | -69.463 | 2776.457 | 2404.688 |
| 46 | 130 | 0.466 | -69.463 | 2.519 | -6.723 | 7.180 | -2.519 | 7.190 | 7.618 | -70.693 | 2825.010 | 2284.096 |
| 47 | 130 | 0.465 | -70.693 | 2.519 | -7.190 | 7.618 | -2.519 | 7.655 | 8.058 | -71.787 | 2870.615 | 2162.358 |
| 48 | 130 | 0.464 | -71.787 | 2.519 | -7.655 | 8.058 | -2.519 | 8.119 | 8.501 | -72.765 | 2913.596 | 2039.669 |
| 49 | 130 | 0.463 | -72.765 | 2.519 | -8.119 | 8.501 | -2.519 | 8.582 | 8.944 | -73.644 | 2954.228 | 1916.181 |
| 50 | 130 | 0.462 | -73.644 | 2.519 | -8.582 | 8.944 | -2.519 | 9.044 | 9.389 | -74.439 | 2992.746 | 1792.019 |
| 51 | 130 | 0.462 | -74.439 | 2.519 | -9.044 | 9.389 | -2.519 | 9.506 | 9.834 | -75.160 | 3029.355 | 1667.280 |
| 52 | 130 | 0.461 | -75.160 | 2.519 | -9.506 | 9.834 | -2.519 | 9.967 | 10.280 | -75.818 | 3064.229 | 1542.045 |
| 53 | 130 | 0.460 | -75.818 | 2.519 | -9.967 | 10.280 | -2.519 | 10.428 | 10.727 | -76.421 | 3097.524 | 1416.381 |
| 54 | 130 | 0.460 | -76.421 | 2.519 | -10.428 | 10.727 | -2.519 | 10.887 | 11.175 | -76.974 | 3129.374 | 1290.343 |
| 55 | 130 | 0.459 | -76.974 | 2.519 | -10.887 | 11.175 | -2.519 | 11.347 | 11.623 | -77.485 | 3159.896 | 1163.977 |
| 56 | 130 | 0.459 | -77.485 | 2.519 | -11.347 | 11.623 | -2.519 | 11.806 | 12.071 | -77.957 | 3189.196 | 1037.322 |
| 57 | 130 | 0.458 | -77.957 | 2.519 | -11.806 | 12.071 | -2.519 | 12.264 | 12.520 | -78.395 | 3217.367 | 910.411 |
| 58 | 130 | 0.458 | -78.395 | 2.519 | -12.264 | 12.520 | -2.519 | 12.722 | 12.969 | -78.802 | 3244.491 | 783.272 |
| 59 | 130 | 0.458 | -78.802 | 2.519 | -12.722 | 12.969 | -2.519 | 13.180 | 13.418 | -79.181 | 3270.643 | 655.930 |
| 60 | 130 | 0.457 | -79.181 | 2.519 | -13.180 | 13.418 | -2.519 | 13.637 | 13.868 | -79.536 | 3295.890 | 528.405 |
| 61 | 130 | 0.457 | -79.536 | 2.519 | -13.637 | 13.868 | -2.519 | 14.094 | 14.317 | -79.868 | 3320.292 | 400.715 |
| 62 | 130 | 0.457 | -79.868 | 2.519 | -14.094 | 14.317 | -2.519 | 14.551 | 14.767 | -80.180 | 3343.903 | 272.878 |
| 63 | 130 | 0.456 | -80.180 | 2.519 | -14.551 | 14.767 | -2.519 | 15.007 | 15.217 | -80.473 | 3366.772 | 144.905 |
| | | | | | | | | | | | 3388.945 | 16.810 |
| | | | | | | | | | | | 3391.849 | 0 |

| Segment no. | Height of Segment | DL+LL(L) | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | X | Y |
| 1 | 129 | 0.450 | 80.500 | 2.412 | 14.412 | 14.613 | -2.412 | -13.962 | 14.169 | 80.200 | 0 | 0 |
| 2 | 129 | 0.450 | 80.200 | 2.412 | 13.962 | 14.169 | -2.412 | -13.512 | 13.725 | 79.879 | 21.291 | 127.231 |
| 3 | 129 | 0.451 | 79.879 | 2.412 | 13.512 | 13.725 | -2.412 | -13.061 | 13.282 | 79.538 | 43.249 | 254.348 |
| 4 | 129 | 0.451 | 79.538 | 2.412 | 13.061 | 13.282 | -2.412 | -12.610 | 12.838 | 79.172 | 65.917 | 381.341 |
| 5 | 129 | 0.451 | 79.172 | 2.412 | 12.610 | 12.838 | -2.412 | -12.158 | 12.395 | 78.780 | 89.342 | 508.196 |
| 6 | 129 | 0.452 | 78.780 | 2.412 | 12.158 | 12.395 | -2.412 | -11.707 | 11.953 | 78.359 | 113.575 | 634.900 |
| 7 | 129 | 0.452 | 78.359 | 2.412 | 11.707 | 11.953 | -2.412 | -11.254 | 11.510 | 77.905 | 138.675 | 761.434 |
| 8 | 129 | 0.453 | 77.905 | 2.412 | 11.254 | 11.510 | -2.412 | -10.802 | 11.068 | 77.414 | 164.705 | 887.781 |
| 9 | 129 | 0.453 | 77.414 | 2.412 | 10.802 | 11.068 | -2.412 | -10.349 | 10.626 | 76.881 | 191.735 | 1013.917 |
| 10 | 129 | 0.454 | 76.881 | 2.412 | 10.349 | 10.626 | -2.412 | -9.895 | 10.185 | 76.302 | 219.846 | 1139.817 |
| 11 | 129 | 0.454 | 76.302 | 2.412 | 9.895 | 10.185 | -2.412 | -9.441 | 9.744 | 75.670 | 249.125 | 1265.450 |
| 12 | 129 | 0.455 | 75.670 | 2.412 | 9.441 | 9.744 | -2.412 | -8.986 | 9.304 | 74.976 | 279.673 | 1390.781 |
| 13 | 129 | 0.455 | 74.976 | 2.412 | 8.986 | 9.304 | -2.412 | -8.531 | 8.865 | 74.213 | 311.602 | 1515.767 |
| 14 | 129 | 0.456 | 74.213 | 2.412 | 8.531 | 8.865 | -2.412 | -8.074 | 8.427 | 73.369 | 345.042 | 1640.358 |
| 15 | 129 | 0.457 | 73.369 | 2.412 | 8.074 | 8.427 | -2.412 | -7.617 | 7.990 | 72.431 | 380.137 | 1764.492 |
| 16 | 129 | 0.458 | 72.431 | 2.412 | 7.617 | 7.990 | -2.412 | -7.159 | 7.555 | 71.383 | 417.057 | 1888.096 |
| 17 | 129 | 0.459 | 71.383 | 2.412 | 7.159 | 7.555 | -2.412 | -6.700 | 7.121 | 70.204 | 455.996 | 2011.079 |
| 18 | 129 | 0.460 | 70.204 | 2.412 | 6.700 | 7.121 | -2.412 | -6.240 | 6.690 | 68.869 | 497.178 | 2133.329 |
| 19 | 129 | 0.461 | 68.869 | 2.412 | 6.240 | 6.690 | -2.412 | -5.779 | 6.262 | 67.348 | 540.867 | 2254.705 |
| 20 | 129 | 0.463 | 67.348 | 2.412 | 5.779 | 6.262 | -2.412 | -5.316 | 5.838 | 65.598 | 587.371 | 2375.031 |
| 21 | 129 | 0.464 | 65.598 | 2.412 | 5.316 | 5.838 | -2.412 | -4.852 | 5.418 | 63.568 | 637.054 | 2494.080 |
| 22 | 129 | 0.466 | 63.568 | 2.412 | 4.852 | 5.418 | -2.412 | -4.386 | 5.005 | 61.192 | 690.349 | 2611.556 |
| 23 | 129 | 0.468 | 61.192 | 2.412 | 4.386 | 5.005 | -2.412 | -3.917 | 4.600 | 58.379 | 747.770 | 2727.072 |
| 24 | 129 | 0.471 | 58.379 | 2.412 | 3.917 | 4.600 | -2.412 | -3.446 | 4.206 | 55.014 | 809.933 | 2840.106 |
| 25 | 129 | 0.474 | 55.014 | 2.412 | 3.446 | 4.206 | -2.412 | -2.972 | 3.828 | 50.945 | 877.568 | 2949.954 |
| 26 | 129 | 0.477 | 50.945 | 2.412 | 2.972 | 3.828 | -2.412 | -2.496 | 3.471 | 45.978 | 951.534 | 3055.642 |
| 27 | 129 | 0.480 | 45.978 | 2.412 | 2.496 | 3.471 | -2.412 | -2.015 | 3.143 | 39.880 | 1032.813 | 3155.816 |
| 28 | 129 | 0.484 | 39.880 | 2.412 | 2.015 | 3.143 | -2.412 | -1.531 | 2.857 | 32.407 | 1122.460 | 3248.576 |
| 29 | 129 | 0.488 | 32.407 | 2.412 | 1.531 | 2.857 | -2.412 | -1.043 | 2.628 | 23.391 | 1221.453 | 3331.288 |
| 30 | 129 | 0.491 | 23.391 | 2.412 | 1.043 | 2.628 | -2.412 | -0.552 | 2.474 | 12.902 | 1330.363 | 3400.422 |
| 31 | 129 | 0.492 | 12.902 | 2.412 | 0.552 | 2.474 | -2.412 | -0.060 | 2.413 | 1.425 | 1448.762 | 3451.636 |
| 32 | 129 | 0.492 | 1.425 | 2.412 | 0.060 | 2.413 | -2.412 | 0.432 | 2.450 | -10.166 | 1574.505 | 3480.440 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 129 | 0.441 | -10.166 | 2.412 | -0.432 | 2.450 | -2.412 | 0.874 | 2.565 | -19.917 | 1703.465 | 3483.649 |
| 34 | 129 | 0.441 | -19.917 | 2.412 | -0.874 | 2.565 | -2.412 | 1.315 | 2.747 | -28.607 | 1830.440 | 3460.880 |
| 35 | 129 | 0.441 | -28.607 | 2.412 | -1.315 | 2.747 | -2.412 | 1.757 | 2.984 | -36.069 | 1951.724 | 3416.934 |
| 36 | 129 | 0.441 | -36.069 | 2.412 | -1.757 | 2.984 | -2.412 | 2.198 | 3.263 | -42.347 | 2064.976 | 3355.170 |
| 37 | 129 | 0.441 | -42.347 | 2.412 | -2.198 | 3.263 | -2.412 | 2.640 | 3.575 | -47.582 | 2169.248 | 3279.220 |
| 38 | 129 | 0.441 | -47.582 | 2.412 | -2.640 | 3.575 | -2.412 | 3.081 | 3.913 | -51.946 | 2264.589 | 3192.323 |
| 39 | 129 | 0.441 | -51.946 | 2.412 | -3.081 | 3.913 | -2.412 | 3.522 | 4.269 | -55.601 | 2351.604 | 3097.090 |
| 40 | 129 | 0.441 | -55.601 | 2.412 | -3.522 | 4.269 | -2.412 | 3.964 | 4.640 | -58.682 | 2431.120 | 2995.511 |
| 41 | 129 | 0.441 | -58.682 | 2.412 | -3.964 | 4.640 | -2.412 | 4.405 | 5.022 | -61.300 | 2504.000 | 2889.071 |
| 42 | 129 | 0.441 | -61.300 | 2.412 | -4.405 | 5.022 | -2.412 | 4.847 | 5.414 | -63.544 | 2571.053 | 2778.867 |
| 43 | 129 | 0.441 | -63.544 | 2.412 | -4.847 | 5.414 | -2.412 | 5.288 | 5.812 | -65.483 | 2633.001 | 2665.715 |
| 44 | 129 | 0.441 | -65.483 | 2.412 | -5.288 | 5.812 | -2.412 | 5.730 | 6.216 | -67.172 | 2690.471 | 2550.224 |
| 45 | 129 | 0.441 | -67.172 | 2.412 | -5.730 | 6.216 | -2.412 | 6.171 | 6.626 | -68.653 | 2744.001 | 2432.855 |
| 46 | 129 | 0.441 | -68.653 | 2.412 | -6.171 | 6.626 | -2.412 | 6.612 | 7.038 | -69.961 | 2794.049 | 2313.959 |
| 47 | 129 | 0.441 | -69.961 | 2.412 | -6.612 | 7.038 | -2.412 | 7.054 | 7.455 | -71.124 | 2841.007 | 2193.809 |
| 48 | 129 | 0.441 | -71.124 | 2.412 | -7.054 | 7.455 | -2.412 | 7.495 | 7.874 | -72.163 | 2885.210 | 2072.619 |
| 49 | 129 | 0.441 | -72.163 | 2.412 | -7.495 | 7.874 | -2.412 | 7.937 | 8.295 | -73.097 | 2926.945 | 1950.557 |
| 50 | 129 | 0.441 | -73.097 | 2.412 | -7.937 | 8.295 | -2.412 | 8.378 | 8.718 | -73.940 | 2966.459 | 1827.757 |
| 51 | 129 | 0.441 | -73.940 | 2.412 | -8.378 | 8.718 | -2.412 | 8.820 | 9.143 | -74.706 | 3003.966 | 1704.330 |
| 52 | 129 | 0.441 | -74.706 | 2.412 | -8.820 | 9.143 | -2.412 | 9.261 | 9.570 | -75.403 | 3039.652 | 1580.365 |
| 53 | 129 | 0.441 | -75.403 | 2.412 | -9.261 | 9.570 | -2.412 | 9.702 | 9.998 | -76.040 | 3073.679 | 1455.933 |
| 54 | 129 | 0.441 | -76.040 | 2.412 | -9.702 | 9.998 | -2.412 | 10.144 | 10.427 | -76.626 | 3106.190 | 1331.097 |
| 55 | 129 | 0.441 | -76.626 | 2.412 | -10.144 | 10.427 | -2.412 | 10.585 | 10.856 | -77.164 | 3137.309 | 1205.907 |
| 56 | 129 | 0.441 | -77.164 | 2.412 | -10.585 | 10.856 | -2.412 | 11.027 | 11.287 | -77.662 | 3167.149 | 1080.406 |
| 57 | 129 | 0.441 | -77.662 | 2.412 | -11.027 | 11.287 | -2.412 | 11.468 | 11.719 | -78.123 | 3195.807 | 954.629 |
| 58 | 129 | 0.441 | -78.123 | 2.412 | -11.468 | 11.719 | -2.412 | 11.909 | 12.151 | -78.552 | 3223.370 | 828.608 |
| 59 | 129 | 0.441 | -78.552 | 2.412 | -11.909 | 12.151 | -2.412 | 12.351 | 12.584 | -78.951 | 3249.919 | 702.370 |
| 60 | 129 | 0.441 | -78.951 | 2.412 | -12.351 | 12.584 | -2.412 | 12.792 | 13.018 | -79.323 | 3275.523 | 575.936 |
| 61 | 129 | 0.441 | -79.323 | 2.412 | -12.792 | 13.018 | -2.412 | 13.234 | 13.452 | -79.671 | 3300.247 | 449.328 |
| 62 | 129 | 0.441 | -79.671 | 2.412 | -13.234 | 13.452 | -2.412 | 13.675 | 13.886 | -79.998 | 3324.147 | 322.561 |
| 63 | 129 | 0.441 | -79.998 | 2.412 | -13.675 | 13.886 | -2.412 | 14.117 | 14.321 | -80.305 | 3347.275 | 195.651 |
| | | | | | | | | | | | 3369.680 | 68.612 |
| | | | | | | | | | | | 3381.162 | 0 |

| Segment no. | Height of Segment | DL+LL(R) | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | X | Y |
| 1 | 127 | 0.441 | 80.200 | 2.431 | 14.074 | 14.282 | -2.431 | -13.633 | 13.848 | 79.889 | 0 | 0 |
| 2 | 127 | 0.441 | 79.889 | 2.431 | 13.633 | 13.848 | -2.431 | -13.191 | 13.413 | 79.558 | 21.617 | 125.147 |
| 3 | 127 | 0.441 | 79.558 | 2.431 | 13.191 | 13.413 | -2.431 | -12.750 | 12.979 | 79.205 | 43.912 | 250.174 |
| 4 | 127 | 0.441 | 79.205 | 2.431 | 12.750 | 12.979 | -2.431 | -12.308 | 12.546 | 78.827 | 66.929 | 375.071 |
| 5 | 127 | 0.441 | 78.827 | 2.431 | 12.308 | 12.546 | -2.431 | -11.867 | 12.113 | 78.423 | 90.716 | 499.824 |
| 6 | 127 | 0.441 | 78.423 | 2.431 | 11.867 | 12.113 | -2.431 | -11.425 | 11.681 | 77.988 | 115.324 | 624.417 |
| 7 | 127 | 0.441 | 77.988 | 2.431 | 11.425 | 11.681 | -2.431 | -10.984 | 11.250 | 77.520 | 140.812 | 748.833 |
| 8 | 127 | 0.441 | 77.520 | 2.431 | 10.984 | 11.250 | -2.431 | -10.543 | 10.819 | 77.015 | 167.242 | 873.052 |
| 9 | 127 | 0.441 | 77.015 | 2.431 | 10.543 | 10.819 | -2.431 | -10.101 | 10.390 | 76.468 | 194.685 | 997.052 |
| 10 | 127 | 0.441 | 76.468 | 2.431 | 10.101 | 10.390 | -2.431 | -9.660 | 9.961 | 75.874 | 223.221 | 1120.804 |
| 11 | 127 | 0.441 | 75.874 | 2.431 | 9.660 | 9.961 | -2.431 | -9.218 | 9.533 | 75.227 | 252.937 | 1244.279 |
| 12 | 127 | 0.441 | 75.227 | 2.431 | 9.218 | 9.533 | -2.431 | -8.777 | 9.107 | 74.519 | 283.932 | 1367.439 |
| 13 | 127 | 0.441 | 74.519 | 2.431 | 8.777 | 9.107 | -2.431 | -8.335 | 8.683 | 73.741 | 316.316 | 1490.240 |
| 14 | 127 | 0.441 | 73.741 | 2.431 | 8.335 | 8.683 | -2.431 | -7.894 | 8.260 | 72.884 | 350.216 | 1612.632 |
| 15 | 127 | 0.441 | 72.884 | 2.431 | 7.894 | 8.260 | -2.431 | -7.453 | 7.839 | 71.934 | 385.774 | 1734.553 |
| 16 | 127 | 0.441 | 71.934 | 2.431 | 7.453 | 7.839 | -2.431 | -7.011 | 7.421 | 70.877 | 423.151 | 1855.928 |
| 17 | 127 | 0.441 | 70.877 | 2.431 | 7.011 | 7.421 | -2.431 | -6.570 | 7.005 | 69.694 | 462.536 | 1976.667 |
| 18 | 127 | 0.441 | 69.694 | 2.431 | 6.570 | 7.005 | -2.431 | -6.128 | 6.593 | 68.363 | 504.140 | 2096.659 |
| 19 | 127 | 0.441 | 68.363 | 2.431 | 6.128 | 6.593 | -2.431 | -5.687 | 6.185 | 66.855 | 548.213 | 2215.766 |
| 20 | 127 | 0.441 | 66.855 | 2.431 | 5.687 | 6.185 | -2.431 | -5.246 | 5.781 | 65.135 | 595.042 | 2333.818 |
| 21 | 127 | 0.441 | 65.135 | 2.431 | 5.246 | 5.781 | -2.431 | -4.804 | 5.384 | 63.159 | 644.961 | 2450.596 |
| 22 | 127 | 0.441 | 63.159 | 2.431 | 4.804 | 5.384 | -2.431 | -4.363 | 4.994 | 60.872 | 698.362 | 2565.823 |
| 23 | 127 | 0.441 | 60.872 | 2.431 | 4.363 | 4.994 | -2.431 | -3.921 | 4.614 | 58.203 | 755.704 | 2679.141 |
| 24 | 127 | 0.441 | 58.203 | 2.431 | 3.921 | 4.614 | -2.431 | -3.480 | 4.245 | 55.062 | 817.522 | 2790.080 |
| 25 | 127 | 0.441 | 55.062 | 2.431 | 3.480 | 4.245 | -2.431 | -3.038 | 3.891 | 51.337 | 884.440 | 2898.020 |
| 26 | 127 | 0.441 | 51.337 | 2.431 | 3.038 | 3.891 | -2.431 | -2.597 | 3.557 | 46.891 | 957.171 | 3002.131 |
| 27 | 127 | 0.441 | 46.891 | 2.431 | 2.597 | 3.557 | -2.431 | -2.156 | 3.249 | 41.563 | 1036.513 | 3101.297 |
| 28 | 127 | 0.441 | 41.563 | 2.431 | 2.156 | 3.249 | -2.431 | -1.714 | 2.975 | 35.188 | 1123.303 | 3194.014 |
| 29 | 127 | 0.441 | 35.188 | 2.431 | 1.714 | 2.975 | -2.431 | -1.273 | 2.744 | 27.634 | 1218.327 | 3278.272 |
| 30 | 127 | 0.441 | 27.634 | 2.431 | 1.273 | 2.744 | -2.431 | -0.831 | 2.569 | 18.879 | 1322.119 | 3351.458 |
| 31 | 127 | 0.441 | 18.879 | 2.431 | 0.831 | 2.569 | -2.431 | -0.390 | 2.462 | 9.111 | 1434.632 | 3410.363 |
| 32 | 127 | 0.492 | 9.111 | 2.431 | 0.390 | 2.462 | -2.431 | 0.103 | 2.433 | -2.417 | 1554.801 | 3451.455 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 127 | 0.492 | -2.417 | 2.431 | -0.103 | 2.433 | -2.431 | 0.595 | 2.503 | -13.755 | 1680.198 | 3471.567 |
| 34 | 127 | 0.491 | -13.755 | 2.431 | -0.595 | 2.503 | -2.431 | 1.086 | 2.662 | -24.068 | 1807.085 | 3466.212 |
| 35 | 127 | 0.488 | -24.068 | 2.431 | -1.086 | 2.662 | -2.431 | 1.574 | 2.896 | -32.915 | 1930.443 | 3436.016 |
| 36 | 127 | 0.484 | -32.915 | 2.431 | -1.574 | 2.896 | -2.431 | 2.058 | 3.185 | -40.246 | 2046.402 | 3384.223 |
| 37 | 127 | 0.480 | -40.246 | 2.431 | -2.058 | 3.185 | -2.431 | 2.538 | 3.515 | -46.235 | 2153.016 | 3315.212 |
| 38 | 127 | 0.477 | -46.235 | 2.431 | -2.538 | 3.515 | -2.431 | 3.015 | 3.873 | -51.121 | 2249.953 | 3233.161 |
| 39 | 127 | 0.474 | -51.121 | 2.431 | -3.015 | 3.873 | -2.431 | 3.489 | 4.252 | -55.131 | 2337.799 | 3141.444 |
| 40 | 127 | 0.471 | -55.131 | 2.431 | -3.489 | 4.252 | -2.431 | 3.960 | 4.646 | -58.453 | 2417.514 | 3042.578 |
| 41 | 127 | 0.468 | -58.453 | 2.431 | -3.960 | 4.646 | -2.431 | 4.428 | 5.052 | -61.234 | 2490.120 | 2938.379 |
| 42 | 127 | 0.466 | -61.234 | 2.431 | -4.428 | 5.052 | -2.431 | 4.894 | 5.465 | -63.587 | 2556.567 | 2830.149 |
| 43 | 127 | 0.464 | -63.587 | 2.431 | -4.894 | 5.465 | -2.431 | 5.359 | 5.884 | -65.599 | 2617.685 | 2718.822 |
| 44 | 127 | 0.463 | -65.599 | 2.431 | -5.359 | 5.884 | -2.431 | 5.822 | 6.309 | -67.336 | 2674.179 | 2605.080 |
| 45 | 127 | 0.461 | -67.336 | 2.431 | -5.822 | 6.309 | -2.431 | 6.283 | 6.737 | -68.848 | 2726.646 | 2489.424 |
| 46 | 127 | 0.460 | -68.848 | 2.431 | -6.283 | 6.737 | -2.431 | 6.743 | 7.168 | -70.175 | 2775.583 | 2372.231 |
| 47 | 127 | 0.459 | -70.175 | 2.431 | -6.743 | 7.168 | -2.431 | 7.202 | 7.601 | -71.348 | 2821.411 | 2253.788 |
| 48 | 127 | 0.458 | -71.348 | 2.431 | -7.202 | 7.601 | -2.431 | 7.660 | 8.036 | -72.392 | 2864.483 | 2134.315 |
| 49 | 127 | 0.457 | -72.392 | 2.431 | -7.660 | 8.036 | -2.431 | 8.117 | 8.473 | -73.327 | 2905.100 | 2013.985 |
| 50 | 127 | 0.456 | -73.327 | 2.431 | -8.117 | 8.473 | -2.431 | 8.573 | 8.911 | -74.169 | 2943.517 | 1892.935 |
| 51 | 127 | 0.455 | -74.169 | 2.431 | -8.573 | 8.911 | -2.431 | 9.029 | 9.350 | -74.930 | 2979.954 | 1771.274 |
| 52 | 127 | 0.455 | -74.930 | 2.431 | -9.029 | 9.350 | -2.431 | 9.483 | 9.790 | -75.622 | 3014.600 | 1649.091 |
| 53 | 127 | 0.454 | -75.622 | 2.431 | -9.483 | 9.790 | -2.431 | 9.938 | 10.231 | -76.254 | 3047.619 | 1526.459 |
| 54 | 127 | 0.454 | -76.254 | 2.431 | -9.938 | 10.231 | -2.431 | 10.391 | 10.672 | -76.833 | 3079.155 | 1403.436 |
| 55 | 127 | 0.453 | -76.833 | 2.431 | -10.391 | 10.672 | -2.431 | 10.844 | 11.114 | -77.365 | 3109.332 | 1280.074 |
| 56 | 127 | 0.453 | -77.365 | 2.431 | -10.844 | 11.114 | -2.431 | 11.297 | 11.556 | -77.856 | 3138.262 | 1156.413 |
| 57 | 127 | 0.452 | -77.856 | 2.431 | -11.297 | 11.556 | -2.431 | 11.749 | 11.998 | -78.310 | 3166.043 | 1032.489 |
| 58 | 127 | 0.452 | -78.310 | 2.431 | -11.749 | 11.998 | -2.431 | 12.201 | 12.441 | -78.732 | 3192.760 | 908.331 |
| 59 | 127 | 0.451 | -78.732 | 2.431 | -12.201 | 12.441 | -2.431 | 12.652 | 12.884 | -79.124 | 3218.492 | 783.965 |
| 60 | 127 | 0.451 | -79.124 | 2.431 | -12.652 | 12.884 | -2.431 | 13.104 | 13.327 | -79.490 | 3243.309 | 659.413 |
| 61 | 127 | 0.451 | -79.490 | 2.431 | -13.104 | 13.327 | -2.431 | 13.554 | 13.771 | -79.832 | 3267.272 | 534.694 |
| 62 | 127 | 0.450 | -79.832 | 2.431 | -13.554 | 13.771 | -2.431 | 14.005 | 14.214 | -80.152 | 3290.438 | 409.825 |
| 63 | 127 | 0.450 | -80.152 | 2.431 | -14.005 | 14.214 | -2.431 | 14.455 | 14.658 | -80.453 | 3312.858 | 284.820 |
| | | | | | | | | | | | 3334.578 | 159.691 |
| | | | | | | | | | | | 3362.161 | 0 |

| Segment no. | Height of Segment | DL + LL(F) | Wind Load (Cpi=0) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 134 | 0.444 | 0.046 | 0.045 | 0.008 | 82.500 | 1.736 | 13.183 | 13.296 | -1.780 | -12.731 | 12.855 | 82.038 | 0 | 0 |
| 2 | 134 | 0.444 | 0.046 | 0.045 | 0.008 | 82.038 | 1.780 | 12.731 | 12.855 | -1.825 | -12.279 | 12.414 | 81.544 | 17.491 | 132.854 |
| 3 | 134 | 0.444 | 0.046 | 0.045 | 0.008 | 81.544 | 1.825 | 12.279 | 12.414 | -1.870 | -11.827 | 11.974 | 81.013 | 36.051 | 265.562 |
| 4 | 134 | 0.444 | 0.046 | 0.045 | 0.008 | 81.013 | 1.870 | 11.827 | 11.974 | -1.915 | -11.374 | 11.534 | 80.442 | 55.755 | 398.105 |
| 5 | 134 | 0.445 | 0.046 | 0.045 | 0.009 | 80.442 | 1.915 | 11.374 | 11.534 | -1.960 | -10.921 | 11.095 | 79.825 | 76.686 | 530.461 |
| 6 | 134 | 0.445 | 0.046 | 0.045 | 0.009 | 79.825 | 1.960 | 10.921 | 11.095 | -2.005 | -10.467 | 10.657 | 79.158 | 98.936 | 662.600 |
| 7 | 134 | 0.445 | 0.046 | 0.045 | 0.009 | 79.158 | 2.005 | 10.467 | 10.657 | -2.049 | -10.013 | 10.221 | 78.433 | 122.607 | 794.493 |
| 8 | 134 | 0.445 | 0.046 | 0.045 | 0.010 | 78.433 | 2.049 | 10.013 | 10.221 | -2.094 | -9.559 | 9.785 | 77.644 | 147.812 | 926.101 |
| 9 | 134 | 0.445 | 0.046 | 0.044 | 0.010 | 77.644 | 2.094 | 9.559 | 9.785 | -2.138 | -9.103 | 9.351 | 76.781 | 174.680 | 1057.380 |
| 10 | 134 | 0.445 | 0.046 | 0.044 | 0.010 | 76.781 | 2.138 | 9.103 | 9.351 | -2.183 | -8.648 | 8.919 | 75.834 | 203.354 | 1188.276 |
| 11 | 134 | 0.445 | 0.046 | 0.044 | 0.011 | 75.834 | 2.183 | 8.648 | 8.919 | -2.227 | -8.192 | 8.489 | 74.791 | 233.996 | 1318.726 |
| 12 | 134 | 0.446 | 0.046 | 0.044 | 0.011 | 74.791 | 2.227 | 8.192 | 8.489 | -2.271 | -7.735 | 8.061 | 73.636 | 266.790 | 1448.651 |
| 13 | 134 | 0.446 | 0.046 | 0.044 | 0.012 | 73.636 | 2.271 | 7.735 | 8.061 | -2.315 | -7.277 | 7.636 | 72.351 | 301.945 | 1577.957 |
| 14 | 134 | 0.446 | 0.046 | 0.044 | 0.012 | 72.351 | 2.315 | 7.277 | 7.636 | -2.359 | -6.818 | 7.215 | 70.915 | 339.699 | 1706.529 |
| 15 | 134 | 0.446 | 0.046 | 0.044 | 0.013 | 70.915 | 2.359 | 6.818 | 7.215 | -2.403 | -6.359 | 6.798 | 69.301 | 380.325 | 1834.222 |
| 16 | 134 | 0.447 | 0.046 | 0.043 | 0.014 | 69.301 | 2.403 | 6.359 | 6.798 | -2.446 | -5.898 | 6.386 | 67.476 | 424.140 | 1960.856 |
| 17 | 134 | 0.447 | -0.068 | -0.065 | -0.022 | 67.476 | 2.446 | 5.898 | 6.386 | -2.381 | -5.474 | 5.969 | 66.487 | 471.504 | 2086.206 |
| 18 | 134 | 0.447 | -0.068 | -0.064 | -0.023 | 66.487 | 2.381 | 5.474 | 5.969 | -2.317 | -5.050 | 5.556 | 65.351 | 522.836 | 2209.984 |
| 19 | 134 | 0.448 | -0.068 | -0.064 | -0.025 | 65.351 | 2.317 | 5.050 | 5.556 | -2.253 | -4.627 | 5.146 | 64.033 | 576.296 | 2332.859 |
| 20 | 134 | 0.448 | -0.068 | -0.063 | -0.027 | 64.033 | 2.253 | 4.627 | 5.146 | -2.190 | -4.205 | 4.742 | 62.487 | 632.181 | 2454.649 |
| 21 | 134 | 0.449 | -0.068 | -0.062 | -0.028 | 62.487 | 2.190 | 4.205 | 4.742 | -2.128 | -3.785 | 4.343 | 60.654 | 690.854 | 2575.121 |
| 22 | 134 | 0.449 | -0.068 | -0.061 | -0.031 | 60.654 | 2.128 | 3.785 | 4.343 | -2.067 | -3.367 | 3.951 | 58.451 | 752.755 | 2693.966 |
| 23 | 134 | 0.450 | -0.068 | -0.060 | -0.033 | 58.451 | 2.067 | 3.367 | 3.951 | -2.007 | -2.950 | 3.568 | 55.768 | 818.427 | 2810.770 |
| 24 | 134 | 0.451 | -0.068 | -0.058 | -0.036 | 55.768 | 2.007 | 2.950 | 3.568 | -1.949 | -2.536 | 3.198 | 52.449 | 888.539 | 2924.964 |
| 25 | 134 | 0.452 | -0.068 | -0.056 | -0.039 | 52.449 | 1.949 | 2.536 | 3.198 | -1.893 | -2.123 | 2.845 | 48.279 | 963.920 | 3035.751 |
| 26 | 134 | 0.453 | -0.068 | -0.053 | -0.043 | 48.279 | 1.893 | 2.123 | 2.845 | -1.840 | -1.714 | 2.515 | 42.966 | 1045.590 | 3141.987 |
| 27 | 134 | 0.454 | -0.068 | -0.049 | -0.047 | 42.966 | 1.840 | 1.714 | 2.515 | -1.791 | -1.308 | 2.217 | 36.137 | 1134.768 | 3242.003 |
| 28 | 134 | 0.455 | -0.068 | -0.044 | -0.052 | 36.137 | 1.791 | 1.308 | 2.217 | -1.746 | -0.905 | 1.967 | 27.391 | 1232.823 | 3333.333 |
| 29 | 134 | 0.456 | -0.068 | -0.038 | -0.057 | 27.391 | 1.746 | 0.905 | 1.967 | -1.708 | -0.506 | 1.782 | 16.495 | 1341.042 | 3412.356 |
| 30 | 134 | 0.457 | -0.068 | -0.029 | -0.062 | 16.495 | 1.708 | 0.506 | 1.782 | -1.679 | -0.111 | 1.683 | 3.778 | 1460.019 | 3474.004 |
| 31 | 134 | 0.457 | -0.068 | -0.019 | -0.066 | 3.778 | 1.679 | 0.111 | 1.683 | -1.660 | 0.281 | 1.684 | -9.595 | 1588.504 | 3512.051 |
| 32 | 134 | 0.457 | -0.068 | -0.006 | -0.068 | -9.595 | 1.660 | -0.281 | 1.684 | -1.654 | 0.670 | 1.785 | -22.054 | 1722.213 | 3520.881 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 134 | 0.457 | -0.068 | 0.006 | -0.068 | -22.054 | 1.654 | -0.670 | 1.785 | -1.660 | 1.059 | 1.970 | -32.538 | 1854.338 | 3498.544 |
| 34 | 134 | 0.457 | -0.068 | 0.019 | -0.066 | -32.538 | 1.660 | -1.059 | 1.970 | -1.679 | 1.450 | 2.219 | -40.819 | 1978.534 | 3448.230 |
| 35 | 134 | 0.456 | -0.068 | 0.029 | -0.062 | -40.819 | 1.679 | -1.450 | 2.219 | -1.708 | 1.845 | 2.514 | -47.193 | 2091.501 | 3376.158 |
| 36 | 134 | 0.455 | -0.068 | 0.038 | -0.057 | -47.193 | 1.708 | -1.845 | 2.514 | -1.746 | 2.242 | 2.842 | -52.088 | 2192.909 | 3288.566 |
| 37 | 134 | 0.454 | -0.068 | 0.044 | -0.052 | -52.088 | 1.746 | -2.242 | 2.842 | -1.791 | 2.644 | 3.193 | -55.890 | 2283.967 | 3190.258 |
| 38 | 134 | 0.453 | -0.068 | 0.049 | -0.047 | -55.890 | 1.791 | -2.644 | 3.193 | -1.840 | 3.049 | 3.561 | -58.889 | 2366.302 | 3084.537 |
| 39 | 134 | 0.452 | -0.068 | 0.053 | -0.043 | -58.889 | 1.840 | -3.049 | 3.561 | -1.893 | 3.458 | 3.942 | -61.296 | 2441.447 | 2973.590 |
| 40 | 134 | 0.451 | -0.068 | 0.056 | -0.039 | -61.296 | 1.893 | -3.458 | 3.942 | -1.949 | 3.869 | 4.332 | -63.260 | 2510.684 | 2858.863 |
| 41 | 134 | 0.450 | -0.068 | 0.058 | -0.036 | -63.260 | 1.949 | -3.869 | 4.332 | -2.007 | 4.283 | 4.730 | -64.887 | 2575.041 | 2741.329 |
| 42 | 134 | 0.449 | -0.068 | 0.060 | -0.033 | -64.887 | 2.007 | -4.283 | 4.730 | -2.067 | 4.699 | 5.133 | -66.254 | 2635.333 | 2621.659 |
| 43 | 134 | 0.449 | -0.068 | 0.061 | -0.031 | -66.254 | 2.067 | -4.699 | 5.133 | -2.128 | 5.117 | 5.542 | -67.415 | 2692.203 | 2500.326 |
| 44 | 134 | 0.448 | -0.068 | 0.062 | -0.028 | -67.415 | 2.128 | -5.117 | 5.542 | -2.190 | 5.536 | 5.954 | -68.414 | 2746.163 | 2377.671 |
| 45 | 134 | 0.448 | -0.068 | 0.063 | -0.027 | -68.414 | 2.190 | -5.536 | 5.954 | -2.253 | 5.957 | 6.369 | -69.280 | 2797.626 | 2253.947 |
| 46 | 134 | 0.447 | -0.068 | 0.064 | -0.025 | -69.280 | 2.253 | -5.957 | 6.369 | -2.317 | 6.380 | 6.787 | -70.039 | 2846.925 | 2129.345 |
| 47 | 134 | 0.447 | -0.068 | 0.064 | -0.023 | -70.039 | 2.317 | -6.380 | 6.787 | -2.381 | 6.803 | 7.208 | -70.708 | 2894.334 | 2004.012 |
| 48 | 134 | 0.447 | -0.023 | 0.022 | -0.007 | -70.708 | 2.381 | -6.803 | 7.208 | -2.403 | 7.242 | 7.631 | -71.644 | 2940.080 | 1878.062 |
| 49 | 134 | 0.446 | -0.023 | 0.022 | -0.007 | -71.644 | 2.403 | -7.242 | 7.631 | -2.425 | 7.682 | 8.055 | -72.482 | 2984.352 | 1751.587 |
| 50 | 134 | 0.446 | -0.023 | 0.022 | -0.007 | -72.482 | 2.425 | -7.682 | 8.055 | -2.447 | 8.121 | 8.482 | -73.235 | 3026.551 | 1624.405 |
| 51 | 134 | 0.446 | -0.023 | 0.022 | -0.006 | -73.235 | 2.447 | -8.121 | 8.482 | -2.468 | 8.561 | 8.910 | -73.915 | 3066.886 | 1496.620 |
| 52 | 134 | 0.446 | -0.023 | 0.022 | -0.006 | -73.915 | 2.468 | -8.561 | 8.910 | -2.490 | 9.000 | 9.339 | -74.533 | 3105.538 | 1368.315 |
| 53 | 134 | 0.445 | -0.023 | 0.022 | -0.006 | -74.533 | 2.490 | -9.000 | 9.339 | -2.513 | 9.440 | 9.769 | -75.096 | 3142.664 | 1239.561 |
| 54 | 134 | 0.445 | -0.023 | 0.022 | -0.005 | -75.096 | 2.513 | -9.440 | 9.769 | -2.535 | 9.880 | 10.200 | -75.611 | 3178.400 | 1110.414 |
| 55 | 134 | 0.445 | -0.023 | 0.022 | -0.005 | -75.611 | 2.535 | -9.880 | 10.200 | -2.557 | 10.320 | 10.632 | -76.084 | 3212.865 | 980.922 |
| 56 | 134 | 0.445 | -0.023 | 0.022 | -0.005 | -76.084 | 2.557 | -10.320 | 10.632 | -2.579 | 10.760 | 11.065 | -76.520 | 3246.164 | 851.126 |
| 57 | 134 | 0.445 | -0.023 | 0.022 | -0.005 | -76.520 | 2.579 | -10.760 | 11.065 | -2.601 | 11.200 | 11.498 | -76.923 | 3278.390 | 721.058 |
| 58 | 134 | 0.445 | -0.023 | 0.022 | -0.005 | -76.923 | 2.601 | -11.200 | 11.498 | -2.624 | 11.640 | 11.932 | -77.297 | 3309.625 | 590.750 |
| 59 | 134 | 0.445 | -0.023 | 0.022 | -0.004 | -77.297 | 2.624 | -11.640 | 11.932 | -2.646 | 12.080 | 12.366 | -77.644 | 3339.943 | 460.224 |
| 60 | 134 | 0.444 | -0.023 | 0.022 | -0.004 | -77.644 | 2.646 | -12.080 | 12.366 | -2.669 | 12.520 | 12.801 | -77.968 | 3369.409 | 329.504 |
| 61 | 134 | 0.444 | -0.023 | 0.022 | -0.004 | -77.968 | 2.669 | -12.520 | 12.801 | -2.691 | 12.960 | 13.237 | -78.270 | 3398.082 | 198.608 |
| 62 | 134 | 0.444 | -0.023 | 0.022 | -0.004 | -78.270 | 2.691 | -12.960 | 13.237 | -2.713 | 13.401 | 13.672 | -78.553 | 3426.015 | 67.552 |
| 63 | 134 | 0.444 | -0.023 | 0.022 | -0.004 | -78.553 | 2.713 | -13.401 | 13.672 | -2.736 | 13.841 | 14.109 | -78.819 | 3453.256 | -63.650 |
| | | | | | | | | | | | | | | 3479.849 | -194.985 |

| Segment no. | Height of Segment | DL + LL(F) | Wind Load (Cpi=-0.2) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 132.3 | 0.444 | 0.057 | 0.056 | 0.009 | 83.200 | 1.598 | 13.401 | 13.496 | -1.654 | -12.947 | 13.052 | 82.719 | 0 | 0 |
| 2 | 132.3 | 0.444 | 0.057 | 0.056 | 0.010 | 82.719 | 1.654 | 12.947 | 13.052 | -1.710 | -12.493 | 12.610 | 82.205 | 15.665 | 131.369 |
| 3 | 132.3 | 0.444 | 0.057 | 0.056 | 0.010 | 82.205 | 1.710 | 12.493 | 12.610 | -1.766 | -12.039 | 12.168 | 81.653 | 32.431 | 262.603 |
| 4 | 132.3 | 0.444 | 0.057 | 0.056 | 0.010 | 81.653 | 1.766 | 12.039 | 12.168 | -1.822 | -11.584 | 11.726 | 81.059 | 50.376 | 393.680 |
| 5 | 132.3 | 0.445 | 0.057 | 0.056 | 0.011 | 81.059 | 1.822 | 11.584 | 11.726 | -1.878 | -11.129 | 11.286 | 80.419 | 69.582 | 524.578 |
| 6 | 132.3 | 0.445 | 0.057 | 0.056 | 0.011 | 80.419 | 1.878 | 11.129 | 11.286 | -1.934 | -10.673 | 10.847 | 79.727 | 90.144 | 655.271 |
| 7 | 132.3 | 0.445 | 0.057 | 0.056 | 0.012 | 79.727 | 1.934 | 10.673 | 10.847 | -1.990 | -10.217 | 10.409 | 78.977 | 112.163 | 785.726 |
| 8 | 132.3 | 0.445 | 0.057 | 0.056 | 0.012 | 78.977 | 1.990 | 10.217 | 10.409 | -2.046 | -9.760 | 9.972 | 78.161 | 135.757 | 915.905 |
| 9 | 132.3 | 0.445 | 0.057 | 0.056 | 0.012 | 78.161 | 2.046 | 9.760 | 9.972 | -2.101 | -9.302 | 9.537 | 77.270 | 161.053 | 1045.764 |
| 10 | 132.3 | 0.445 | 0.057 | 0.055 | 0.013 | 77.270 | 2.101 | 9.302 | 9.537 | -2.157 | -8.844 | 9.103 | 76.293 | 188.197 | 1175.250 |
| 11 | 132.3 | 0.445 | 0.057 | 0.055 | 0.014 | 76.293 | 2.157 | 8.844 | 9.103 | -2.212 | -8.385 | 8.672 | 75.219 | 217.351 | 1304.297 |
| 12 | 132.3 | 0.446 | 0.057 | 0.055 | 0.014 | 75.219 | 2.212 | 8.385 | 8.672 | -2.268 | -7.925 | 8.243 | 74.033 | 248.699 | 1432.830 |
| 13 | 132.3 | 0.446 | 0.057 | 0.055 | 0.015 | 74.033 | 2.268 | 7.925 | 8.243 | -2.323 | -7.464 | 7.817 | 72.716 | 282.452 | 1560.752 |
| 14 | 132.3 | 0.446 | 0.057 | 0.055 | 0.016 | 72.716 | 2.323 | 7.464 | 7.817 | -2.377 | -7.003 | 7.395 | 71.248 | 318.845 | 1687.948 |
| 15 | 132.3 | 0.446 | 0.057 | 0.055 | 0.016 | 71.248 | 2.377 | 7.003 | 7.395 | -2.432 | -6.540 | 6.978 | 69.602 | 358.152 | 1814.274 |
| 16 | 132.3 | 0.447 | 0.057 | 0.054 | 0.017 | 69.602 | 2.432 | 6.540 | 6.978 | -2.486 | -6.076 | 6.565 | 67.746 | 400.683 | 1939.551 |
| 17 | 132.3 | 0.447 | -0.057 | -0.054 | -0.018 | 67.746 | 2.486 | 6.076 | 6.565 | -2.432 | -5.648 | 6.149 | 66.699 | 446.795 | 2063.555 |
| 18 | 132.3 | 0.447 | -0.057 | -0.054 | -0.019 | 66.699 | 2.432 | 5.648 | 6.149 | -2.379 | -5.220 | 5.736 | 65.500 | 496.898 | 2186.001 |
| 19 | 132.3 | 0.448 | -0.057 | -0.053 | -0.021 | 65.500 | 2.379 | 5.220 | 5.736 | -2.326 | -4.793 | 5.327 | 64.116 | 549.231 | 2307.510 |
| 20 | 132.3 | 0.448 | -0.057 | -0.053 | -0.022 | 64.116 | 2.326 | 4.793 | 5.327 | -2.273 | -4.367 | 4.923 | 62.501 | 604.094 | 2427.899 |
| 21 | 132.3 | 0.449 | -0.057 | -0.052 | -0.024 | 62.501 | 2.273 | 4.367 | 4.923 | -2.221 | -3.942 | 4.525 | 60.599 | 661.850 | 2546.926 |
| 22 | 132.3 | 0.449 | -0.057 | -0.051 | -0.026 | 60.599 | 2.221 | 3.942 | 4.525 | -2.170 | -3.518 | 4.134 | 58.331 | 722.937 | 2664.279 |
| 23 | 132.3 | 0.450 | -0.057 | -0.050 | -0.028 | 58.331 | 2.170 | 3.518 | 4.134 | -2.121 | -3.096 | 3.753 | 55.593 | 787.885 | 2779.539 |
| 24 | 132.3 | 0.451 | -0.057 | -0.048 | -0.030 | 55.593 | 2.121 | 3.096 | 3.753 | -2.072 | -2.676 | 3.384 | 52.244 | 857.344 | 2892.139 |
| 25 | 132.3 | 0.452 | -0.057 | -0.047 | -0.033 | 52.244 | 2.072 | 2.676 | 3.384 | -2.025 | -2.257 | 3.032 | 48.092 | 932.103 | 3001.293 |
| 26 | 132.3 | 0.453 | -0.057 | -0.044 | -0.036 | 48.092 | 2.025 | 2.257 | 3.032 | -1.981 | -1.840 | 2.704 | 42.887 | 1013.110 | 3105.892 |
| 27 | 132.3 | 0.454 | -0.057 | -0.041 | -0.039 | 42.887 | 1.981 | 1.840 | 2.704 | -1.940 | -1.426 | 2.408 | 36.318 | 1101.477 | 3204.353 |
| 28 | 132.3 | 0.455 | -0.057 | -0.037 | -0.043 | 36.318 | 1.940 | 1.426 | 2.408 | -1.903 | -1.015 | 2.157 | 28.064 | 1198.413 | 3294.391 |
| 29 | 132.3 | 0.456 | -0.057 | -0.032 | -0.047 | 28.064 | 1.903 | 1.015 | 2.157 | -1.872 | -0.606 | 1.967 | 17.947 | 1305.013 | 3372.747 |
| 30 | 132.3 | 0.457 | -0.057 | -0.024 | -0.051 | 17.947 | 1.872 | 0.606 | 1.967 | -1.847 | -0.201 | 1.858 | 6.206 | 1421.757 | 3434.989 |
| 31 | 132.3 | 0.457 | -0.057 | -0.016 | -0.055 | 6.206 | 1.847 | 0.201 | 1.858 | -1.831 | 0.202 | 1.843 | -6.285 | 1547.620 | 3475.756 |
| 32 | 132.3 | 0.457 | -0.057 | -0.005 | -0.057 | -6.285 | 1.831 | -0.202 | 1.843 | -1.826 | 0.602 | 1.923 | -18.257 | 1679.144 | 3490.057 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 132.3 | 0.457 | -0.057 | 0.005 | -0.057 | -18.257 | 1.826 | -0.602 | 1.923 | -1.831 | 1.003 | 2.088 | -28.708 | 1810.649 | 3475.574 |
| 34 | 132.3 | 0.457 | -0.057 | 0.016 | -0.055 | -28.708 | 1.831 | -1.003 | 2.088 | -1.847 | 1.405 | 2.321 | -37.260 | 1936.289 | 3434.126 |
| 35 | 132.3 | 0.456 | -0.057 | 0.024 | -0.051 | -37.260 | 1.847 | -1.405 | 2.321 | -1.872 | 1.809 | 2.603 | -44.035 | 2052.326 | 3370.575 |
| 36 | 132.3 | 0.455 | -0.057 | 0.032 | -0.047 | -44.035 | 1.872 | -1.809 | 2.603 | -1.903 | 2.217 | 2.922 | -49.355 | 2157.623 | 3290.476 |
| 37 | 132.3 | 0.454 | -0.057 | 0.037 | -0.043 | -49.355 | 1.903 | -2.217 | 2.922 | -1.940 | 2.627 | 3.266 | -53.554 | 2252.736 | 3198.515 |
| 38 | 132.3 | 0.453 | -0.057 | 0.041 | -0.039 | -53.554 | 1.940 | -2.627 | 3.266 | -1.981 | 3.040 | 3.629 | -56.908 | 2338.913 | 3098.131 |
| 39 | 132.3 | 0.452 | -0.057 | 0.044 | -0.036 | -56.908 | 1.981 | -3.040 | 3.629 | -2.025 | 3.456 | 4.006 | -59.625 | 2417.506 | 2991.706 |
| 40 | 132.3 | 0.451 | -0.057 | 0.047 | -0.033 | -59.625 | 2.025 | -3.456 | 4.006 | -2.072 | 3.874 | 4.393 | -61.856 | 2489.740 | 2880.866 |
| 41 | 132.3 | 0.450 | -0.057 | 0.048 | -0.030 | -61.856 | 2.072 | -3.874 | 4.393 | -2.121 | 4.293 | 4.789 | -63.715 | 2556.639 | 2766.726 |
| 42 | 132.3 | 0.449 | -0.057 | 0.050 | -0.028 | -63.715 | 2.121 | -4.293 | 4.789 | -2.170 | 4.715 | 5.190 | -65.283 | 2619.042 | 2650.068 |
| 43 | 132.3 | 0.449 | -0.057 | 0.051 | -0.026 | -65.283 | 2.170 | -4.715 | 5.190 | -2.221 | 5.138 | 5.598 | -66.620 | 2677.629 | 2531.448 |
| 44 | 132.3 | 0.448 | -0.057 | 0.052 | -0.024 | -66.620 | 2.221 | -5.138 | 5.598 | -2.273 | 5.562 | 6.009 | -67.772 | 2732.949 | 2411.269 |
| 45 | 132.3 | 0.448 | -0.057 | 0.053 | -0.022 | -67.772 | 2.273 | -5.562 | 6.009 | -2.326 | 5.988 | 6.424 | -68.774 | 2785.450 | 2289.831 |
| 46 | 132.3 | 0.447 | -0.057 | 0.053 | -0.021 | -68.774 | 2.326 | -5.988 | 6.424 | -2.379 | 6.414 | 6.841 | -69.653 | 2835.498 | 2167.363 |
| 47 | 132.3 | 0.447 | -0.057 | 0.054 | -0.019 | -69.653 | 2.379 | -6.414 | 6.841 | -2.432 | 6.842 | 7.261 | -70.429 | 2883.396 | 2044.038 |
| 48 | 132.3 | 0.447 | -0.011 | 0.011 | -0.004 | -70.429 | 2.432 | -6.842 | 7.261 | -2.443 | 7.285 | 7.683 | -71.460 | 2929.397 | 1919.993 |
| 49 | 132.3 | 0.446 | -0.011 | 0.011 | -0.003 | -71.460 | 2.443 | -7.285 | 7.683 | -2.454 | 7.728 | 8.108 | -72.382 | 2973.713 | 1795.336 |
| 50 | 132.3 | 0.446 | -0.011 | 0.011 | -0.003 | -72.382 | 2.454 | -7.728 | 8.108 | -2.465 | 8.170 | 8.534 | -73.212 | 3015.780 | 1669.902 |
| 51 | 132.3 | 0.446 | -0.011 | 0.011 | -0.003 | -73.212 | 2.465 | -8.170 | 8.534 | -2.476 | 8.613 | 8.962 | -73.963 | 3055.823 | 1543.807 |
| 52 | 132.3 | 0.446 | -0.011 | 0.011 | -0.003 | -73.963 | 2.476 | -8.613 | 8.962 | -2.487 | 9.056 | 9.391 | -74.644 | 3094.035 | 1417.146 |
| 53 | 132.3 | 0.445 | -0.011 | 0.011 | -0.003 | -74.644 | 2.487 | -9.056 | 9.391 | -2.498 | 9.498 | 9.821 | -75.266 | 3130.584 | 1289.995 |
| 54 | 132.3 | 0.445 | -0.011 | 0.011 | -0.003 | -75.266 | 2.498 | -9.498 | 9.821 | -2.509 | 9.941 | 10.252 | -75.835 | 3165.619 | 1162.418 |
| 55 | 132.3 | 0.445 | -0.011 | 0.011 | -0.003 | -75.835 | 2.509 | -9.941 | 10.252 | -2.520 | 10.383 | 10.685 | -76.358 | 3199.268 | 1034.468 |
| 56 | 132.3 | 0.445 | -0.011 | 0.011 | -0.002 | -76.358 | 2.520 | -10.383 | 10.685 | -2.531 | 10.826 | 11.118 | -76.840 | 3231.644 | 906.191 |
| 57 | 132.3 | 0.445 | -0.011 | 0.011 | -0.002 | -76.840 | 2.531 | -10.826 | 11.118 | -2.542 | 11.268 | 11.551 | -77.286 | 3262.847 | 777.623 |
| 58 | 132.3 | 0.445 | -0.011 | 0.011 | -0.002 | -77.286 | 2.542 | -11.268 | 11.551 | -2.553 | 11.710 | 11.986 | -77.699 | 3292.968 | 648.798 |
| 59 | 132.3 | 0.445 | -0.011 | 0.011 | -0.002 | -77.699 | 2.553 | -11.710 | 11.986 | -2.565 | 12.153 | 12.420 | -78.083 | 3322.086 | 519.742 |
| 60 | 132.3 | 0.444 | -0.011 | 0.011 | -0.002 | -78.083 | 2.565 | -12.153 | 12.420 | -2.576 | 12.595 | 12.856 | -78.442 | 3350.272 | 390.479 |
| 61 | 132.3 | 0.444 | -0.011 | 0.011 | -0.002 | -78.442 | 2.576 | -12.595 | 12.856 | -2.587 | 13.037 | 13.291 | -78.776 | 3377.590 | 261.030 |
| 62 | 132.3 | 0.444 | -0.011 | 0.011 | -0.002 | -78.776 | 2.587 | -13.037 | 13.291 | -2.598 | 13.480 | 13.728 | -79.090 | 3404.098 | 131.413 |
| 63 | 132.3 | 0.444 | -0.011 | 0.011 | -0.002 | -79.090 | 2.598 | -13.480 | 13.728 | -2.610 | 13.922 | 14.164 | -79.384 | 3429.849 | 1.644 |
| | | | | | | | | | | | | | | 3454.890 | -128.265 |

| Segment no. | Height of Segment | DL + LL(L) | Wind Load (Cpi=0) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 134.5 | 0.444 | 0.046 | 0.045 | 0.008 | 82.600 | 1.705 | 13.130 | 13.240 | -1.750 | -12.678 | 12.798 | 82.140 | 0 | 0 |
| 2 | 134.5 | 0.444 | 0.046 | 0.045 | 0.008 | 82.140 | 1.750 | 12.678 | 12.798 | -1.795 | -12.226 | 12.357 | 81.647 | 17.323 | 133.380 |
| 3 | 134.5 | 0.444 | 0.046 | 0.045 | 0.008 | 81.647 | 1.795 | 12.226 | 12.357 | -1.840 | -11.774 | 11.917 | 81.117 | 35.717 | 266.616 |
| 4 | 134.5 | 0.444 | 0.046 | 0.045 | 0.008 | 81.117 | 1.840 | 11.774 | 11.917 | -1.885 | -11.321 | 11.477 | 80.547 | 55.256 | 399.689 |
| 5 | 134.5 | 0.445 | 0.046 | 0.045 | 0.009 | 80.547 | 1.885 | 11.321 | 11.477 | -1.930 | -10.868 | 11.038 | 79.932 | 76.024 | 532.576 |
| 6 | 134.5 | 0.445 | 0.046 | 0.045 | 0.009 | 79.932 | 1.930 | 10.868 | 11.038 | -1.974 | -10.414 | 10.600 | 79.265 | 98.113 | 665.250 |
| 7 | 134.5 | 0.445 | 0.046 | 0.045 | 0.009 | 79.265 | 1.974 | 10.414 | 10.600 | -2.019 | -9.960 | 10.163 | 78.541 | 121.627 | 797.679 |
| 8 | 134.5 | 0.445 | 0.046 | 0.045 | 0.010 | 78.541 | 2.019 | 9.960 | 10.163 | -2.064 | -9.506 | 9.727 | 77.752 | 146.680 | 929.825 |
| 9 | 134.5 | 0.445 | 0.046 | 0.044 | 0.010 | 77.752 | 2.064 | 9.506 | 9.727 | -2.108 | -9.051 | 9.293 | 76.888 | 173.401 | 1061.644 |
| 10 | 134.5 | 0.445 | 0.046 | 0.044 | 0.010 | 76.888 | 2.108 | 9.051 | 9.293 | -2.152 | -8.595 | 8.860 | 75.940 | 201.935 | 1193.082 |
| 11 | 134.5 | 0.445 | 0.046 | 0.044 | 0.011 | 75.940 | 2.152 | 8.595 | 8.860 | -2.197 | -8.139 | 8.430 | 74.895 | 232.447 | 1324.076 |
| 12 | 134.5 | 0.446 | 0.046 | 0.044 | 0.011 | 74.895 | 2.197 | 8.139 | 8.430 | -2.241 | -7.682 | 8.002 | 73.737 | 265.121 | 1454.546 |
| 13 | 134.5 | 0.446 | 0.046 | 0.044 | 0.012 | 73.737 | 2.241 | 7.682 | 8.002 | -2.285 | -7.224 | 7.577 | 72.448 | 300.171 | 1584.399 |
| 14 | 134.5 | 0.446 | 0.046 | 0.044 | 0.012 | 72.448 | 2.285 | 7.224 | 7.577 | -2.329 | -6.766 | 7.155 | 71.006 | 337.838 | 1713.517 |
| 15 | 134.5 | 0.446 | 0.046 | 0.044 | 0.013 | 71.006 | 2.329 | 6.766 | 7.155 | -2.372 | -6.306 | 6.738 | 69.383 | 378.399 | 1841.755 |
| 16 | 134.5 | 0.447 | 0.046 | 0.043 | 0.014 | 69.383 | 2.372 | 6.306 | 6.738 | -2.416 | -5.846 | 6.325 | 67.545 | 422.176 | 1968.932 |
| 17 | 134.5 | 0.447 | -0.068 | -0.065 | -0.022 | 67.545 | 2.416 | 5.846 | 6.325 | -2.351 | -5.421 | 5.909 | 66.552 | 469.537 | 2094.818 |
| 18 | 134.5 | 0.447 | -0.068 | -0.064 | -0.023 | 66.552 | 2.351 | 5.421 | 5.909 | -2.287 | -4.997 | 5.495 | 65.408 | 520.909 | 2219.120 |
| 19 | 134.5 | 0.448 | -0.068 | -0.064 | -0.025 | 65.408 | 2.287 | 4.997 | 5.495 | -2.223 | -4.574 | 5.086 | 64.079 | 574.429 | 2342.513 |
| 20 | 134.5 | 0.448 | -0.068 | -0.063 | -0.027 | 64.079 | 2.223 | 4.574 | 5.086 | -2.160 | -4.153 | 4.681 | 62.517 | 630.402 | 2464.813 |
| 21 | 134.5 | 0.449 | -0.068 | -0.062 | -0.028 | 62.517 | 2.160 | 4.153 | 4.681 | -2.098 | -3.732 | 4.282 | 60.660 | 689.197 | 2585.782 |
| 22 | 134.5 | 0.449 | -0.068 | -0.061 | -0.031 | 60.660 | 2.098 | 3.732 | 4.282 | -2.037 | -3.314 | 3.890 | 58.424 | 751.267 | 2705.103 |
| 23 | 134.5 | 0.450 | -0.068 | -0.060 | -0.033 | 58.424 | 2.037 | 3.314 | 3.890 | -1.977 | -2.897 | 3.508 | 55.691 | 817.171 | 2822.350 |
| 24 | 134.5 | 0.451 | -0.068 | -0.058 | -0.036 | 55.691 | 1.977 | 2.897 | 3.508 | -1.919 | -2.483 | 3.138 | 52.298 | 887.600 | 2936.937 |
| 25 | 134.5 | 0.452 | -0.068 | -0.056 | -0.039 | 52.298 | 1.919 | 2.483 | 3.138 | -1.863 | -2.070 | 2.785 | 48.020 | 963.412 | 3048.035 |
| 26 | 134.5 | 0.453 | -0.068 | -0.053 | -0.043 | 48.020 | 1.863 | 2.070 | 2.785 | -1.810 | -1.661 | 2.457 | 42.545 | 1045.665 | 3154.452 |
| 27 | 134.5 | 0.454 | -0.068 | -0.049 | -0.047 | 42.545 | 1.810 | 1.661 | 2.457 | -1.760 | -1.255 | 2.162 | 35.479 | 1135.629 | 3254.436 |
| 28 | 134.5 | 0.455 | -0.068 | -0.044 | -0.052 | 35.479 | 1.760 | 1.255 | 2.162 | -1.716 | -0.852 | 1.916 | 26.403 | 1234.721 | 3345.381 |
| 29 | 134.5 | 0.456 | -0.068 | -0.038 | -0.057 | 26.403 | 1.716 | 0.852 | 1.916 | -1.678 | -0.453 | 1.738 | 15.108 | 1344.248 | 3423.445 |
| 30 | 134.5 | 0.457 | -0.068 | -0.029 | -0.062 | 15.108 | 1.678 | 0.453 | 1.738 | -1.649 | -0.058 | 1.650 | 2.015 | 1464.718 | 3483.256 |
| 31 | 134.5 | 0.457 | -0.068 | -0.019 | -0.066 | 2.015 | 1.649 | 0.058 | 1.650 | -1.630 | 0.334 | 1.664 | -11.564 | 1594.569 | 3518.311 |
| 32 | 134.5 | 0.457 | -0.068 | -0.006 | -0.068 | -11.564 | 1.630 | -0.334 | 1.664 | -1.624 | 0.723 | 1.777 | -23.998 | 1728.986 | 3523.041 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 134.5 | 0.441 | -0.068 | 0.006 | -0.068 | -23.998 | 1.624 | -0.723 | 1.777 | -1.630 | 1.096 | 1.964 | -33.918 | 1860.756 | 3496.077 |
| 34 | 134.5 | 0.441 | -0.068 | 0.019 | -0.066 | -33.918 | 1.630 | -1.096 | 1.964 | -1.649 | 1.472 | 2.210 | -41.753 | 1983.630 | 3441.376 |
| 35 | 134.5 | 0.441 | -0.068 | 0.029 | -0.062 | -41.753 | 1.649 | -1.472 | 2.210 | -1.678 | 1.851 | 2.499 | -47.810 | 2095.242 | 3366.323 |
| 36 | 134.5 | 0.441 | -0.068 | 0.038 | -0.057 | -47.810 | 1.678 | -1.851 | 2.499 | -1.716 | 2.236 | 2.819 | -52.494 | 2195.583 | 3276.758 |
| 37 | 134.5 | 0.441 | -0.068 | 0.044 | -0.052 | -52.494 | 1.716 | -2.236 | 2.819 | -1.760 | 2.625 | 3.161 | -56.155 | 2285.912 | 3177.104 |
| 38 | 134.5 | 0.441 | -0.068 | 0.049 | -0.047 | -56.155 | 1.760 | -2.625 | 3.161 | -1.810 | 3.019 | 3.520 | -59.062 | 2367.802 | 3070.406 |
| 39 | 134.5 | 0.441 | -0.068 | 0.053 | -0.043 | -59.062 | 1.810 | -3.019 | 3.520 | -1.863 | 3.418 | 3.892 | -61.406 | 2442.710 | 2958.697 |
| 40 | 134.5 | 0.441 | -0.068 | 0.056 | -0.039 | -61.406 | 1.863 | -3.418 | 3.892 | -1.919 | 3.820 | 4.275 | -63.327 | 2511.859 | 2843.334 |
| 41 | 134.5 | 0.441 | -0.068 | 0.058 | -0.036 | -63.327 | 1.919 | -3.820 | 4.275 | -1.977 | 4.225 | 4.665 | -64.924 | 2576.231 | 2725.238 |
| 42 | 134.5 | 0.441 | -0.068 | 0.060 | -0.033 | -64.924 | 1.977 | -4.225 | 4.665 | -2.037 | 4.633 | 5.061 | -66.270 | 2636.607 | 2605.051 |
| 43 | 134.5 | 0.441 | -0.068 | 0.061 | -0.031 | -66.270 | 2.037 | -4.633 | 5.061 | -2.098 | 5.044 | 5.463 | -67.417 | 2693.610 | 2483.228 |
| 44 | 134.5 | 0.441 | -0.068 | 0.062 | -0.028 | -67.417 | 2.098 | -5.044 | 5.463 | -2.160 | 5.457 | 5.869 | -68.404 | 2747.736 | 2360.100 |
| 45 | 134.5 | 0.441 | -0.068 | 0.063 | -0.027 | -68.404 | 2.160 | -5.457 | 5.869 | -2.223 | 5.872 | 6.279 | -69.263 | 2799.388 | 2235.913 |
| 46 | 134.5 | 0.441 | -0.068 | 0.064 | -0.025 | -69.263 | 2.223 | -5.872 | 6.279 | -2.287 | 6.289 | 6.691 | -70.016 | 2848.891 | 2110.854 |
| 47 | 134.5 | 0.441 | -0.068 | 0.064 | -0.023 | -70.016 | 2.287 | -6.289 | 6.691 | -2.351 | 6.707 | 7.107 | -70.681 | 2896.515 | 1985.068 |
| 48 | 134.5 | 0.441 | -0.023 | 0.022 | -0.007 | -70.681 | 2.351 | -6.707 | 7.107 | -2.373 | 7.141 | 7.525 | -71.619 | 2942.482 | 1858.666 |
| 49 | 134.5 | 0.441 | -0.023 | 0.022 | -0.007 | -71.619 | 2.373 | -7.141 | 7.525 | -2.394 | 7.575 | 7.945 | -72.459 | 2986.979 | 1731.740 |
| 50 | 134.5 | 0.441 | -0.023 | 0.022 | -0.007 | -72.459 | 2.394 | -7.575 | 7.945 | -2.416 | 8.010 | 8.366 | -73.214 | 3029.391 | 1604.102 |
| 51 | 134.5 | 0.441 | -0.023 | 0.022 | -0.006 | -73.214 | 2.416 | -8.010 | 8.366 | -2.438 | 8.445 | 8.790 | -73.896 | 3069.929 | 1475.857 |
| 52 | 134.5 | 0.441 | -0.023 | 0.022 | -0.006 | -73.896 | 2.438 | -8.445 | 8.790 | -2.460 | 8.881 | 9.215 | -74.516 | 3108.773 | 1347.088 |
| 53 | 134.5 | 0.441 | -0.023 | 0.022 | -0.006 | -74.516 | 2.460 | -8.881 | 9.215 | -2.482 | 9.316 | 9.641 | -75.080 | 3146.081 | 1217.866 |
| 54 | 134.5 | 0.441 | -0.023 | 0.022 | -0.005 | -75.080 | 2.482 | -9.316 | 9.641 | -2.504 | 9.752 | 10.069 | -75.597 | 3181.989 | 1088.248 |
| 55 | 134.5 | 0.441 | -0.023 | 0.022 | -0.005 | -75.597 | 2.504 | -9.752 | 10.069 | -2.527 | 10.189 | 10.497 | -76.072 | 3216.618 | 958.282 |
| 56 | 134.5 | 0.441 | -0.023 | 0.022 | -0.005 | -76.072 | 2.527 | -10.189 | 10.497 | -2.549 | 10.625 | 10.926 | -76.510 | 3250.073 | 828.009 |
| 57 | 134.5 | 0.441 | -0.023 | 0.022 | -0.005 | -76.510 | 2.549 | -10.625 | 10.926 | -2.571 | 11.062 | 11.357 | -76.915 | 3282.446 | 697.463 |
| 58 | 134.5 | 0.441 | -0.023 | 0.022 | -0.005 | -76.915 | 2.571 | -11.062 | 11.357 | -2.594 | 11.498 | 11.787 | -77.290 | 3313.822 | 566.674 |
| 59 | 134.5 | 0.441 | -0.023 | 0.022 | -0.004 | -77.290 | 2.594 | -11.498 | 11.787 | -2.616 | 11.935 | 12.219 | -77.638 | 3344.273 | 435.667 |
| 60 | 134.5 | 0.441 | -0.023 | 0.022 | -0.004 | -77.638 | 2.616 | -11.935 | 12.219 | -2.638 | 12.373 | 12.651 | -77.963 | 3373.867 | 304.463 |
| 61 | 134.5 | 0.441 | -0.023 | 0.022 | -0.004 | -77.963 | 2.638 | -12.373 | 12.651 | -2.661 | 12.810 | 13.083 | -78.266 | 3402.661 | 173.081 |
| 62 | 134.5 | 0.441 | -0.023 | 0.022 | -0.004 | -78.266 | 2.661 | -12.810 | 13.083 | -2.683 | 13.247 | 13.516 | -78.550 | 3430.711 | 41.538 |
| 63 | 134.5 | 0.441 | -0.023 | 0.022 | -0.004 | -78.550 | 2.683 | -13.247 | 13.516 | -2.706 | 13.685 | 13.950 | -78.816 | 3458.063 | -90.151 |
| | | | | | | | | | | | | | | 3484.763 | -221.974 |

| Segment no. | Height of Segment | DL + LL(L) | Wind Load (Cpi=-0.2) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 132.4 | 0.444 | 0.057 | 0.056 | 0.009 | 83.200 | 1.592 | 13.348 | 13.442 | -1.648 | -12.894 | 12.999 | 82.717 | 0 | 0 |
| 2 | 132.4 | 0.444 | 0.057 | 0.056 | 0.010 | 82.717 | 1.648 | 12.894 | 12.999 | -1.704 | -12.440 | 12.556 | 82.200 | 15.677 | 131.469 |
| 3 | 132.4 | 0.444 | 0.057 | 0.056 | 0.010 | 82.200 | 1.704 | 12.440 | 12.556 | -1.760 | -11.986 | 12.114 | 81.646 | 32.460 | 262.801 |
| 4 | 132.4 | 0.444 | 0.057 | 0.056 | 0.010 | 81.646 | 1.760 | 11.986 | 12.114 | -1.816 | -11.531 | 11.673 | 81.049 | 50.428 | 393.976 |
| 5 | 132.4 | 0.445 | 0.057 | 0.056 | 0.011 | 81.049 | 1.816 | 11.531 | 11.673 | -1.872 | -11.076 | 11.233 | 80.406 | 69.665 | 524.971 |
| 6 | 132.4 | 0.445 | 0.057 | 0.056 | 0.011 | 80.406 | 1.872 | 11.076 | 11.233 | -1.928 | -10.620 | 10.794 | 79.710 | 90.264 | 655.759 |
| 7 | 132.4 | 0.445 | 0.057 | 0.056 | 0.012 | 79.710 | 1.928 | 10.620 | 10.794 | -1.984 | -10.164 | 10.356 | 78.955 | 112.330 | 786.307 |
| 8 | 132.4 | 0.445 | 0.057 | 0.056 | 0.012 | 78.955 | 1.984 | 10.164 | 10.356 | -2.040 | -9.707 | 9.919 | 78.134 | 135.981 | 916.577 |
| 9 | 132.4 | 0.445 | 0.057 | 0.056 | 0.012 | 78.134 | 2.040 | 9.707 | 9.919 | -2.095 | -9.249 | 9.484 | 77.236 | 161.345 | 1046.525 |
| 10 | 132.4 | 0.445 | 0.057 | 0.055 | 0.013 | 77.236 | 2.095 | 9.249 | 9.484 | -2.151 | -8.791 | 9.050 | 76.253 | 188.570 | 1176.096 |
| 11 | 132.4 | 0.445 | 0.057 | 0.055 | 0.014 | 76.253 | 2.151 | 8.791 | 9.050 | -2.206 | -8.332 | 8.619 | 75.170 | 217.821 | 1305.224 |
| 12 | 132.4 | 0.446 | 0.057 | 0.055 | 0.014 | 75.170 | 2.206 | 8.332 | 8.619 | -2.261 | -7.872 | 8.191 | 73.974 | 249.284 | 1433.831 |
| 13 | 132.4 | 0.446 | 0.057 | 0.055 | 0.015 | 73.974 | 2.261 | 7.872 | 8.191 | -2.316 | -7.412 | 7.765 | 72.645 | 283.172 | 1561.821 |
| 14 | 132.4 | 0.446 | 0.057 | 0.055 | 0.016 | 72.645 | 2.316 | 7.412 | 7.765 | -2.371 | -6.950 | 7.343 | 71.162 | 319.725 | 1689.075 |
| 15 | 132.4 | 0.446 | 0.057 | 0.055 | 0.016 | 71.162 | 2.371 | 6.950 | 7.343 | -2.426 | -6.487 | 6.926 | 69.498 | 359.219 | 1815.448 |
| 16 | 132.4 | 0.447 | 0.057 | 0.054 | 0.017 | 69.498 | 2.426 | 6.487 | 6.926 | -2.480 | -6.023 | 6.514 | 67.621 | 401.970 | 1940.756 |
| 17 | 132.4 | 0.447 | -0.057 | -0.054 | -0.018 | 67.621 | 2.480 | 6.023 | 6.514 | -2.426 | -5.595 | 6.098 | 66.557 | 448.342 | 2064.770 |
| 18 | 132.4 | 0.447 | -0.057 | -0.054 | -0.019 | 66.557 | 2.426 | 5.595 | 6.098 | -2.372 | -5.167 | 5.685 | 65.337 | 498.750 | 2187.198 |
| 19 | 132.4 | 0.448 | -0.057 | -0.053 | -0.021 | 65.337 | 2.372 | 5.167 | 5.685 | -2.319 | -4.740 | 5.277 | 63.927 | 551.423 | 2308.670 |
| 20 | 132.4 | 0.448 | -0.057 | -0.053 | -0.022 | 63.927 | 2.319 | 4.740 | 5.277 | -2.267 | -4.314 | 4.873 | 62.280 | 606.670 | 2428.992 |
| 21 | 132.4 | 0.449 | -0.057 | -0.052 | -0.024 | 62.280 | 2.267 | 4.314 | 4.873 | -2.215 | -3.889 | 4.476 | 60.337 | 664.862 | 2547.918 |
| 22 | 132.4 | 0.449 | -0.057 | -0.051 | -0.026 | 60.337 | 2.215 | 3.889 | 4.476 | -2.164 | -3.465 | 4.086 | 58.017 | 726.448 | 2665.123 |
| 23 | 132.4 | 0.450 | -0.057 | -0.050 | -0.028 | 58.017 | 2.164 | 3.465 | 4.086 | -2.114 | -3.043 | 3.706 | 55.212 | 791.973 | 2780.172 |
| 24 | 132.4 | 0.451 | -0.057 | -0.048 | -0.030 | 55.212 | 2.114 | 3.043 | 3.706 | -2.066 | -2.623 | 3.339 | 51.774 | 862.101 | 2892.474 |
| 25 | 132.4 | 0.452 | -0.057 | -0.047 | -0.033 | 51.774 | 2.066 | 2.623 | 3.339 | -2.019 | -2.204 | 2.989 | 47.506 | 937.641 | 3001.210 |
| 26 | 132.4 | 0.453 | -0.057 | -0.044 | -0.036 | 47.506 | 2.019 | 2.204 | 2.989 | -1.975 | -1.787 | 2.664 | 42.146 | 1019.566 | 3105.220 |
| 27 | 132.4 | 0.454 | -0.057 | -0.041 | -0.039 | 42.146 | 1.975 | 1.787 | 2.664 | -1.934 | -1.373 | 2.372 | 35.379 | 1109.005 | 3202.844 |
| 28 | 132.4 | 0.455 | -0.057 | -0.037 | -0.043 | 35.379 | 1.934 | 1.373 | 2.372 | -1.897 | -0.962 | 2.127 | 26.887 | 1207.171 | 3291.688 |
| 29 | 132.4 | 0.456 | -0.057 | -0.032 | -0.047 | 26.887 | 1.897 | 0.962 | 2.127 | -1.865 | -0.553 | 1.946 | 16.523 | 1315.122 | 3368.345 |
| 30 | 132.4 | 0.457 | -0.057 | -0.024 | -0.051 | 16.523 | 1.865 | 0.553 | 1.946 | -1.841 | -0.148 | 1.847 | 4.596 | 1433.209 | 3428.221 |
| 31 | 132.4 | 0.457 | -0.057 | -0.016 | -0.055 | 4.596 | 1.841 | 0.148 | 1.847 | -1.825 | 0.255 | 1.843 | -7.941 | 1560.142 | 3465.876 |
| 32 | 132.4 | 0.457 | -0.057 | -0.005 | -0.057 | -7.941 | 1.825 | -0.255 | 1.843 | -1.820 | 0.655 | 1.934 | -19.801 | 1692.116 | 3476.485 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 132.4 | 0.441 | -0.057 | 0.005 | -0.057 | -19.801 | 1.820 | -0.655 | 1.934 | -1.825 | 1.040 | 2.101 | -29.672 | 1823.247 | 3458.195 |
| 34 | 132.4 | 0.441 | -0.057 | 0.016 | -0.055 | -29.672 | 1.825 | -1.040 | 2.101 | -1.841 | 1.426 | 2.329 | -37.774 | 1947.818 | 3413.343 |
| 35 | 132.4 | 0.441 | -0.057 | 0.024 | -0.051 | -37.774 | 1.841 | -1.426 | 2.329 | -1.865 | 1.816 | 2.604 | -44.241 | 2062.857 | 3347.799 |
| 36 | 132.4 | 0.441 | -0.057 | 0.032 | -0.047 | -44.241 | 1.865 | -1.816 | 2.604 | -1.897 | 2.210 | 2.913 | -49.367 | 2167.510 | 3266.698 |
| 37 | 132.4 | 0.441 | -0.057 | 0.037 | -0.043 | -49.367 | 1.897 | -2.210 | 2.913 | -1.934 | 2.608 | 3.247 | -53.449 | 2262.363 | 3174.326 |
| 38 | 132.4 | 0.441 | -0.057 | 0.041 | -0.039 | -53.449 | 1.934 | -2.608 | 3.247 | -1.975 | 3.010 | 3.600 | -56.735 | 2348.584 | 3073.848 |
| 39 | 132.4 | 0.441 | -0.057 | 0.044 | -0.036 | -56.735 | 1.975 | -3.010 | 3.600 | -2.019 | 3.416 | 3.968 | -59.413 | 2427.433 | 2967.487 |
| 40 | 132.4 | 0.441 | -0.057 | 0.047 | -0.033 | -59.413 | 2.019 | -3.416 | 3.968 | -2.066 | 3.825 | 4.347 | -61.625 | 2500.057 | 2856.783 |
| 41 | 132.4 | 0.441 | -0.057 | 0.048 | -0.030 | -61.625 | 2.066 | -3.825 | 4.347 | -2.114 | 4.236 | 4.734 | -63.476 | 2567.428 | 2742.805 |
| 42 | 132.4 | 0.441 | -0.057 | 0.050 | -0.028 | -63.476 | 2.114 | -4.236 | 4.734 | -2.164 | 4.650 | 5.129 | -65.042 | 2630.350 | 2626.312 |
| 43 | 132.4 | 0.441 | -0.057 | 0.051 | -0.026 | -65.042 | 2.164 | -4.650 | 5.129 | -2.215 | 5.066 | 5.529 | -66.382 | 2689.476 | 2507.848 |
| 44 | 132.4 | 0.441 | -0.057 | 0.052 | -0.024 | -66.382 | 2.215 | -5.066 | 5.529 | -2.267 | 5.483 | 5.933 | -67.540 | 2745.343 | 2387.812 |
| 45 | 132.4 | 0.441 | -0.057 | 0.053 | -0.022 | -67.540 | 2.267 | -5.483 | 5.933 | -2.319 | 5.903 | 6.342 | -68.548 | 2798.387 | 2266.502 |
| 46 | 132.4 | 0.441 | -0.057 | 0.053 | -0.021 | -68.548 | 2.319 | -5.903 | 6.342 | -2.372 | 6.323 | 6.754 | -69.434 | 2848.970 | 2144.145 |
| 47 | 132.4 | 0.441 | -0.057 | 0.054 | -0.019 | -69.434 | 2.372 | -6.323 | 6.754 | -2.426 | 6.745 | 7.168 | -70.218 | 2897.390 | 2020.917 |
| 48 | 132.4 | 0.441 | -0.011 | 0.011 | -0.004 | -70.218 | 2.426 | -6.745 | 7.168 | -2.437 | 7.183 | 7.585 | -71.261 | 2943.900 | 1896.955 |
| 49 | 132.4 | 0.441 | -0.011 | 0.011 | -0.003 | -71.261 | 2.437 | -7.183 | 7.585 | -2.448 | 7.621 | 8.004 | -72.194 | 2988.709 | 1772.368 |
| 50 | 132.4 | 0.441 | -0.011 | 0.011 | -0.003 | -72.194 | 2.448 | -7.621 | 8.004 | -2.459 | 8.059 | 8.426 | -73.035 | 3031.244 | 1646.986 |
| 51 | 132.4 | 0.441 | -0.011 | 0.011 | -0.003 | -73.035 | 2.459 | -8.059 | 8.426 | -2.470 | 8.497 | 8.849 | -73.795 | 3071.731 | 1520.928 |
| 52 | 132.4 | 0.441 | -0.011 | 0.011 | -0.003 | -73.795 | 2.470 | -8.497 | 8.849 | -2.481 | 8.936 | 9.274 | -74.486 | 3110.364 | 1394.290 |
| 53 | 132.4 | 0.441 | -0.011 | 0.011 | -0.003 | -74.486 | 2.481 | -8.936 | 9.274 | -2.492 | 9.374 | 9.700 | -75.116 | 3147.313 | 1267.151 |
| 54 | 132.4 | 0.441 | -0.011 | 0.011 | -0.003 | -75.116 | 2.492 | -9.374 | 9.700 | -2.503 | 9.813 | 10.127 | -75.693 | 3182.728 | 1139.575 |
| 55 | 132.4 | 0.441 | -0.011 | 0.011 | -0.003 | -75.693 | 2.503 | -9.813 | 10.127 | -2.514 | 10.252 | 10.556 | -76.223 | 3216.737 | 1011.617 |
| 56 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -76.223 | 2.514 | -10.252 | 10.556 | -2.525 | 10.691 | 10.985 | -76.712 | 3249.455 | 883.324 |
| 57 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -76.712 | 2.525 | -10.691 | 10.985 | -2.536 | 11.130 | 11.415 | -77.164 | 3280.985 | 754.733 |
| 58 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -77.164 | 2.536 | -11.130 | 11.415 | -2.547 | 11.569 | 11.846 | -77.583 | 3311.417 | 625.878 |
| 59 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -77.583 | 2.547 | -11.569 | 11.846 | -2.558 | 12.008 | 12.278 | -77.973 | 3340.831 | 496.786 |
| 60 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -77.973 | 2.558 | -12.008 | 12.278 | -2.570 | 12.447 | 12.710 | -78.336 | 3369.300 | 367.483 |
| 61 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -78.336 | 2.570 | -12.447 | 12.710 | -2.581 | 12.887 | 13.143 | -78.676 | 3396.889 | 237.989 |
| 62 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -78.676 | 2.581 | -12.887 | 13.143 | -2.592 | 13.326 | 13.576 | -78.993 | 3423.656 | 108.323 |
| 63 | 132.4 | 0.441 | -0.011 | 0.011 | -0.002 | -78.993 | 2.592 | -13.326 | 13.576 | -2.603 | 13.766 | 14.010 | -79.291 | 3449.654 | -21.499 |
| | | | | | | | | | | | | | | 3474.933 | -151.463 |

| Segment no. | Height of Segment | DL + LL(R) | Wind Load (Cpi=0) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 132.7 | 0.441 | 0.046 | 0.045 | 0.008 | 82.500 | 1.717 | 13.043 | 13.156 | -1.762 | -12.594 | 12.717 | 82.035 | 0 | 0 |
| 2 | 132.7 | 0.441 | 0.046 | 0.045 | 0.008 | 82.035 | 1.762 | 12.594 | 12.717 | -1.807 | -12.145 | 12.279 | 81.537 | 17.321 | 131.565 |
| 3 | 132.7 | 0.441 | 0.046 | 0.045 | 0.008 | 81.537 | 1.807 | 12.145 | 12.279 | -1.852 | -11.696 | 11.841 | 81.002 | 35.709 | 262.985 |
| 4 | 132.7 | 0.441 | 0.046 | 0.045 | 0.008 | 81.002 | 1.852 | 11.696 | 11.841 | -1.897 | -11.246 | 11.405 | 80.426 | 55.238 | 394.240 |
| 5 | 132.7 | 0.441 | 0.046 | 0.045 | 0.009 | 80.426 | 1.897 | 11.246 | 11.405 | -1.942 | -10.796 | 10.969 | 79.805 | 75.992 | 525.307 |
| 6 | 132.7 | 0.441 | 0.046 | 0.045 | 0.009 | 79.805 | 1.942 | 10.796 | 10.969 | -1.986 | -10.346 | 10.535 | 79.132 | 98.062 | 656.158 |
| 7 | 132.7 | 0.441 | 0.046 | 0.045 | 0.009 | 79.132 | 1.986 | 10.346 | 10.535 | -2.031 | -9.895 | 10.101 | 78.401 | 121.551 | 786.763 |
| 8 | 132.7 | 0.441 | 0.046 | 0.045 | 0.010 | 78.401 | 2.031 | 9.895 | 10.101 | -2.076 | -9.444 | 9.669 | 77.605 | 146.571 | 917.083 |
| 9 | 132.7 | 0.441 | 0.046 | 0.044 | 0.010 | 77.605 | 2.076 | 9.444 | 9.669 | -2.120 | -8.993 | 9.239 | 76.735 | 173.252 | 1047.073 |
| 10 | 132.7 | 0.441 | 0.046 | 0.044 | 0.010 | 76.735 | 2.120 | 8.993 | 9.239 | -2.164 | -8.541 | 8.811 | 75.779 | 201.736 | 1176.680 |
| 11 | 132.7 | 0.441 | 0.046 | 0.044 | 0.011 | 75.779 | 2.164 | 8.541 | 8.811 | -2.209 | -8.089 | 8.385 | 74.727 | 232.185 | 1305.839 |
| 12 | 132.7 | 0.441 | 0.046 | 0.044 | 0.011 | 74.727 | 2.209 | 8.089 | 8.385 | -2.253 | -7.636 | 7.961 | 73.562 | 264.784 | 1434.473 |
| 13 | 132.7 | 0.441 | 0.046 | 0.044 | 0.012 | 73.562 | 2.253 | 7.636 | 7.961 | -2.297 | -7.182 | 7.541 | 72.266 | 299.740 | 1562.486 |
| 14 | 132.7 | 0.441 | 0.046 | 0.044 | 0.012 | 72.266 | 2.297 | 7.182 | 7.541 | -2.341 | -6.729 | 7.124 | 70.818 | 337.292 | 1689.762 |
| 15 | 132.7 | 0.441 | 0.046 | 0.044 | 0.013 | 70.818 | 2.341 | 6.729 | 7.124 | -2.384 | -6.274 | 6.712 | 69.191 | 377.712 | 1816.156 |
| 16 | 132.7 | 0.441 | 0.046 | 0.043 | 0.014 | 69.191 | 2.384 | 6.274 | 6.712 | -2.428 | -5.819 | 6.305 | 67.352 | 421.313 | 1941.489 |
| 17 | 132.7 | 0.441 | -0.068 | -0.065 | -0.022 | 67.352 | 2.428 | 5.819 | 6.305 | -2.363 | -5.399 | 5.894 | 66.362 | 468.456 | 2065.532 |
| 18 | 132.7 | 0.441 | -0.068 | -0.064 | -0.023 | 66.362 | 2.363 | 5.399 | 5.894 | -2.299 | -4.981 | 5.486 | 65.227 | 519.556 | 2187.999 |
| 19 | 132.7 | 0.441 | -0.068 | -0.064 | -0.025 | 65.227 | 2.299 | 4.981 | 5.486 | -2.235 | -4.565 | 5.082 | 63.911 | 572.762 | 2309.566 |
| 20 | 132.7 | 0.441 | -0.068 | -0.063 | -0.027 | 63.911 | 2.235 | 4.565 | 5.082 | -2.172 | -4.150 | 4.684 | 62.372 | 628.367 | 2430.054 |
| 21 | 132.7 | 0.441 | -0.068 | -0.062 | -0.028 | 62.372 | 2.172 | 4.150 | 4.684 | -2.110 | -3.737 | 4.291 | 60.550 | 686.723 | 2549.233 |
| 22 | 132.7 | 0.441 | -0.068 | -0.061 | -0.031 | 60.550 | 2.110 | 3.737 | 4.291 | -2.049 | -3.326 | 3.907 | 58.369 | 748.261 | 2666.802 |
| 23 | 132.7 | 0.441 | -0.068 | -0.060 | -0.033 | 58.369 | 2.049 | 3.326 | 3.907 | -1.989 | -2.918 | 3.531 | 55.720 | 813.504 | 2782.356 |
| 24 | 132.7 | 0.441 | -0.068 | -0.058 | -0.036 | 55.720 | 1.989 | 2.918 | 3.531 | -1.931 | -2.513 | 3.169 | 52.458 | 883.099 | 2895.342 |
| 25 | 132.7 | 0.441 | -0.068 | -0.056 | -0.039 | 52.458 | 1.931 | 2.513 | 3.169 | -1.875 | -2.110 | 2.823 | 48.383 | 957.841 | 3004.991 |
| 26 | 132.7 | 0.441 | -0.068 | -0.053 | -0.043 | 48.383 | 1.875 | 2.110 | 2.823 | -1.822 | -1.712 | 2.500 | 43.222 | 1038.700 | 3110.210 |
| 27 | 132.7 | 0.441 | -0.068 | -0.049 | -0.047 | 43.222 | 1.822 | 1.712 | 2.500 | -1.772 | -1.318 | 2.209 | 36.636 | 1126.833 | 3209.416 |
| 28 | 132.7 | 0.441 | -0.068 | -0.044 | -0.052 | 36.636 | 1.772 | 1.318 | 2.209 | -1.728 | -0.929 | 1.962 | 28.253 | 1223.532 | 3300.293 |
| 29 | 132.7 | 0.441 | -0.068 | -0.038 | -0.057 | 28.253 | 1.728 | 0.929 | 1.962 | -1.690 | -0.544 | 1.776 | 17.846 | 1330.016 | 3379.479 |
| 30 | 132.7 | 0.441 | -0.068 | -0.029 | -0.062 | 17.846 | 1.690 | 0.544 | 1.776 | -1.661 | -0.165 | 1.669 | 5.657 | 1446.907 | 3442.295 |
| 31 | 132.7 | 0.441 | -0.068 | -0.019 | -0.066 | 5.657 | 1.661 | 0.165 | 1.669 | -1.642 | 0.211 | 1.656 | -7.326 | 1573.222 | 3482.962 |
| 32 | 132.7 | 0.457 | -0.068 | -0.006 | -0.068 | -7.326 | 1.642 | -0.211 | 1.656 | -1.636 | 0.600 | 1.742 | -20.157 | 1705.276 | 3496.044 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 132.7 | 0.457 | -0.068 | 0.006 | -0.068 | -20.157 | 1.636 | -0.600 | 1.742 | -1.642 | 0.990 | 1.917 | -31.077 | 1836.892 | 3479.123 |
| 34 | 132.7 | 0.457 | -0.068 | 0.019 | -0.066 | -31.077 | 1.642 | -0.990 | 1.917 | -1.661 | 1.381 | 2.160 | -39.738 | 1961.465 | 3433.397 |
| 35 | 132.7 | 0.456 | -0.068 | 0.029 | -0.062 | -39.738 | 1.661 | -1.381 | 2.160 | -1.690 | 1.775 | 2.451 | -46.400 | 2075.120 | 3364.899 |
| 36 | 132.7 | 0.455 | -0.068 | 0.038 | -0.057 | -46.400 | 1.690 | -1.775 | 2.451 | -1.728 | 2.173 | 2.776 | -51.503 | 2177.162 | 3280.066 |
| 37 | 132.7 | 0.454 | -0.068 | 0.044 | -0.052 | -51.503 | 1.728 | -2.173 | 2.776 | -1.772 | 2.574 | 3.125 | -55.452 | 2268.674 | 3183.968 |
| 38 | 132.7 | 0.453 | -0.068 | 0.049 | -0.047 | -55.452 | 1.772 | -2.574 | 3.125 | -1.822 | 2.979 | 3.492 | -58.556 | 2351.276 | 3080.111 |
| 39 | 132.7 | 0.452 | -0.068 | 0.053 | -0.043 | -58.556 | 1.822 | -2.979 | 3.492 | -1.875 | 3.388 | 3.872 | -61.039 | 2426.529 | 2970.812 |
| 40 | 132.7 | 0.451 | -0.068 | 0.056 | -0.039 | -61.039 | 1.875 | -3.388 | 3.872 | -1.931 | 3.799 | 4.262 | -63.059 | 2495.754 | 2857.599 |
| 41 | 132.7 | 0.450 | -0.068 | 0.058 | -0.036 | -63.059 | 1.931 | -3.799 | 4.262 | -1.989 | 4.213 | 4.659 | -64.728 | 2560.009 | 2741.493 |
| 42 | 132.7 | 0.449 | -0.068 | 0.060 | -0.033 | -64.728 | 1.989 | -4.213 | 4.659 | -2.049 | 4.629 | 5.062 | -66.126 | 2620.132 | 2623.195 |
| 43 | 132.7 | 0.449 | -0.068 | 0.061 | -0.031 | -66.126 | 2.049 | -4.629 | 5.062 | -2.110 | 5.047 | 5.470 | -67.312 | 2676.784 | 2503.196 |
| 44 | 132.7 | 0.448 | -0.068 | 0.062 | -0.028 | -67.312 | 2.110 | -5.047 | 5.470 | -2.172 | 5.467 | 5.882 | -68.330 | 2730.491 | 2381.850 |
| 45 | 132.7 | 0.448 | -0.068 | 0.063 | -0.027 | -68.330 | 2.172 | -5.467 | 5.882 | -2.235 | 5.888 | 6.298 | -69.212 | 2781.675 | 2259.418 |
| 46 | 132.7 | 0.447 | -0.068 | 0.064 | -0.025 | -69.212 | 2.235 | -5.888 | 6.298 | -2.299 | 6.310 | 6.716 | -69.983 | 2830.676 | 2136.096 |
| 47 | 132.7 | 0.447 | -0.068 | 0.064 | -0.023 | -69.983 | 2.299 | -6.310 | 6.716 | -2.363 | 6.733 | 7.136 | -70.662 | 2877.773 | 2012.035 |
| 48 | 132.7 | 0.447 | -0.023 | 0.022 | -0.007 | -70.662 | 2.363 | -6.733 | 7.136 | -2.385 | 7.173 | 7.559 | -71.610 | 2923.197 | 1887.352 |
| 49 | 132.7 | 0.446 | -0.023 | 0.022 | -0.007 | -71.610 | 2.385 | -7.173 | 7.559 | -2.406 | 7.612 | 7.983 | -72.457 | 2967.140 | 1762.139 |
| 50 | 132.7 | 0.446 | -0.023 | 0.022 | -0.007 | -72.457 | 2.406 | -7.612 | 7.983 | -2.428 | 8.052 | 8.410 | -73.218 | 3009.005 | 1636.216 |
| 51 | 132.7 | 0.446 | -0.023 | 0.022 | -0.006 | -73.218 | 2.428 | -8.052 | 8.410 | -2.450 | 8.491 | 8.838 | -73.904 | 3049.004 | 1509.688 |
| 52 | 132.7 | 0.446 | -0.023 | 0.022 | -0.006 | -73.904 | 2.450 | -8.491 | 8.838 | -2.472 | 8.931 | 9.267 | -74.527 | 3087.320 | 1382.640 |
| 53 | 132.7 | 0.445 | -0.023 | 0.022 | -0.006 | -74.527 | 2.472 | -8.931 | 9.267 | -2.494 | 9.371 | 9.697 | -75.095 | 3124.110 | 1255.141 |
| 54 | 132.7 | 0.445 | -0.023 | 0.022 | -0.005 | -75.095 | 2.494 | -9.371 | 9.697 | -2.516 | 9.810 | 10.128 | -75.614 | 3159.511 | 1127.251 |
| 55 | 132.7 | 0.445 | -0.023 | 0.022 | -0.005 | -75.614 | 2.516 | -9.810 | 10.128 | -2.539 | 10.250 | 10.560 | -76.090 | 3193.645 | 999.016 |
| 56 | 132.7 | 0.445 | -0.023 | 0.022 | -0.005 | -76.090 | 2.539 | -10.250 | 10.560 | -2.561 | 10.690 | 10.993 | -76.529 | 3226.616 | 870.477 |
| 57 | 132.7 | 0.445 | -0.023 | 0.022 | -0.005 | -76.529 | 2.561 | -10.690 | 10.993 | -2.583 | 11.130 | 11.426 | -76.934 | 3258.516 | 741.669 |
| 58 | 132.7 | 0.445 | -0.023 | 0.022 | -0.005 | -76.934 | 2.583 | -11.130 | 11.426 | -2.605 | 11.570 | 11.860 | -77.310 | 3289.430 | 612.620 |
| 59 | 132.7 | 0.445 | -0.023 | 0.022 | -0.004 | -77.310 | 2.605 | -11.570 | 11.860 | -2.628 | 12.010 | 12.294 | -77.658 | 3319.430 | 483.355 |
| 60 | 132.7 | 0.444 | -0.023 | 0.022 | -0.004 | -77.658 | 2.628 | -12.010 | 12.294 | -2.650 | 12.450 | 12.729 | -77.983 | 3348.582 | 353.897 |
| 61 | 132.7 | 0.444 | -0.023 | 0.022 | -0.004 | -77.983 | 2.650 | -12.450 | 12.729 | -2.673 | 12.891 | 13.165 | -78.287 | 3376.945 | 224.264 |
| 62 | 132.7 | 0.444 | -0.023 | 0.022 | -0.004 | -78.287 | 2.673 | -12.891 | 13.165 | -2.695 | 13.331 | 13.601 | -78.571 | 3404.573 | 94.471 |
| 63 | 132.7 | 0.444 | -0.023 | 0.022 | -0.004 | -78.571 | 2.695 | -13.331 | 13.601 | -2.718 | 13.771 | 14.037 | -78.837 | 3431.512 | -35.465 |
| | | | | | | | | | | | | | | 3457.808 | -165.534 |

| Segment no. | Height of Segment | DL + LL(R) | Wind Load (Cpi=-0.2) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 133 | 0.441 | 0.057 | 0.056 | 0.009 | 83.300 | 1.556 | 13.242 | 13.333 | -1.612 | -12.791 | 12.892 | 82.818 | 0 | 0 |
| 2 | 133 | 0.441 | 0.057 | 0.056 | 0.010 | 82.818 | 1.612 | 12.791 | 12.892 | -1.668 | -12.340 | 12.452 | 82.302 | 15.517 | 132.092 |
| 3 | 133 | 0.441 | 0.057 | 0.056 | 0.010 | 82.302 | 1.668 | 12.340 | 12.452 | -1.724 | -11.889 | 12.013 | 81.749 | 32.145 | 264.048 |
| 4 | 133 | 0.441 | 0.057 | 0.056 | 0.010 | 81.749 | 1.724 | 11.889 | 12.013 | -1.780 | -11.437 | 11.575 | 81.153 | 49.960 | 395.850 |
| 5 | 133 | 0.441 | 0.057 | 0.056 | 0.011 | 81.153 | 1.780 | 11.437 | 11.575 | -1.836 | -10.985 | 11.137 | 80.511 | 69.048 | 527.473 |
| 6 | 133 | 0.441 | 0.057 | 0.056 | 0.011 | 80.511 | 1.836 | 10.985 | 11.137 | -1.892 | -10.532 | 10.701 | 79.816 | 89.502 | 658.890 |
| 7 | 133 | 0.441 | 0.057 | 0.056 | 0.012 | 79.816 | 1.892 | 10.532 | 10.701 | -1.948 | -10.079 | 10.266 | 79.062 | 111.429 | 790.071 |
| 8 | 133 | 0.441 | 0.057 | 0.056 | 0.012 | 79.062 | 1.948 | 10.079 | 10.266 | -2.004 | -9.626 | 9.832 | 78.242 | 134.945 | 920.975 |
| 9 | 133 | 0.441 | 0.057 | 0.056 | 0.012 | 78.242 | 2.004 | 9.626 | 9.832 | -2.059 | -9.172 | 9.400 | 77.347 | 160.180 | 1051.559 |
| 10 | 133 | 0.441 | 0.057 | 0.055 | 0.013 | 77.347 | 2.059 | 9.172 | 9.400 | -2.115 | -8.717 | 8.970 | 76.365 | 187.282 | 1181.768 |
| 11 | 133 | 0.441 | 0.057 | 0.055 | 0.014 | 76.365 | 2.115 | 8.717 | 8.970 | -2.170 | -8.262 | 8.543 | 75.285 | 216.417 | 1311.538 |
| 12 | 133 | 0.441 | 0.057 | 0.055 | 0.014 | 75.285 | 2.170 | 8.262 | 8.543 | -2.225 | -7.807 | 8.118 | 74.091 | 247.770 | 1440.790 |
| 13 | 133 | 0.441 | 0.057 | 0.055 | 0.015 | 74.091 | 2.225 | 7.807 | 8.118 | -2.280 | -7.351 | 7.696 | 72.766 | 281.554 | 1569.427 |
| 14 | 133 | 0.441 | 0.057 | 0.055 | 0.016 | 72.766 | 2.280 | 7.351 | 7.696 | -2.335 | -6.894 | 7.278 | 71.287 | 318.012 | 1697.333 |
| 15 | 133 | 0.441 | 0.057 | 0.055 | 0.016 | 71.287 | 2.335 | 6.894 | 7.278 | -2.390 | -6.436 | 6.865 | 69.630 | 357.417 | 1824.361 |
| 16 | 133 | 0.441 | 0.057 | 0.054 | 0.017 | 69.630 | 2.390 | 6.436 | 6.865 | -2.444 | -5.977 | 6.457 | 67.761 | 400.087 | 1950.331 |
| 17 | 133 | 0.441 | -0.057 | -0.054 | -0.018 | 67.761 | 2.444 | 5.977 | 6.457 | -2.390 | -5.554 | 6.046 | 66.717 | 446.382 | 2075.013 |
| 18 | 133 | 0.441 | -0.057 | -0.054 | -0.019 | 66.717 | 2.390 | 5.554 | 6.046 | -2.336 | -5.132 | 5.639 | 65.522 | 496.720 | 2198.120 |
| 19 | 133 | 0.441 | -0.057 | -0.053 | -0.021 | 65.522 | 2.336 | 5.132 | 5.639 | -2.283 | -4.711 | 5.235 | 64.143 | 549.292 | 2320.288 |
| 20 | 133 | 0.441 | -0.057 | -0.053 | -0.022 | 64.143 | 2.283 | 4.711 | 5.235 | -2.231 | -4.292 | 4.837 | 62.536 | 604.400 | 2441.334 |
| 21 | 133 | 0.441 | -0.057 | -0.052 | -0.024 | 62.536 | 2.231 | 4.292 | 4.837 | -2.179 | -3.874 | 4.445 | 60.646 | 662.406 | 2561.018 |
| 22 | 133 | 0.441 | -0.057 | -0.051 | -0.026 | 60.646 | 2.179 | 3.874 | 4.445 | -2.128 | -3.458 | 4.061 | 58.395 | 723.744 | 2679.030 |
| 23 | 133 | 0.441 | -0.057 | -0.050 | -0.028 | 58.395 | 2.128 | 3.458 | 4.061 | -2.078 | -3.045 | 3.686 | 55.683 | 788.942 | 2794.953 |
| 24 | 133 | 0.441 | -0.057 | -0.048 | -0.030 | 55.683 | 2.078 | 3.045 | 3.686 | -2.030 | -2.633 | 3.325 | 52.374 | 858.642 | 2908.226 |
| 25 | 133 | 0.441 | -0.057 | -0.047 | -0.033 | 52.374 | 2.030 | 2.633 | 3.325 | -1.983 | -2.225 | 2.980 | 48.284 | 933.623 | 3018.076 |
| 26 | 133 | 0.441 | -0.057 | -0.044 | -0.036 | 48.284 | 1.983 | 2.225 | 2.980 | -1.939 | -1.819 | 2.659 | 43.174 | 1014.820 | 3123.414 |
| 27 | 133 | 0.441 | -0.057 | -0.041 | -0.039 | 43.174 | 1.939 | 1.819 | 2.659 | -1.898 | -1.417 | 2.368 | 36.750 | 1103.323 | 3222.692 |
| 28 | 133 | 0.441 | -0.057 | -0.037 | -0.043 | 36.750 | 1.898 | 1.417 | 2.368 | -1.861 | -1.019 | 2.121 | 28.707 | 1200.317 | 3313.693 |
| 29 | 133 | 0.441 | -0.057 | -0.032 | -0.047 | 28.707 | 1.861 | 1.019 | 2.121 | -1.829 | -0.625 | 1.933 | 18.866 | 1306.884 | 3393.269 |
| 30 | 133 | 0.441 | -0.057 | -0.024 | -0.051 | 18.866 | 1.829 | 0.625 | 1.933 | -1.805 | -0.235 | 1.820 | 7.422 | 1423.537 | 3457.153 |
| 31 | 133 | 0.441 | -0.057 | -0.016 | -0.055 | 7.422 | 1.805 | 0.235 | 1.820 | -1.789 | 0.151 | 1.796 | -4.840 | 1549.392 | 3500.158 |
| 32 | 133 | 0.457 | -0.057 | -0.005 | -0.057 | -4.840 | 1.789 | -0.151 | 1.796 | -1.784 | 0.552 | 1.867 | -17.199 | 1681.278 | 3517.339 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 133 | 0.457 | -0.057 | 0.005 | -0.057 | -17.199 | 1.784 | -0.552 | 1.867 | -1.789 | 0.953 | 2.027 | -28.037 | 1813.804 | 3506.118 |
| 34 | 133 | 0.457 | -0.057 | 0.016 | -0.055 | -28.037 | 1.789 | -0.953 | 2.027 | -1.805 | 1.355 | 2.257 | -36.895 | 1940.856 | 3466.791 |
| 35 | 133 | 0.456 | -0.057 | 0.024 | -0.051 | -36.895 | 1.805 | -1.355 | 2.257 | -1.829 | 1.759 | 2.538 | -43.883 | 2058.249 | 3404.276 |
| 36 | 133 | 0.455 | -0.057 | 0.032 | -0.047 | -43.883 | 1.829 | -1.759 | 2.538 | -1.861 | 2.166 | 2.856 | -49.342 | 2164.614 | 3324.430 |
| 37 | 133 | 0.454 | -0.057 | 0.037 | -0.043 | -49.342 | 1.861 | -2.166 | 2.856 | -1.898 | 2.577 | 3.200 | -53.629 | 2260.475 | 3232.236 |
| 38 | 133 | 0.453 | -0.057 | 0.041 | -0.039 | -53.629 | 1.898 | -2.577 | 3.200 | -1.939 | 2.990 | 3.563 | -57.037 | 2347.129 | 3131.340 |
| 39 | 133 | 0.452 | -0.057 | 0.044 | -0.036 | -57.037 | 1.939 | -2.990 | 3.563 | -1.983 | 3.405 | 3.941 | -59.786 | 2425.999 | 3024.249 |
| 40 | 133 | 0.451 | -0.057 | 0.047 | -0.033 | -59.786 | 1.983 | -3.405 | 3.941 | -2.030 | 3.823 | 4.329 | -62.037 | 2498.363 | 2912.658 |
| 41 | 133 | 0.450 | -0.057 | 0.048 | -0.030 | -62.037 | 2.030 | -3.823 | 4.329 | -2.078 | 4.243 | 4.725 | -63.906 | 2565.293 | 2797.726 |
| 42 | 133 | 0.449 | -0.057 | 0.050 | -0.028 | -63.906 | 2.078 | -4.243 | 4.725 | -2.128 | 4.665 | 5.127 | -65.478 | 2627.657 | 2680.254 |
| 43 | 133 | 0.449 | -0.057 | 0.051 | -0.026 | -65.478 | 2.128 | -4.665 | 5.127 | -2.179 | 5.088 | 5.535 | -66.816 | 2686.158 | 2560.811 |
| 44 | 133 | 0.448 | -0.057 | 0.052 | -0.024 | -66.816 | 2.179 | -5.088 | 5.535 | -2.231 | 5.512 | 5.946 | -67.966 | 2741.359 | 2439.807 |
| 45 | 133 | 0.448 | -0.057 | 0.053 | -0.022 | -67.966 | 2.231 | -5.512 | 5.946 | -2.283 | 5.938 | 6.361 | -68.966 | 2793.720 | 2317.548 |
| 46 | 133 | 0.447 | -0.057 | 0.053 | -0.021 | -68.966 | 2.283 | -5.938 | 6.361 | -2.336 | 6.364 | 6.779 | -69.841 | 2843.615 | 2194.262 |
| 47 | 133 | 0.447 | -0.057 | 0.054 | -0.019 | -69.841 | 2.336 | -6.364 | 6.779 | -2.390 | 6.791 | 7.200 | -70.613 | 2891.352 | 2070.124 |
| 48 | 133 | 0.447 | -0.011 | 0.011 | -0.004 | -70.613 | 2.390 | -6.791 | 7.200 | -2.401 | 7.234 | 7.622 | -71.642 | 2937.188 | 1945.272 |
| 49 | 133 | 0.446 | -0.011 | 0.011 | -0.003 | -71.642 | 2.401 | -7.234 | 7.622 | -2.412 | 7.677 | 8.047 | -72.561 | 2981.337 | 1819.813 |
| 50 | 133 | 0.446 | -0.011 | 0.011 | -0.003 | -72.561 | 2.412 | -7.677 | 8.047 | -2.423 | 8.120 | 8.474 | -73.388 | 3023.226 | 1693.582 |
| 51 | 133 | 0.446 | -0.011 | 0.011 | -0.003 | -73.388 | 2.423 | -8.120 | 8.474 | -2.433 | 8.563 | 8.902 | -74.135 | 3063.084 | 1566.695 |
| 52 | 133 | 0.446 | -0.011 | 0.011 | -0.003 | -74.135 | 2.433 | -8.563 | 8.902 | -2.444 | 9.005 | 9.331 | -74.813 | 3101.107 | 1439.246 |
| 53 | 133 | 0.445 | -0.011 | 0.011 | -0.003 | -74.813 | 2.444 | -9.005 | 9.331 | -2.456 | 9.448 | 9.762 | -75.431 | 3137.465 | 1311.312 |
| 54 | 133 | 0.445 | -0.011 | 0.011 | -0.003 | -75.431 | 2.456 | -9.448 | 9.762 | -2.467 | 9.890 | 10.193 | -75.997 | 3172.307 | 1182.957 |
| 55 | 133 | 0.445 | -0.011 | 0.011 | -0.003 | -75.997 | 2.467 | -9.890 | 10.193 | -2.478 | 10.333 | 10.626 | -76.516 | 3205.762 | 1054.233 |
| 56 | 133 | 0.445 | -0.011 | 0.011 | -0.002 | -76.516 | 2.478 | -10.333 | 10.626 | -2.489 | 10.775 | 11.059 | -76.994 | 3237.946 | 925.186 |
| 57 | 133 | 0.445 | -0.011 | 0.011 | -0.002 | -76.994 | 2.489 | -10.775 | 11.059 | -2.500 | 11.218 | 11.493 | -77.437 | 3268.958 | 795.852 |
| 58 | 133 | 0.445 | -0.011 | 0.011 | -0.002 | -77.437 | 2.500 | -11.218 | 11.493 | -2.511 | 11.660 | 11.927 | -77.846 | 3298.890 | 666.264 |
| 59 | 133 | 0.445 | -0.011 | 0.011 | -0.002 | -77.846 | 2.511 | -11.660 | 11.927 | -2.522 | 12.102 | 12.362 | -78.227 | 3327.820 | 536.449 |
| 60 | 133 | 0.444 | -0.011 | 0.011 | -0.002 | -78.227 | 2.522 | -12.102 | 12.362 | -2.533 | 12.545 | 12.798 | -78.582 | 3355.821 | 406.430 |
| 61 | 133 | 0.444 | -0.011 | 0.011 | -0.002 | -78.582 | 2.533 | -12.545 | 12.798 | -2.545 | 12.987 | 13.234 | -78.914 | 3382.956 | 276.227 |
| 62 | 133 | 0.444 | -0.011 | 0.011 | -0.002 | -78.914 | 2.545 | -12.987 | 13.234 | -2.556 | 13.429 | 13.670 | -79.224 | 3409.285 | 145.859 |
| 63 | 133 | 0.444 | -0.011 | 0.011 | -0.002 | -79.224 | 2.556 | -13.429 | 13.670 | -2.567 | 13.871 | 14.107 | -79.515 | 3434.859 | 15.341 |
| | | | | | | | | | | | | | | 3459.726 | -115.313 |

| Segment no. | Height of Segment | DL per block | Wind Load (Cpi=0) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 136.3 | 0.331 | 0.046 | 0.045 | 0.008 | 83.300 | 1.115 | 9.495 | 9.560 | -1.160 | -9.156 | 9.230 | 82.777 | 0 | 0 |
| 2 | 136.3 | 0.331 | 0.046 | 0.045 | 0.008 | 82.777 | 1.160 | 9.156 | 9.230 | -1.205 | -8.817 | 8.899 | 82.216 | 15.902 | 135.369 |
| 3 | 136.3 | 0.331 | 0.046 | 0.045 | 0.008 | 82.216 | 1.205 | 8.817 | 8.899 | -1.250 | -8.478 | 8.570 | 81.612 | 33.038 | 270.588 |
| 4 | 136.3 | 0.331 | 0.046 | 0.045 | 0.008 | 81.612 | 1.250 | 8.478 | 8.570 | -1.295 | -8.139 | 8.241 | 80.959 | 51.498 | 405.632 |
| 5 | 136.3 | 0.331 | 0.046 | 0.045 | 0.009 | 80.959 | 1.295 | 8.139 | 8.241 | -1.340 | -7.799 | 7.914 | 80.253 | 71.381 | 540.474 |
| 6 | 136.3 | 0.331 | 0.046 | 0.045 | 0.009 | 80.253 | 1.340 | 7.799 | 7.914 | -1.385 | -7.459 | 7.587 | 79.485 | 92.799 | 675.081 |
| 7 | 136.3 | 0.331 | 0.046 | 0.045 | 0.009 | 79.485 | 1.385 | 7.459 | 7.587 | -1.429 | -7.119 | 7.261 | 78.649 | 115.875 | 809.413 |
| 8 | 136.3 | 0.331 | 0.046 | 0.045 | 0.010 | 78.649 | 1.429 | 7.119 | 7.261 | -1.474 | -6.778 | 6.937 | 77.734 | 140.748 | 943.424 |
| 9 | 136.3 | 0.331 | 0.046 | 0.044 | 0.010 | 77.734 | 1.474 | 6.778 | 6.937 | -1.518 | -6.437 | 6.614 | 76.729 | 167.576 | 1077.058 |
| 10 | 136.3 | 0.331 | 0.046 | 0.044 | 0.010 | 76.729 | 1.518 | 6.437 | 6.614 | -1.563 | -6.096 | 6.293 | 75.622 | 196.533 | 1210.246 |
| 11 | 136.3 | 0.331 | 0.046 | 0.044 | 0.011 | 75.622 | 1.563 | 6.096 | 6.293 | -1.607 | -5.754 | 5.974 | 74.397 | 227.821 | 1342.907 |
| 12 | 136.3 | 0.331 | 0.046 | 0.044 | 0.011 | 74.397 | 1.607 | 5.754 | 5.974 | -1.651 | -5.412 | 5.658 | 73.033 | 261.666 | 1474.938 |
| 13 | 136.3 | 0.331 | 0.046 | 0.044 | 0.012 | 73.033 | 1.651 | 5.412 | 5.658 | -1.695 | -5.069 | 5.345 | 71.508 | 298.327 | 1606.215 |
| 14 | 136.3 | 0.331 | 0.046 | 0.044 | 0.012 | 71.508 | 1.695 | 5.069 | 5.345 | -1.739 | -4.725 | 5.035 | 69.795 | 338.103 | 1736.582 |
| 15 | 136.3 | 0.331 | 0.046 | 0.044 | 0.013 | 69.795 | 1.739 | 4.725 | 5.035 | -1.783 | -4.381 | 4.730 | 67.858 | 381.332 | 1865.845 |
| 16 | 136.3 | 0.331 | 0.046 | 0.043 | 0.014 | 67.858 | 1.783 | 4.381 | 4.730 | -1.826 | -4.036 | 4.430 | 65.656 | 428.408 | 1993.757 |
| 17 | 136.3 | 0.331 | -0.068 | -0.065 | -0.022 | 65.656 | 1.826 | 4.036 | 4.430 | -1.761 | -3.727 | 4.122 | 64.705 | 479.779 | 2120.005 |
| 18 | 136.3 | 0.331 | -0.068 | -0.064 | -0.023 | 64.705 | 1.761 | 3.727 | 4.122 | -1.697 | -3.419 | 3.817 | 63.604 | 535.965 | 2244.186 |
| 19 | 136.3 | 0.331 | -0.068 | -0.064 | -0.025 | 63.604 | 1.697 | 3.419 | 3.817 | -1.633 | -3.113 | 3.515 | 62.315 | 594.204 | 2367.418 |
| 20 | 136.3 | 0.331 | -0.068 | -0.063 | -0.027 | 62.315 | 1.633 | 3.113 | 3.515 | -1.570 | -2.808 | 3.218 | 60.789 | 654.800 | 2489.507 |
| 21 | 136.3 | 0.331 | -0.068 | -0.062 | -0.028 | 60.789 | 1.570 | 2.808 | 3.218 | -1.508 | -2.506 | 2.925 | 58.960 | 718.126 | 2610.203 |
| 22 | 136.3 | 0.331 | -0.068 | -0.061 | -0.031 | 58.960 | 1.508 | 2.506 | 2.925 | -1.447 | -2.206 | 2.638 | 56.732 | 784.643 | 2729.170 |
| 23 | 136.3 | 0.331 | -0.068 | -0.060 | -0.033 | 56.732 | 1.447 | 2.206 | 2.638 | -1.387 | -1.908 | 2.359 | 53.977 | 854.925 | 2845.952 |
| 24 | 136.3 | 0.331 | -0.068 | -0.058 | -0.036 | 53.977 | 1.387 | 1.908 | 2.359 | -1.329 | -1.613 | 2.090 | 50.506 | 929.693 | 2959.915 |
| 25 | 136.3 | 0.331 | -0.068 | -0.056 | -0.039 | 50.506 | 1.329 | 1.613 | 2.090 | -1.273 | -1.321 | 1.835 | 46.056 | 1009.853 | 3070.151 |
| 26 | 136.3 | 0.331 | -0.068 | -0.053 | -0.043 | 46.056 | 1.273 | 1.321 | 1.835 | -1.220 | -1.033 | 1.599 | 40.253 | 1096.539 | 3175.333 |
| 27 | 136.3 | 0.331 | -0.068 | -0.049 | -0.047 | 40.253 | 1.220 | 1.033 | 1.599 | -1.171 | -0.749 | 1.390 | 32.619 | 1191.126 | 3273.470 |
| 28 | 136.3 | 0.331 | -0.068 | -0.044 | -0.052 | 32.619 | 1.171 | 0.749 | 1.390 | -1.126 | -0.470 | 1.220 | 22.657 | 1295.150 | 3361.543 |
| 29 | 136.3 | 0.331 | -0.068 | -0.038 | -0.057 | 22.657 | 1.126 | 0.470 | 1.220 | -1.088 | -0.196 | 1.106 | 10.210 | 1409.952 | 3435.015 |
| 30 | 136.3 | 0.331 | -0.068 | -0.029 | -0.062 | 10.210 | 1.088 | 0.196 | 1.106 | -1.059 | 0.073 | 1.062 | -3.956 | 1535.733 | 3487.520 |
| 31 | 136.3 | 0.331 | -0.068 | -0.019 | -0.066 | -3.956 | 1.059 | -0.073 | 1.062 | -1.040 | 0.339 | 1.094 | -18.025 | 1669.875 | 3511.680 |
| 32 | 136.3 | 0.331 | -0.068 | -0.006 | -0.068 | -18.025 | 1.040 | -0.339 | 1.094 | -1.034 | 0.602 | 1.196 | -30.191 | 1805.850 | 3502.276 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 136.3 | 0.331 | -0.068 | 0.006 | -0.068 | -30.191 | 1.034 | -0.602 | 1.196 | -1.040 | 0.864 | 1.353 | -39.726 | 1935.460 | 3460.099 |
| 34 | 136.3 | 0.331 | -0.068 | 0.019 | -0.066 | -39.726 | 1.040 | -0.864 | 1.353 | -1.059 | 1.130 | 1.549 | -46.851 | 2053.272 | 3391.556 |
| 35 | 136.3 | 0.331 | -0.068 | 0.029 | -0.062 | -46.851 | 1.059 | -1.130 | 1.549 | -1.088 | 1.399 | 1.773 | -52.120 | 2158.102 | 3304.445 |
| 36 | 136.3 | 0.331 | -0.068 | 0.038 | -0.057 | -52.120 | 1.088 | -1.399 | 1.773 | -1.126 | 1.673 | 2.017 | -56.055 | 2251.318 | 3205.004 |
| 37 | 136.3 | 0.331 | -0.068 | 0.044 | -0.052 | -56.055 | 1.126 | -1.673 | 2.017 | -1.171 | 1.952 | 2.276 | -59.052 | 2335.008 | 3097.423 |
| 38 | 136.3 | 0.331 | -0.068 | 0.049 | -0.047 | -59.052 | 1.171 | -1.952 | 2.276 | -1.220 | 2.236 | 2.547 | -61.382 | 2411.117 | 2984.352 |
| 39 | 136.3 | 0.331 | -0.068 | 0.053 | -0.043 | -61.382 | 1.220 | -2.236 | 2.547 | -1.273 | 2.524 | 2.827 | -63.233 | 2481.211 | 2867.457 |
| 40 | 136.3 | 0.331 | -0.068 | 0.056 | -0.039 | -63.233 | 1.273 | -2.524 | 2.827 | -1.329 | 2.816 | 3.114 | -64.732 | 2546.494 | 2747.808 |
| 41 | 136.3 | 0.331 | -0.068 | 0.058 | -0.036 | -64.732 | 1.329 | -2.816 | 3.114 | -1.387 | 3.111 | 3.406 | -65.966 | 2607.879 | 2626.113 |
| 42 | 136.3 | 0.331 | -0.068 | 0.060 | -0.033 | -65.966 | 1.387 | -3.111 | 3.406 | -1.447 | 3.409 | 3.703 | -66.998 | 2666.060 | 2502.855 |
| 43 | 136.3 | 0.331 | -0.068 | 0.061 | -0.031 | -66.998 | 1.447 | -3.409 | 3.703 | -1.508 | 3.709 | 4.004 | -67.873 | 2721.572 | 2378.372 |
| 44 | 136.3 | 0.331 | -0.068 | 0.062 | -0.028 | -67.873 | 1.508 | -3.709 | 4.004 | -1.570 | 4.011 | 4.308 | -68.622 | 2774.833 | 2252.909 |
| 45 | 136.3 | 0.331 | -0.068 | 0.063 | -0.027 | -68.622 | 1.570 | -4.011 | 4.308 | -1.633 | 4.316 | 4.615 | -69.272 | 2826.173 | 2126.648 |
| 46 | 136.3 | 0.331 | -0.068 | 0.064 | -0.025 | -69.272 | 1.633 | -4.316 | 4.615 | -1.697 | 4.622 | 4.924 | -69.839 | 2875.857 | 1999.725 |
| 47 | 136.3 | 0.331 | -0.068 | 0.064 | -0.023 | -69.839 | 1.697 | -4.622 | 4.924 | -1.761 | 4.930 | 5.235 | -70.340 | 2924.098 | 1872.248 |
| 48 | 136.3 | 0.331 | -0.023 | 0.022 | -0.007 | -70.340 | 1.761 | -4.930 | 5.235 | -1.783 | 5.254 | 5.548 | -71.255 | 2971.074 | 1744.299 |
| 49 | 136.3 | 0.331 | -0.023 | 0.022 | -0.007 | -71.255 | 1.783 | -5.254 | 5.548 | -1.805 | 5.578 | 5.862 | -72.072 | 3016.931 | 1615.945 |
| 50 | 136.3 | 0.331 | -0.023 | 0.022 | -0.007 | -72.072 | 1.805 | -5.578 | 5.862 | -1.826 | 5.902 | 6.178 | -72.805 | 3060.733 | 1486.875 |
| 51 | 136.3 | 0.331 | -0.023 | 0.022 | -0.006 | -72.805 | 1.826 | -5.902 | 6.178 | -1.848 | 6.227 | 6.496 | -73.468 | 3102.690 | 1357.193 |
| 52 | 136.3 | 0.331 | -0.023 | 0.022 | -0.006 | -73.468 | 1.848 | -6.227 | 6.496 | -1.870 | 6.552 | 6.814 | -74.068 | 3142.982 | 1226.985 |
| 53 | 136.3 | 0.331 | -0.023 | 0.022 | -0.006 | -74.068 | 1.870 | -6.552 | 6.814 | -1.892 | 6.878 | 7.133 | -74.615 | 3181.767 | 1096.319 |
| 54 | 136.3 | 0.331 | -0.023 | 0.022 | -0.005 | -74.615 | 1.892 | -6.878 | 7.133 | -1.915 | 7.203 | 7.453 | -75.115 | 3219.181 | 965.255 |
| 55 | 136.3 | 0.331 | -0.023 | 0.022 | -0.005 | -75.115 | 1.915 | -7.203 | 7.453 | -1.937 | 7.529 | 7.774 | -75.574 | 3255.341 | 833.839 |
| 56 | 136.3 | 0.331 | -0.023 | 0.022 | -0.005 | -75.574 | 1.937 | -7.529 | 7.774 | -1.959 | 7.855 | 8.096 | -75.996 | 3290.354 | 702.113 |
| 57 | 136.3 | 0.331 | -0.023 | 0.022 | -0.005 | -75.996 | 1.959 | -7.855 | 8.096 | -1.981 | 8.181 | 8.418 | -76.387 | 3324.310 | 570.110 |
| 58 | 136.3 | 0.331 | -0.023 | 0.022 | -0.005 | -76.387 | 1.981 | -8.181 | 8.418 | -2.004 | 8.508 | 8.741 | -76.748 | 3357.293 | 437.861 |
| 59 | 136.3 | 0.331 | -0.023 | 0.022 | -0.004 | -76.748 | 2.004 | -8.508 | 8.741 | -2.026 | 8.834 | 9.064 | -77.084 | 3389.374 | 305.390 |
| 60 | 136.3 | 0.331 | -0.023 | 0.022 | -0.004 | -77.084 | 2.026 | -8.834 | 9.064 | -2.048 | 9.161 | 9.387 | -77.396 | 3420.618 | 172.720 |
| 61 | 136.3 | 0.331 | -0.023 | 0.022 | -0.004 | -77.396 | 2.048 | -9.161 | 9.387 | -2.071 | 9.488 | 9.712 | -77.688 | 3451.085 | 39.869 |
| 62 | 136.3 | 0.331 | -0.023 | 0.022 | -0.004 | -77.688 | 2.071 | -9.488 | 9.712 | -2.093 | 9.815 | 10.036 | -77.961 | 3480.826 | -93.147 |
| 63 | 136.3 | 0.331 | -0.023 | 0.022 | -0.004 | -77.961 | 2.093 | -9.815 | 10.036 | -2.116 | 10.142 | 10.361 | -78.217 | 3509.890 | -226.312 |
| | | | | | | | | | | | | | | 3538.319 | -359.615 |

| Segment no. | Height of Segment | DL per block | Wind Load (Cpi=-0.2) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 134 | 0.331 | 0.057 | 0.056 | 0.009 | 84.300 | 0.969 | 9.713 | 9.761 | -1.026 | -9.372 | 9.428 | 83.755 | 0 | 0 |
| 2 | 134 | 0.331 | 0.057 | 0.056 | 0.010 | 83.755 | 1.026 | 9.372 | 9.428 | -1.082 | -9.032 | 9.096 | 83.169 | 13.309 | 133.337 |
| 3 | 134 | 0.331 | 0.057 | 0.056 | 0.010 | 83.169 | 1.082 | 9.032 | 9.096 | -1.138 | -8.691 | 8.765 | 82.540 | 27.886 | 266.542 |
| 4 | 134 | 0.331 | 0.057 | 0.056 | 0.010 | 82.540 | 1.138 | 8.691 | 8.765 | -1.194 | -8.349 | 8.434 | 81.861 | 43.824 | 399.591 |
| 5 | 134 | 0.331 | 0.057 | 0.056 | 0.011 | 81.861 | 1.194 | 8.349 | 8.434 | -1.250 | -8.007 | 8.104 | 81.127 | 61.221 | 532.457 |
| 6 | 134 | 0.331 | 0.057 | 0.056 | 0.011 | 81.127 | 1.250 | 8.007 | 8.104 | -1.306 | -7.665 | 7.776 | 80.332 | 80.192 | 665.107 |
| 7 | 134 | 0.331 | 0.057 | 0.056 | 0.012 | 80.332 | 1.306 | 7.665 | 7.776 | -1.362 | -7.323 | 7.448 | 79.466 | 100.859 | 797.504 |
| 8 | 134 | 0.331 | 0.057 | 0.056 | 0.012 | 79.466 | 1.362 | 7.323 | 7.448 | -1.417 | -6.980 | 7.122 | 78.520 | 123.364 | 929.600 |
| 9 | 134 | 0.331 | 0.057 | 0.056 | 0.012 | 78.520 | 1.417 | 6.980 | 7.122 | -1.473 | -6.636 | 6.798 | 77.485 | 147.863 | 1061.342 |
| 10 | 134 | 0.331 | 0.057 | 0.055 | 0.013 | 77.485 | 1.473 | 6.636 | 6.798 | -1.529 | -6.292 | 6.475 | 76.345 | 174.532 | 1192.661 |
| 11 | 134 | 0.331 | 0.057 | 0.055 | 0.014 | 76.345 | 1.529 | 6.292 | 6.475 | -1.584 | -5.947 | 6.155 | 75.087 | 203.570 | 1323.477 |
| 12 | 134 | 0.331 | 0.057 | 0.055 | 0.014 | 75.087 | 1.584 | 5.947 | 6.155 | -1.639 | -5.602 | 5.837 | 73.691 | 235.203 | 1453.690 |
| 13 | 134 | 0.331 | 0.057 | 0.055 | 0.015 | 73.691 | 1.639 | 5.602 | 5.837 | -1.694 | -5.256 | 5.522 | 72.135 | 269.688 | 1583.176 |
| 14 | 134 | 0.331 | 0.057 | 0.055 | 0.016 | 72.135 | 1.694 | 5.256 | 5.522 | -1.749 | -4.909 | 5.212 | 70.392 | 307.318 | 1711.784 |
| 15 | 134 | 0.331 | 0.057 | 0.055 | 0.016 | 70.392 | 1.749 | 4.909 | 5.212 | -1.804 | -4.562 | 4.905 | 68.429 | 348.426 | 1839.323 |
| 16 | 134 | 0.331 | 0.057 | 0.054 | 0.017 | 68.429 | 1.804 | 4.562 | 4.905 | -1.858 | -4.213 | 4.605 | 66.206 | 393.394 | 1965.553 |
| 17 | 134 | 0.331 | -0.057 | -0.054 | -0.018 | 66.206 | 1.858 | 4.213 | 4.605 | -1.804 | -3.901 | 4.298 | 65.183 | 442.659 | 2090.168 |
| 18 | 134 | 0.331 | -0.057 | -0.054 | -0.019 | 65.183 | 1.804 | 3.901 | 4.298 | -1.750 | -3.589 | 3.993 | 64.004 | 496.720 | 2212.778 |
| 19 | 134 | 0.331 | -0.057 | -0.053 | -0.021 | 64.004 | 1.750 | 3.589 | 3.993 | -1.697 | -3.279 | 3.692 | 62.633 | 552.964 | 2334.404 |
| 20 | 134 | 0.331 | -0.057 | -0.053 | -0.022 | 62.633 | 1.697 | 3.279 | 3.692 | -1.645 | -2.970 | 3.395 | 61.024 | 611.698 | 2454.846 |
| 21 | 134 | 0.331 | -0.057 | -0.052 | -0.024 | 61.024 | 1.645 | 2.970 | 3.395 | -1.593 | -2.663 | 3.103 | 59.111 | 673.295 | 2573.849 |
| 22 | 134 | 0.331 | -0.057 | -0.051 | -0.026 | 59.111 | 1.593 | 2.663 | 3.103 | -1.542 | -2.357 | 2.817 | 56.809 | 738.212 | 2691.074 |
| 23 | 134 | 0.331 | -0.057 | -0.050 | -0.028 | 56.809 | 1.542 | 2.357 | 2.817 | -1.492 | -2.054 | 2.538 | 54.000 | 807.005 | 2806.068 |
| 24 | 134 | 0.331 | -0.057 | -0.048 | -0.030 | 54.000 | 1.492 | 2.054 | 2.538 | -1.444 | -1.753 | 2.271 | 50.522 | 880.360 | 2918.206 |
| 25 | 134 | 0.331 | -0.057 | -0.047 | -0.033 | 50.522 | 1.444 | 1.753 | 2.271 | -1.397 | -1.454 | 2.017 | 46.153 | 959.123 | 3026.615 |
| 26 | 134 | 0.331 | -0.057 | -0.044 | -0.036 | 46.153 | 1.397 | 1.454 | 2.017 | -1.353 | -1.159 | 1.781 | 40.595 | 1044.316 | 3130.046 |
| 27 | 134 | 0.331 | -0.057 | -0.041 | -0.039 | 40.595 | 1.353 | 1.159 | 1.781 | -1.312 | -0.868 | 1.573 | 33.484 | 1137.143 | 3226.686 |
| 28 | 134 | 0.331 | -0.057 | -0.037 | -0.043 | 33.484 | 1.312 | 0.868 | 1.573 | -1.275 | -0.580 | 1.400 | 24.463 | 1238.894 | 3313.880 |
| 29 | 134 | 0.331 | -0.057 | -0.032 | -0.047 | 24.463 | 1.275 | 0.580 | 1.400 | -1.243 | -0.296 | 1.278 | 13.406 | 1350.656 | 3387.807 |
| 30 | 134 | 0.331 | -0.057 | -0.024 | -0.051 | 13.406 | 1.243 | 0.296 | 1.278 | -1.219 | -0.017 | 1.219 | 0.786 | 1472.627 | 3443.297 |
| 31 | 134 | 0.331 | -0.057 | -0.016 | -0.055 | 0.786 | 1.219 | 0.017 | 1.219 | -1.203 | 0.260 | 1.231 | -12.174 | 1602.975 | 3474.365 |
| 32 | 134 | 0.331 | -0.057 | -0.005 | -0.057 | -12.174 | 1.203 | -0.260 | 1.231 | -1.198 | 0.534 | 1.311 | -24.025 | 1736.963 | 3476.203 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 134 | 0.331 | -0.057 | 0.005 | -0.057 | -24.025 | 1.198 | -0.534 | 1.311 | -1.203 | 0.808 | 1.449 | -33.893 | 1867.949 | 3447.944 |
| 34 | 134 | 0.331 | -0.057 | 0.016 | -0.055 | -33.893 | 1.203 | -0.808 | 1.449 | -1.219 | 1.084 | 1.631 | -41.665 | 1990.340 | 3393.387 |
| 35 | 134 | 0.331 | -0.057 | 0.024 | -0.051 | -41.665 | 1.219 | -1.084 | 1.631 | -1.243 | 1.364 | 1.845 | -47.656 | 2101.571 | 3318.663 |
| 36 | 134 | 0.331 | -0.057 | 0.032 | -0.047 | -47.656 | 1.243 | -1.364 | 1.845 | -1.275 | 1.648 | 2.083 | -52.274 | 2201.675 | 3229.583 |
| 37 | 134 | 0.331 | -0.057 | 0.037 | -0.043 | -52.274 | 1.275 | -1.648 | 2.083 | -1.312 | 1.935 | 2.338 | -55.874 | 2291.934 | 3130.541 |
| 38 | 134 | 0.331 | -0.057 | 0.041 | -0.039 | -55.874 | 1.312 | -1.935 | 2.338 | -1.353 | 2.227 | 2.606 | -58.724 | 2373.926 | 3024.554 |
| 39 | 134 | 0.331 | -0.057 | 0.044 | -0.036 | -58.724 | 1.353 | -2.227 | 2.606 | -1.397 | 2.522 | 2.883 | -61.018 | 2449.102 | 2913.628 |
| 40 | 134 | 0.331 | -0.057 | 0.047 | -0.033 | -61.018 | 1.397 | -2.522 | 2.883 | -1.444 | 2.820 | 3.168 | -62.894 | 2518.671 | 2799.102 |
| 41 | 134 | 0.331 | -0.057 | 0.048 | -0.030 | -62.894 | 1.444 | -2.820 | 3.168 | -1.492 | 3.121 | 3.460 | -64.452 | 2583.599 | 2681.883 |
| 42 | 134 | 0.331 | -0.057 | 0.050 | -0.028 | -64.452 | 1.492 | -3.121 | 3.460 | -1.542 | 3.425 | 3.756 | -65.762 | 2644.654 | 2562.601 |
| 43 | 134 | 0.331 | -0.057 | 0.051 | -0.026 | -65.762 | 1.542 | -3.425 | 3.756 | -1.593 | 3.730 | 4.056 | -66.878 | 2702.445 | 2441.703 |
| 44 | 134 | 0.331 | -0.057 | 0.052 | -0.024 | -66.878 | 1.593 | -3.730 | 4.056 | -1.645 | 4.038 | 4.360 | -67.837 | 2757.455 | 2319.515 |
| 45 | 134 | 0.331 | -0.057 | 0.053 | -0.022 | -67.837 | 1.645 | -4.038 | 4.360 | -1.697 | 4.347 | 4.666 | -68.671 | 2810.077 | 2196.280 |
| 46 | 134 | 0.331 | -0.057 | 0.053 | -0.021 | -68.671 | 1.697 | -4.347 | 4.666 | -1.750 | 4.657 | 4.975 | -69.402 | 2860.627 | 2072.180 |
| 47 | 134 | 0.331 | -0.057 | 0.054 | -0.019 | -69.402 | 1.750 | -4.657 | 4.975 | -1.804 | 4.969 | 5.286 | -70.046 | 2909.365 | 1947.358 |
| 48 | 134 | 0.331 | -0.011 | 0.011 | -0.004 | -70.046 | 1.804 | -4.969 | 5.286 | -1.815 | 5.296 | 5.598 | -71.086 | 2956.509 | 1821.925 |
| 49 | 134 | 0.331 | -0.011 | 0.011 | -0.003 | -71.086 | 1.815 | -5.296 | 5.598 | -1.825 | 5.623 | 5.912 | -72.016 | 3002.238 | 1695.969 |
| 50 | 134 | 0.331 | -0.011 | 0.011 | -0.003 | -72.016 | 1.825 | -5.623 | 5.912 | -1.836 | 5.951 | 6.228 | -72.851 | 3045.673 | 1569.204 |
| 51 | 134 | 0.331 | -0.011 | 0.011 | -0.003 | -72.851 | 1.836 | -5.951 | 6.228 | -1.847 | 6.279 | 6.545 | -73.606 | 3087.047 | 1441.751 |
| 52 | 134 | 0.331 | -0.011 | 0.011 | -0.003 | -73.606 | 1.847 | -6.279 | 6.545 | -1.858 | 6.607 | 6.864 | -74.291 | 3126.558 | 1313.709 |
| 53 | 134 | 0.331 | -0.011 | 0.011 | -0.003 | -74.291 | 1.858 | -6.607 | 6.864 | -1.869 | 6.936 | 7.183 | -74.915 | 3164.378 | 1185.157 |
| 54 | 134 | 0.331 | -0.011 | 0.011 | -0.003 | -74.915 | 1.869 | -6.936 | 7.183 | -1.880 | 7.264 | 7.503 | -75.486 | 3200.659 | 1056.162 |
| 55 | 134 | 0.331 | -0.011 | 0.011 | -0.003 | -75.486 | 1.880 | -7.264 | 7.503 | -1.892 | 7.592 | 7.824 | -76.010 | 3235.533 | 926.780 |
| 56 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -76.010 | 1.892 | -7.592 | 7.824 | -1.903 | 7.921 | 8.146 | -76.493 | 3269.116 | 797.056 |
| 57 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -76.493 | 1.903 | -7.921 | 8.146 | -1.914 | 8.250 | 8.469 | -76.939 | 3301.511 | 667.031 |
| 58 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -76.939 | 1.914 | -8.250 | 8.469 | -1.925 | 8.578 | 8.792 | -77.352 | 3332.809 | 536.737 |
| 59 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -77.352 | 1.925 | -8.578 | 8.792 | -1.936 | 8.907 | 9.115 | -77.736 | 3363.092 | 406.204 |
| 60 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -77.736 | 1.936 | -8.907 | 9.115 | -1.947 | 9.236 | 9.439 | -78.094 | 3392.432 | 275.455 |
| 61 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -78.094 | 1.947 | -9.236 | 9.439 | -1.959 | 9.565 | 9.764 | -78.428 | 3420.896 | 144.513 |
| 62 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -78.428 | 1.959 | -9.565 | 9.764 | -1.970 | 9.894 | 10.088 | -78.740 | 3448.541 | 13.396 |
| 63 | 134 | 0.331 | -0.011 | 0.011 | -0.002 | -78.740 | 1.970 | -9.894 | 10.088 | -1.981 | 10.223 | 10.413 | -79.033 | 3475.422 | -117.880 |
| | | | | | | | | | | | | | | 3501.586 | -249.301 |

| Segment no. | Height of Segment | DL+LL(PL-3/4) | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | X | Y |
| 1 | 134 | 0.461 | 80.500 | 2.394 | 14.305 | 14.504 | -2.394 | -13.843 | 14.049 | 80.189 | 0 | 0 |
| 2 | 134 | 0.461 | 80.189 | 2.394 | 13.843 | 14.049 | -2.394 | -13.382 | 13.594 | 79.858 | 22.116 | 132.162 |
| 3 | 134 | 0.461 | 79.858 | 2.394 | 13.382 | 13.594 | -2.394 | -12.921 | 13.140 | 79.504 | 44.949 | 264.203 |
| 4 | 134 | 0.461 | 79.504 | 2.394 | 12.921 | 13.140 | -2.394 | -12.459 | 12.687 | 79.124 | 68.545 | 396.109 |
| 5 | 134 | 0.461 | 79.124 | 2.394 | 12.459 | 12.687 | -2.394 | -11.998 | 12.234 | 78.716 | 92.955 | 527.867 |
| 6 | 134 | 0.461 | 78.716 | 2.394 | 11.998 | 12.234 | -2.394 | -11.536 | 11.782 | 78.277 | 118.239 | 659.460 |
| 7 | 134 | 0.461 | 78.277 | 2.394 | 11.536 | 11.782 | -2.394 | -11.075 | 11.331 | 77.803 | 144.457 | 790.870 |
| 8 | 134 | 0.461 | 77.803 | 2.394 | 11.075 | 11.331 | -2.394 | -10.614 | 10.880 | 77.290 | 171.683 | 922.075 |
| 9 | 134 | 0.461 | 77.290 | 2.394 | 10.614 | 10.880 | -2.394 | -10.152 | 10.431 | 76.732 | 199.992 | 1053.050 |
| 10 | 134 | 0.461 | 76.732 | 2.394 | 10.152 | 10.431 | -2.394 | -9.691 | 9.982 | 76.125 | 229.474 | 1183.767 |
| 11 | 134 | 0.461 | 76.125 | 2.394 | 9.691 | 9.982 | -2.394 | -9.229 | 9.535 | 75.460 | 260.227 | 1314.190 |
| 12 | 134 | 0.461 | 75.460 | 2.394 | 9.229 | 9.535 | -2.394 | -8.768 | 9.089 | 74.729 | 292.362 | 1444.280 |
| 13 | 134 | 0.461 | 74.729 | 2.394 | 8.768 | 9.089 | -2.394 | -8.307 | 8.645 | 73.924 | 326.004 | 1573.988 |
| 14 | 134 | 0.461 | 73.924 | 2.394 | 8.307 | 8.645 | -2.394 | -7.845 | 8.202 | 73.031 | 361.296 | 1703.257 |
| 15 | 134 | 0.461 | 73.031 | 2.394 | 7.845 | 8.202 | -2.394 | -7.384 | 7.762 | 72.037 | 398.403 | 1832.017 |
| 16 | 134 | 0.461 | 72.037 | 2.394 | 7.384 | 7.762 | -2.394 | -6.922 | 7.325 | 70.924 | 437.510 | 1960.183 |
| 17 | 134 | 0.461 | 70.924 | 2.394 | 6.922 | 7.325 | -2.394 | -6.461 | 6.890 | 69.670 | 478.835 | 2087.652 |
| 18 | 134 | 0.461 | 69.670 | 2.394 | 6.461 | 6.890 | -2.394 | -6.000 | 6.459 | 68.248 | 522.629 | 2214.294 |
| 19 | 134 | 0.461 | 68.248 | 2.394 | 6.000 | 6.459 | -2.394 | -5.538 | 6.033 | 66.624 | 569.184 | 2339.947 |
| 20 | 134 | 0.461 | 66.624 | 2.394 | 5.538 | 6.033 | -2.394 | -5.077 | 5.613 | 64.755 | 618.842 | 2464.405 |
| 21 | 134 | 0.461 | 64.755 | 2.394 | 5.077 | 5.613 | -2.394 | -4.615 | 5.199 | 62.586 | 672.008 | 2587.407 |
| 22 | 134 | 0.461 | 62.586 | 2.394 | 4.615 | 5.199 | -2.394 | -4.154 | 4.794 | 60.046 | 729.158 | 2708.609 |
| 23 | 134 | 0.461 | 60.046 | 2.394 | 4.154 | 4.794 | -2.394 | -3.693 | 4.401 | 57.045 | 790.854 | 2827.561 |
| 24 | 134 | 0.461 | 57.045 | 2.394 | 3.693 | 4.401 | -2.394 | -3.231 | 4.021 | 53.467 | 857.760 | 2943.663 |
| 25 | 134 | 0.461 | 53.467 | 2.394 | 3.231 | 4.021 | -2.394 | -2.770 | 3.661 | 49.164 | 930.653 | 3056.102 |
| 26 | 134 | 0.461 | 49.164 | 2.394 | 2.770 | 3.661 | -2.394 | -2.308 | 3.325 | 43.959 | 1010.421 | 3163.773 |
| 27 | 134 | 0.461 | 43.959 | 2.394 | 2.308 | 3.325 | -2.394 | -1.847 | 3.023 | 37.652 | 1098.043 | 3265.156 |
| 28 | 134 | 0.461 | 37.652 | 2.394 | 1.847 | 3.023 | -2.394 | -1.386 | 2.766 | 30.062 | 1194.502 | 3358.170 |
| 29 | 134 | 0.461 | 30.062 | 2.394 | 1.386 | 2.766 | -2.394 | -0.924 | 2.566 | 21.109 | 1300.594 | 3440.026 |
| 30 | 134 | 0.461 | 21.109 | 2.394 | 0.924 | 2.566 | -2.394 | -0.463 | 2.438 | 10.940 | 1416.569 | 3507.151 |
| 31 | 134 | 0.461 | 10.940 | 2.394 | 0.463 | 2.438 | -2.394 | -0.001 | 2.394 | 0.032 | 1541.577 | 3555.411 |
| 32 | 134 | 0.461 | 0.032 | 2.394 | 0.001 | 2.394 | -2.394 | 0.460 | 2.438 | -10.879 | 1673.142 | 3580.842 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 134 | 0.461 | -10.879 | 2.394 | -0.460 | 2.438 | -2.394 | 0.921 | 2.565 | -21.054 | 1807.142 | 3580.916 |
| 34 | 134 | 0.461 | -21.054 | 2.394 | -0.921 | 2.565 | -2.394 | 1.383 | 2.765 | -30.015 | 1938.733 | 3555.624 |
| 35 | 134 | 0.461 | -30.015 | 2.394 | -1.383 | 2.765 | -2.394 | 1.844 | 3.022 | -37.612 | 2063.788 | 3507.485 |
| 36 | 134 | 0.461 | -37.612 | 2.394 | -1.844 | 3.022 | -2.394 | 2.306 | 3.324 | -43.926 | 2179.818 | 3440.455 |
| 37 | 134 | 0.461 | -43.926 | 2.394 | -2.306 | 3.324 | -2.394 | 2.767 | 3.659 | -49.137 | 2285.967 | 3358.672 |
| 38 | 134 | 0.461 | -49.137 | 2.394 | -2.767 | 3.659 | -2.394 | 3.229 | 4.019 | -53.445 | 2382.479 | 3265.713 |
| 39 | 134 | 0.461 | -53.445 | 2.394 | -3.229 | 4.019 | -2.394 | 3.690 | 4.398 | -57.027 | 2470.149 | 3164.372 |
| 40 | 134 | 0.461 | -57.027 | 2.394 | -3.690 | 4.398 | -2.394 | 4.151 | 4.792 | -60.031 | 2549.959 | 3056.732 |
| 41 | 134 | 0.461 | -60.031 | 2.394 | -4.151 | 4.792 | -2.394 | 4.613 | 5.197 | -62.573 | 2622.888 | 2944.316 |
| 42 | 134 | 0.461 | -62.573 | 2.394 | -4.613 | 5.197 | -2.394 | 5.074 | 5.610 | -64.744 | 2689.826 | 2828.233 |
| 43 | 134 | 0.461 | -64.744 | 2.394 | -5.074 | 5.610 | -2.394 | 5.536 | 6.031 | -66.614 | 2751.550 | 2709.295 |
| 44 | 134 | 0.461 | -66.614 | 2.394 | -5.536 | 6.031 | -2.394 | 5.997 | 6.457 | -68.239 | 2808.724 | 2588.105 |
| 45 | 134 | 0.461 | -68.239 | 2.394 | -5.997 | 6.457 | -2.394 | 6.458 | 6.888 | -69.663 | 2861.911 | 2465.112 |
| 46 | 134 | 0.461 | -69.663 | 2.394 | -6.458 | 6.888 | -2.394 | 6.920 | 7.322 | -70.917 | 2911.589 | 2340.661 |
| 47 | 134 | 0.461 | -70.917 | 2.394 | -6.920 | 7.322 | -2.394 | 7.381 | 7.760 | -72.031 | 2958.160 | 2215.014 |
| 48 | 134 | 2.061 | -72.031 | 2.394 | -7.381 | 7.760 | -2.394 | 9.443 | 9.741 | -75.774 | 3001.969 | 2088.378 |
| 49 | 134 | 0.461 | -75.774 | 2.394 | -9.443 | 9.741 | -2.394 | 9.904 | 10.189 | -76.412 | 3043.307 | 1960.914 |
| 50 | 134 | 0.461 | -76.412 | 2.394 | -9.904 | 10.189 | -2.394 | 10.365 | 10.638 | -76.996 | 3076.236 | 1831.023 |
| 51 | 134 | 0.461 | -76.996 | 2.394 | -10.365 | 10.638 | -2.394 | 10.827 | 11.088 | -77.532 | 3107.718 | 1700.773 |
| 52 | 134 | 0.461 | -77.532 | 2.394 | -10.827 | 11.088 | -2.394 | 11.288 | 11.539 | -78.027 | 3137.870 | 1570.210 |
| 53 | 134 | 0.461 | -78.027 | 2.394 | -11.288 | 11.539 | -2.394 | 11.750 | 11.991 | -78.484 | 3166.799 | 1439.370 |
| 54 | 134 | 0.461 | -78.484 | 2.394 | -11.750 | 11.991 | -2.394 | 12.211 | 12.443 | -78.909 | 3194.598 | 1308.285 |
| 55 | 134 | 0.461 | -78.909 | 2.394 | -12.211 | 12.443 | -2.394 | 12.672 | 12.896 | -79.303 | 3221.349 | 1176.982 |
| 56 | 134 | 0.461 | -79.303 | 2.394 | -12.672 | 12.896 | -2.394 | 13.134 | 13.350 | -79.670 | 3247.127 | 1045.485 |
| 57 | 134 | 0.461 | -79.670 | 2.394 | -13.134 | 13.350 | -2.394 | 13.595 | 13.804 | -80.014 | 3272.000 | 913.814 |
| 58 | 134 | 0.461 | -80.014 | 2.394 | -13.595 | 13.804 | -2.394 | 14.057 | 14.259 | -80.335 | 3296.027 | 781.985 |
| 59 | 134 | 0.461 | -80.335 | 2.394 | -14.057 | 14.259 | -2.394 | 14.518 | 14.714 | -80.637 | 3319.264 | 650.016 |
| 60 | 134 | 0.461 | -80.637 | 2.394 | -14.518 | 14.714 | -2.394 | 14.979 | 15.169 | -80.921 | 3341.760 | 517.917 |
| 61 | 134 | 0.461 | -80.921 | 2.394 | -14.979 | 15.169 | -2.394 | 15.441 | 15.625 | -81.188 | 3363.561 | 385.703 |
| 62 | 134 | 0.461 | -81.188 | 2.394 | -15.441 | 15.625 | -2.394 | 15.902 | 16.081 | -81.439 | 3384.706 | 253.382 |
| 63 | 134 | 0.461 | -81.439 | 2.394 | -15.902 | 16.081 | -2.394 | 16.364 | 16.538 | -81.677 | 3405.235 | 120.963 |
| | | | | | | | | | | | 3425.182 | -11.544 |

| Segment no. | Height of Segment | DL+LL(1/2 PL) | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | X | Y |
| 1 | 133 | 0.458 | 79.500 | 2.725 | 14.705 | 14.955 | -2.725 | -14.247 | 14.505 | 79.170 | 0 | 0 |
| 2 | 133 | 0.458 | 79.170 | 2.725 | 14.247 | 14.505 | -2.725 | -13.789 | 14.056 | 78.820 | 24.237 | 130.773 |
| 3 | 133 | 0.458 | 78.820 | 2.725 | 13.789 | 14.056 | -2.725 | -13.331 | 13.607 | 78.446 | 49.227 | 261.404 |
| 4 | 133 | 0.458 | 78.446 | 2.725 | 13.331 | 13.607 | -2.725 | -12.873 | 13.158 | 78.046 | 75.015 | 391.880 |
| 5 | 133 | 0.458 | 78.046 | 2.725 | 12.873 | 13.158 | -2.725 | -12.415 | 12.711 | 77.619 | 101.655 | 522.185 |
| 6 | 133 | 0.458 | 77.619 | 2.725 | 12.415 | 12.711 | -2.725 | -11.957 | 12.264 | 77.160 | 129.202 | 652.301 |
| 7 | 133 | 0.458 | 77.160 | 2.725 | 11.957 | 12.264 | -2.725 | -11.499 | 11.818 | 76.666 | 157.719 | 782.207 |
| 8 | 133 | 0.458 | 76.666 | 2.725 | 11.499 | 11.818 | -2.725 | -11.041 | 11.373 | 76.134 | 187.276 | 911.882 |
| 9 | 133 | 0.458 | 76.134 | 2.725 | 11.041 | 11.373 | -2.725 | -10.583 | 10.928 | 75.559 | 217.948 | 1041.297 |
| 10 | 133 | 0.458 | 75.559 | 2.725 | 10.583 | 10.928 | -2.725 | -10.125 | 10.486 | 74.935 | 249.821 | 1170.421 |
| 11 | 133 | 0.458 | 74.935 | 2.725 | 10.125 | 10.486 | -2.725 | -9.667 | 10.044 | 74.256 | 282.989 | 1299.219 |
| 12 | 133 | 0.458 | 74.256 | 2.725 | 9.667 | 10.044 | -2.725 | -9.209 | 9.604 | 73.515 | 317.558 | 1427.648 |
| 13 | 133 | 0.458 | 73.515 | 2.725 | 9.209 | 9.604 | -2.725 | -8.751 | 9.166 | 72.702 | 353.647 | 1555.658 |
| 14 | 133 | 0.458 | 72.702 | 2.725 | 8.751 | 9.166 | -2.725 | -8.293 | 8.730 | 71.808 | 391.388 | 1683.191 |
| 15 | 133 | 0.458 | 71.808 | 2.725 | 8.293 | 8.730 | -2.725 | -7.835 | 8.296 | 70.821 | 430.934 | 1810.175 |
| 16 | 133 | 0.458 | 70.821 | 2.725 | 7.835 | 8.296 | -2.725 | -7.377 | 7.865 | 69.725 | 472.456 | 1936.528 |
| 17 | 133 | 0.458 | 69.725 | 2.725 | 7.377 | 7.865 | -2.725 | -6.920 | 7.437 | 68.502 | 516.150 | 2062.146 |
| 18 | 133 | 0.458 | 68.502 | 2.725 | 6.920 | 7.437 | -2.725 | -6.462 | 7.013 | 67.131 | 562.238 | 2186.905 |
| 19 | 133 | 0.458 | 67.131 | 2.725 | 6.462 | 7.013 | -2.725 | -6.004 | 6.593 | 65.584 | 610.979 | 2310.652 |
| 20 | 133 | 0.458 | 65.584 | 2.725 | 6.004 | 6.593 | -2.725 | -5.546 | 6.179 | 63.828 | 662.666 | 2433.198 |
| 21 | 133 | 0.458 | 63.828 | 2.725 | 5.546 | 6.179 | -2.725 | -5.088 | 5.772 | 61.823 | 717.643 | 2554.303 |
| 22 | 133 | 0.458 | 61.823 | 2.725 | 5.088 | 5.772 | -2.725 | -4.630 | 5.372 | 59.516 | 776.304 | 2673.667 |
| 23 | 133 | 0.458 | 59.516 | 2.725 | 4.630 | 5.372 | -2.725 | -4.172 | 4.983 | 56.844 | 839.107 | 2790.906 |
| 24 | 133 | 0.458 | 56.844 | 2.725 | 4.172 | 4.983 | -2.725 | -3.714 | 4.607 | 53.727 | 906.578 | 2905.521 |
| 25 | 133 | 0.458 | 53.727 | 2.725 | 3.714 | 4.607 | -2.725 | -3.256 | 4.246 | 50.068 | 979.319 | 3016.866 |
| 26 | 133 | 0.458 | 50.068 | 2.725 | 3.256 | 4.246 | -2.725 | -2.798 | 3.906 | 45.752 | 1058.007 | 3124.091 |
| 27 | 133 | 0.458 | 45.752 | 2.725 | 2.798 | 3.906 | -2.725 | -2.340 | 3.592 | 40.648 | 1143.377 | 3226.077 |
| 28 | 133 | 0.458 | 40.648 | 2.725 | 2.340 | 3.592 | -2.725 | -1.882 | 3.312 | 34.626 | 1236.180 | 3321.348 |
| 29 | 133 | 0.458 | 34.626 | 2.725 | 1.882 | 3.312 | -2.725 | -1.424 | 3.075 | 27.587 | 1337.090 | 3407.985 |
| 30 | 133 | 0.458 | 27.587 | 2.725 | 1.424 | 3.075 | -2.725 | -0.966 | 2.892 | 19.517 | 1446.533 | 3483.558 |
| 31 | 133 | 0.458 | 19.517 | 2.725 | 0.966 | 2.892 | -2.725 | -0.508 | 2.772 | 10.560 | 1564.412 | 3545.149 |
| 32 | 133 | 2.058 | 10.560 | 2.725 | 0.508 | 2.772 | -2.725 | 1.550 | 3.135 | -29.627 | 1689.771 | 3589.583 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 133 | 0.458 | -29.627 | 2.725 | -1.550 | 3.135 | -2.725 | 2.008 | 3.385 | -36.380 | 1820.518 | 3613.957 |
| 34 | 133 | 0.458 | -36.380 | 2.725 | -2.008 | 3.385 | -2.725 | 2.466 | 3.675 | -42.138 | 1936.130 | 3548.209 |
| 35 | 133 | 0.458 | -42.138 | 2.725 | -2.466 | 3.675 | -2.725 | 2.924 | 3.997 | -47.011 | 2043.209 | 3469.321 |
| 36 | 133 | 0.458 | -47.011 | 2.725 | -2.924 | 3.997 | -2.725 | 3.382 | 4.343 | -51.134 | 2141.833 | 3380.090 |
| 37 | 133 | 0.458 | -51.134 | 2.725 | -3.382 | 4.343 | -2.725 | 3.840 | 4.709 | -54.633 | 2232.519 | 3282.802 |
| 38 | 133 | 0.458 | -54.633 | 2.725 | -3.840 | 4.709 | -2.725 | 4.298 | 5.089 | -57.619 | 2315.976 | 3179.245 |
| 39 | 133 | 0.458 | -57.619 | 2.725 | -4.298 | 5.089 | -2.725 | 4.756 | 5.481 | -60.184 | 2392.958 | 3070.789 |
| 40 | 133 | 0.458 | -60.184 | 2.725 | -4.756 | 5.481 | -2.725 | 5.214 | 5.883 | -62.402 | 2464.186 | 2958.469 |
| 41 | 133 | 0.458 | -62.402 | 2.725 | -5.214 | 5.883 | -2.725 | 5.672 | 6.292 | -64.334 | 2530.316 | 2843.075 |
| 42 | 133 | 0.458 | -64.334 | 2.725 | -5.672 | 6.292 | -2.725 | 6.130 | 6.708 | -66.028 | 2591.931 | 2725.208 |
| 43 | 133 | 0.458 | -66.028 | 2.725 | -6.130 | 6.708 | -2.725 | 6.587 | 7.129 | -67.524 | 2649.536 | 2605.331 |
| 44 | 133 | 0.458 | -67.524 | 2.725 | -6.587 | 7.129 | -2.725 | 7.045 | 7.554 | -68.852 | 2703.572 | 2483.802 |
| 45 | 133 | 0.458 | -68.852 | 2.725 | -7.045 | 7.554 | -2.725 | 7.503 | 7.983 | -70.038 | 2754.417 | 2360.905 |
| 46 | 133 | 0.458 | -70.038 | 2.725 | -7.503 | 7.983 | -2.725 | 7.961 | 8.415 | -71.103 | 2802.400 | 2236.862 |
| 47 | 133 | 0.458 | -71.103 | 2.725 | -7.961 | 8.415 | -2.725 | 8.419 | 8.849 | -72.063 | 2847.806 | 2111.853 |
| 48 | 133 | 0.458 | -72.063 | 2.725 | -8.419 | 8.849 | -2.725 | 8.877 | 9.286 | -72.933 | 2890.882 | 1986.022 |
| 49 | 133 | 0.458 | -72.933 | 2.725 | -8.877 | 9.286 | -2.725 | 9.335 | 9.725 | -73.725 | 2931.842 | 1859.486 |
| 50 | 133 | 0.458 | -73.725 | 2.725 | -9.335 | 9.725 | -2.725 | 9.793 | 10.165 | -74.448 | 2970.876 | 1732.343 |
| 51 | 133 | 0.458 | -74.448 | 2.725 | -9.793 | 10.165 | -2.725 | 10.251 | 10.607 | -75.112 | 3008.149 | 1604.673 |
| 52 | 133 | 0.458 | -75.112 | 2.725 | -10.251 | 10.607 | -2.725 | 10.709 | 11.050 | -75.722 | 3043.807 | 1476.542 |
| 53 | 133 | 0.458 | -75.722 | 2.725 | -10.709 | 11.050 | -2.725 | 11.167 | 11.495 | -76.285 | 3077.979 | 1348.007 |
| 54 | 133 | 0.458 | -76.285 | 2.725 | -11.167 | 11.495 | -2.725 | 11.625 | 11.940 | -76.806 | 3110.781 | 1219.115 |
| 55 | 133 | 0.458 | -76.806 | 2.725 | -11.625 | 11.940 | -2.725 | 12.083 | 12.387 | -77.289 | 3142.315 | 1089.908 |
| 56 | 133 | 0.458 | -77.289 | 2.725 | -12.083 | 12.387 | -2.725 | 12.541 | 12.834 | -77.739 | 3172.672 | 960.419 |
| 57 | 133 | 0.458 | -77.739 | 2.725 | -12.541 | 12.834 | -2.725 | 12.999 | 13.282 | -78.159 | 3201.936 | 830.678 |
| 58 | 133 | 0.458 | -78.159 | 2.725 | -12.999 | 13.282 | -2.725 | 13.457 | 13.730 | -78.551 | 3230.180 | 700.712 |
| 59 | 133 | 0.458 | -78.551 | 2.725 | -13.457 | 13.730 | -2.725 | 13.915 | 14.179 | -78.918 | 3257.472 | 570.542 |
| 60 | 133 | 0.458 | -78.918 | 2.725 | -13.915 | 14.179 | -2.725 | 14.373 | 14.629 | -79.263 | 3283.872 | 440.188 |
| 61 | 133 | 0.458 | -79.263 | 2.725 | -14.373 | 14.629 | -2.725 | 14.831 | 15.079 | -79.587 | 3309.436 | 309.668 |
| 62 | 133 | 0.458 | -79.587 | 2.725 | -14.831 | 15.079 | -2.725 | 15.289 | 15.530 | -79.893 | 3334.214 | 178.997 |
| 63 | 133 | 0.458 | -79.893 | 2.725 | -15.289 | 15.530 | -2.725 | 15.747 | 15.981 | -80.181 | 3358.252 | 48.187 |
| | | | | | | | | | | | 3381.593 | -82.749 |

| Segment no. | Height of Segment | DL + LL (1/4PL) | Wind Load (Cpi=0) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 135 | 0.441 | 0.046 | 0.045 | 0.008 | 82.700 | 1.710 | 13.346 | 13.455 | -1.755 | -12.897 | 13.016 | 82.253 | 0 | 0 |
| 2 | 135 | 0.441 | 0.046 | 0.045 | 0.008 | 82.253 | 1.755 | 12.897 | 13.016 | -1.800 | -12.448 | 12.577 | 81.774 | 17.154 | 133.906 |
| 3 | 135 | 0.441 | 0.046 | 0.045 | 0.008 | 81.774 | 1.800 | 12.448 | 12.577 | -1.844 | -11.999 | 12.139 | 81.261 | 35.353 | 267.673 |
| 4 | 135 | 0.441 | 0.046 | 0.045 | 0.008 | 81.261 | 1.844 | 11.999 | 12.139 | -1.889 | -11.549 | 11.702 | 80.709 | 54.669 | 401.284 |
| 5 | 135 | 0.441 | 0.046 | 0.045 | 0.009 | 80.709 | 1.889 | 11.549 | 11.702 | -1.934 | -11.099 | 11.266 | 80.115 | 75.180 | 534.717 |
| 6 | 135 | 0.441 | 0.046 | 0.045 | 0.009 | 80.115 | 1.934 | 11.099 | 11.266 | -1.979 | -10.648 | 10.831 | 79.473 | 96.976 | 667.946 |
| 7 | 135 | 0.441 | 0.046 | 0.045 | 0.009 | 79.473 | 1.979 | 10.648 | 10.831 | -2.023 | -10.198 | 10.397 | 78.777 | 120.152 | 800.942 |
| 8 | 135 | 0.441 | 0.046 | 0.045 | 0.010 | 78.777 | 2.023 | 10.198 | 10.397 | -2.068 | -9.747 | 9.964 | 78.021 | 144.816 | 933.670 |
| 9 | 135 | 0.441 | 0.046 | 0.044 | 0.010 | 78.021 | 2.068 | 9.747 | 9.964 | -2.113 | -9.295 | 9.532 | 77.196 | 171.091 | 1066.088 |
| 10 | 135 | 0.441 | 0.046 | 0.044 | 0.010 | 77.196 | 2.113 | 9.295 | 9.532 | -2.157 | -8.844 | 9.103 | 76.293 | 199.111 | 1198.148 |
| 11 | 135 | 0.441 | 0.046 | 0.044 | 0.011 | 76.293 | 2.157 | 8.844 | 9.103 | -2.201 | -8.391 | 8.675 | 75.301 | 229.029 | 1329.791 |
| 12 | 135 | 0.441 | 0.046 | 0.044 | 0.011 | 75.301 | 2.201 | 8.391 | 8.675 | -2.245 | -7.939 | 8.250 | 74.207 | 261.017 | 1460.947 |
| 13 | 135 | 0.441 | 0.046 | 0.044 | 0.012 | 74.207 | 2.245 | 7.939 | 8.250 | -2.289 | -7.485 | 7.827 | 72.994 | 295.271 | 1591.529 |
| 14 | 135 | 0.441 | 0.046 | 0.044 | 0.012 | 72.994 | 2.289 | 7.485 | 7.827 | -2.333 | -7.031 | 7.408 | 71.642 | 332.014 | 1721.432 |
| 15 | 135 | 0.441 | 0.046 | 0.044 | 0.013 | 71.642 | 2.333 | 7.031 | 7.408 | -2.377 | -6.577 | 6.993 | 70.130 | 371.499 | 1850.529 |
| 16 | 135 | 0.441 | 0.046 | 0.043 | 0.014 | 70.130 | 2.377 | 6.577 | 6.993 | -2.420 | -6.121 | 6.583 | 68.427 | 414.017 | 1978.659 |
| 17 | 135 | 0.941 | -0.068 | -0.065 | -0.022 | 68.427 | 2.420 | 6.121 | 6.583 | -2.356 | -5.202 | 5.710 | 65.638 | 459.902 | 2105.621 |
| 18 | 135 | 0.441 | -0.068 | -0.064 | -0.023 | 65.638 | 2.356 | 5.202 | 5.710 | -2.291 | -4.784 | 5.304 | 64.408 | 509.541 | 2231.164 |
| 19 | 135 | 0.441 | -0.068 | -0.064 | -0.025 | 64.408 | 2.291 | 4.784 | 5.304 | -2.228 | -4.367 | 4.903 | 62.976 | 565.228 | 2354.144 |
| 20 | 135 | 0.441 | -0.068 | -0.063 | -0.027 | 62.976 | 2.228 | 4.367 | 4.903 | -2.165 | -3.953 | 4.506 | 61.293 | 623.543 | 2475.899 |
| 21 | 135 | 0.441 | -0.068 | -0.062 | -0.028 | 61.293 | 2.165 | 3.953 | 4.506 | -2.102 | -3.540 | 4.117 | 59.292 | 684.882 | 2596.159 |
| 22 | 135 | 0.441 | -0.068 | -0.061 | -0.031 | 59.292 | 2.102 | 3.540 | 4.117 | -2.041 | -3.129 | 3.736 | 56.880 | 749.726 | 2714.567 |
| 23 | 135 | 0.441 | -0.068 | -0.060 | -0.033 | 56.880 | 2.041 | 3.129 | 3.736 | -1.981 | -2.721 | 3.366 | 53.934 | 818.666 | 2830.637 |
| 24 | 135 | 0.441 | -0.068 | -0.058 | -0.036 | 53.934 | 1.981 | 2.721 | 3.366 | -1.923 | -2.315 | 3.010 | 50.283 | 892.429 | 2943.703 |
| 25 | 135 | 0.441 | -0.068 | -0.056 | -0.039 | 50.283 | 1.923 | 2.315 | 3.010 | -1.867 | -1.913 | 2.673 | 45.694 | 971.906 | 3052.829 |
| 26 | 135 | 0.441 | -0.068 | -0.053 | -0.043 | 45.694 | 1.867 | 1.913 | 2.673 | -1.814 | -1.515 | 2.364 | 39.861 | 1058.170 | 3156.673 |
| 27 | 135 | 0.441 | -0.068 | -0.049 | -0.047 | 39.861 | 1.814 | 1.515 | 2.364 | -1.765 | -1.121 | 2.091 | 32.417 | 1152.465 | 3253.282 |
| 28 | 135 | 0.441 | -0.068 | -0.044 | -0.052 | 32.417 | 1.765 | 1.121 | 2.091 | -1.720 | -0.731 | 1.869 | 23.030 | 1256.091 | 3339.808 |
| 29 | 135 | 0.441 | -0.068 | -0.038 | -0.057 | 23.030 | 1.720 | 0.731 | 1.869 | -1.683 | -0.347 | 1.718 | 11.650 | 1370.054 | 3412.178 |
| 30 | 135 | 0.441 | -0.068 | -0.029 | -0.062 | 11.650 | 1.683 | 0.347 | 1.718 | -1.653 | 0.033 | 1.654 | -1.134 | 1494.294 | 3464.992 |
| 31 | 135 | 0.441 | -0.068 | -0.019 | -0.066 | -1.134 | 1.653 | -0.033 | 1.654 | -1.635 | 0.408 | 1.685 | -14.026 | 1626.514 | 3492.252 |
| 32 | 135 | 0.441 | -0.068 | -0.006 | -0.068 | -14.026 | 1.635 | -0.408 | 1.685 | -1.628 | 0.782 | 1.806 | -25.646 | 1761.487 | 3489.581 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 135 | 0.441 | -0.068 | 0.006 | -0.068 | -25.646 | 1.628 | -0.782 | 1.806 | -1.635 | 1.155 | 2.001 | -35.245 | 1892.462 | 3456.861 |
| 34 | 135 | 0.441 | -0.068 | 0.019 | -0.066 | -35.245 | 1.635 | -1.155 | 2.001 | -1.653 | 1.531 | 2.253 | -42.794 | 2014.162 | 3398.432 |
| 35 | 135 | 0.441 | -0.068 | 0.029 | -0.062 | -42.794 | 1.653 | -1.531 | 2.253 | -1.683 | 1.910 | 2.546 | -48.625 | 2124.416 | 3320.526 |
| 36 | 135 | 0.441 | -0.068 | 0.038 | -0.057 | -48.625 | 1.683 | -1.910 | 2.546 | -1.720 | 2.295 | 2.868 | -53.139 | 2223.479 | 3228.813 |
| 37 | 135 | 0.441 | -0.068 | 0.044 | -0.052 | -53.139 | 1.720 | -2.295 | 2.868 | -1.765 | 2.684 | 3.212 | -56.674 | 2312.711 | 3127.508 |
| 38 | 135 | 0.441 | -0.068 | 0.049 | -0.047 | -56.674 | 1.765 | -2.684 | 3.212 | -1.814 | 3.078 | 3.573 | -59.486 | 2393.694 | 3019.495 |
| 39 | 135 | 0.441 | -0.068 | 0.053 | -0.043 | -59.486 | 1.814 | -3.078 | 3.573 | -1.867 | 3.477 | 3.946 | -61.758 | 2467.863 | 2906.694 |
| 40 | 135 | 0.441 | -0.068 | 0.056 | -0.039 | -61.758 | 1.867 | -3.477 | 3.946 | -1.923 | 3.879 | 4.329 | -63.624 | 2536.410 | 2790.392 |
| 41 | 135 | 0.441 | -0.068 | 0.058 | -0.036 | -63.624 | 1.923 | -3.879 | 4.329 | -1.981 | 4.284 | 4.720 | -65.178 | 2600.290 | 2671.462 |
| 42 | 135 | 0.441 | -0.068 | 0.060 | -0.033 | -65.178 | 1.981 | -4.284 | 4.720 | -2.041 | 4.692 | 5.117 | -66.490 | 2660.265 | 2550.516 |
| 43 | 135 | 0.441 | -0.068 | 0.061 | -0.031 | -66.490 | 2.041 | -4.692 | 5.117 | -2.102 | 5.103 | 5.519 | -67.609 | 2716.937 | 2427.987 |
| 44 | 135 | 0.441 | -0.068 | 0.062 | -0.028 | -67.609 | 2.102 | -5.103 | 5.519 | -2.165 | 5.516 | 5.925 | -68.574 | 2770.790 | 2304.193 |
| 45 | 135 | 0.441 | -0.068 | 0.063 | -0.027 | -68.574 | 2.165 | -5.516 | 5.925 | -2.228 | 5.931 | 6.335 | -69.414 | 2822.216 | 2179.372 |
| 46 | 135 | 0.441 | -0.068 | 0.064 | -0.025 | -69.414 | 2.228 | -5.931 | 6.335 | -2.291 | 6.347 | 6.748 | -70.151 | 2871.531 | 2053.702 |
| 47 | 135 | 0.441 | -0.068 | 0.064 | -0.023 | -70.151 | 2.291 | -6.347 | 6.748 | -2.356 | 6.765 | 7.164 | -70.803 | 2918.999 | 1927.322 |
| 48 | 135 | 0.441 | -0.023 | 0.022 | -0.007 | -70.803 | 2.356 | -6.765 | 7.164 | -2.377 | 7.199 | 7.582 | -71.728 | 2964.837 | 1800.342 |
| 49 | 135 | 0.441 | -0.023 | 0.022 | -0.007 | -71.728 | 2.377 | -7.199 | 7.582 | -2.399 | 7.634 | 8.002 | -72.555 | 3009.227 | 1672.849 |
| 50 | 135 | 0.441 | -0.023 | 0.022 | -0.007 | -72.555 | 2.399 | -7.634 | 8.002 | -2.421 | 8.069 | 8.424 | -73.300 | 3051.555 | 1544.656 |
| 51 | 135 | 0.441 | -0.023 | 0.022 | -0.006 | -73.300 | 2.421 | -8.069 | 8.424 | -2.443 | 8.504 | 8.848 | -73.974 | 3092.026 | 1415.866 |
| 52 | 135 | 0.441 | -0.023 | 0.022 | -0.006 | -73.974 | 2.443 | -8.504 | 8.848 | -2.465 | 8.939 | 9.273 | -74.586 | 3130.819 | 1286.559 |
| 53 | 135 | 0.441 | -0.023 | 0.022 | -0.006 | -74.586 | 2.465 | -8.939 | 9.273 | -2.487 | 9.375 | 9.699 | -75.145 | 3168.089 | 1156.806 |
| 54 | 135 | 0.441 | -0.023 | 0.022 | -0.005 | -75.145 | 2.487 | -9.375 | 9.699 | -2.509 | 9.811 | 10.127 | -75.656 | 3203.970 | 1026.661 |
| 55 | 135 | 0.441 | -0.023 | 0.022 | -0.005 | -75.656 | 2.509 | -9.811 | 10.127 | -2.531 | 10.247 | 10.555 | -76.126 | 3238.581 | 896.174 |
| 56 | 135 | 0.441 | -0.023 | 0.022 | -0.005 | -76.126 | 2.531 | -10.247 | 10.555 | -2.553 | 10.684 | 10.985 | -76.559 | 3272.026 | 765.382 |
| 57 | 135 | 0.441 | -0.023 | 0.022 | -0.005 | -76.559 | 2.553 | -10.684 | 10.985 | -2.576 | 11.120 | 11.415 | -76.960 | 3304.398 | 634.321 |
| 58 | 135 | 0.441 | -0.023 | 0.022 | -0.005 | -76.960 | 2.576 | -11.120 | 11.415 | -2.598 | 11.557 | 11.846 | -77.331 | 3335.778 | 503.018 |
| 59 | 135 | 0.441 | -0.023 | 0.022 | -0.004 | -77.331 | 2.598 | -11.557 | 11.846 | -2.620 | 11.994 | 12.277 | -77.677 | 3366.239 | 371.500 |
| 60 | 135 | 0.441 | -0.023 | 0.022 | -0.004 | -77.677 | 2.620 | -11.994 | 12.277 | -2.643 | 12.431 | 12.709 | -77.999 | 3395.846 | 239.787 |
| 61 | 135 | 0.441 | -0.023 | 0.022 | -0.004 | -77.999 | 2.643 | -12.431 | 12.709 | -2.665 | 12.869 | 13.142 | -78.299 | 3424.659 | 107.897 |
| 62 | 135 | 0.441 | -0.023 | 0.022 | -0.004 | -78.299 | 2.665 | -12.869 | 13.142 | -2.688 | 13.306 | 13.575 | -78.581 | 3452.730 | -24.152 |
| 63 | 135 | 0.441 | -0.023 | 0.022 | -0.004 | -78.581 | 2.688 | -13.306 | 13.575 | -2.710 | 13.744 | 14.008 | -78.845 | 3480.107 | -156.347 |
| | | | | | | | | | | | | | | 3506.835 | -288.675 |

| Segment no. | Height of Segment | DL + LL (1/4PL) | Wind Load (Cpi=-0.2) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 133 | 0.441 | 0.057 | 0.056 | 0.009 | 83.300 | 1.593 | 13.564 | 13.657 | -1.650 | -13.113 | 13.217 | 82.830 | 0 | 0 |
| 2 | 133 | 0.441 | 0.057 | 0.056 | 0.010 | 82.830 | 1.650 | 13.113 | 13.217 | -1.706 | -12.662 | 12.777 | 82.328 | 15.517 | 132.092 |
| 3 | 133 | 0.441 | 0.057 | 0.056 | 0.010 | 82.328 | 1.706 | 12.662 | 12.777 | -1.762 | -12.211 | 12.337 | 81.789 | 32.118 | 264.052 |
| 4 | 133 | 0.441 | 0.057 | 0.056 | 0.010 | 81.789 | 1.762 | 12.211 | 12.337 | -1.818 | -11.759 | 11.899 | 81.212 | 49.874 | 395.861 |
| 5 | 133 | 0.441 | 0.057 | 0.056 | 0.011 | 81.212 | 1.818 | 11.759 | 11.899 | -1.874 | -11.307 | 11.461 | 80.590 | 68.868 | 527.498 |
| 6 | 133 | 0.441 | 0.057 | 0.056 | 0.011 | 80.590 | 1.874 | 11.307 | 11.461 | -1.930 | -10.854 | 11.025 | 79.918 | 89.189 | 658.936 |
| 7 | 133 | 0.441 | 0.057 | 0.056 | 0.012 | 79.918 | 1.930 | 10.854 | 11.025 | -1.986 | -10.401 | 10.589 | 79.192 | 110.935 | 790.146 |
| 8 | 133 | 0.441 | 0.057 | 0.056 | 0.012 | 79.192 | 1.986 | 10.401 | 10.589 | -2.041 | -9.948 | 10.155 | 78.404 | 134.217 | 921.093 |
| 9 | 133 | 0.441 | 0.057 | 0.056 | 0.012 | 78.404 | 2.041 | 9.948 | 10.155 | -2.097 | -9.494 | 9.723 | 77.545 | 159.157 | 1051.733 |
| 10 | 133 | 0.441 | 0.057 | 0.055 | 0.013 | 77.545 | 2.097 | 9.494 | 9.723 | -2.152 | -9.040 | 9.292 | 76.606 | 185.892 | 1182.019 |
| 11 | 133 | 0.441 | 0.057 | 0.055 | 0.014 | 76.606 | 2.152 | 9.040 | 9.292 | -2.208 | -8.585 | 8.864 | 75.577 | 214.577 | 1311.888 |
| 12 | 133 | 0.441 | 0.057 | 0.055 | 0.014 | 75.577 | 2.208 | 8.585 | 8.864 | -2.263 | -8.129 | 8.438 | 74.443 | 245.385 | 1441.271 |
| 13 | 133 | 0.441 | 0.057 | 0.055 | 0.015 | 74.443 | 2.263 | 8.129 | 8.438 | -2.318 | -7.673 | 8.015 | 73.189 | 278.513 | 1570.079 |
| 14 | 133 | 0.441 | 0.057 | 0.055 | 0.016 | 73.189 | 2.318 | 7.673 | 8.015 | -2.373 | -7.216 | 7.596 | 71.796 | 314.182 | 1698.207 |
| 15 | 133 | 0.441 | 0.057 | 0.055 | 0.016 | 71.796 | 2.373 | 7.216 | 7.596 | -2.427 | -6.758 | 7.181 | 70.241 | 352.647 | 1825.523 |
| 16 | 133 | 0.441 | 0.057 | 0.054 | 0.017 | 70.241 | 2.427 | 6.758 | 7.181 | -2.482 | -6.299 | 6.770 | 68.496 | 394.196 | 1951.867 |
| 17 | 133 | 0.941 | -0.057 | -0.054 | -0.018 | 68.496 | 2.482 | 6.299 | 6.770 | -2.428 | -5.376 | 5.899 | 65.696 | 439.158 | 2077.037 |
| 18 | 133 | 0.441 | -0.057 | -0.054 | -0.019 | 65.696 | 2.428 | 5.376 | 5.899 | -2.374 | -4.954 | 5.494 | 64.394 | 487.911 | 2200.779 |
| 19 | 133 | 0.441 | -0.057 | -0.053 | -0.021 | 64.394 | 2.374 | 4.954 | 5.494 | -2.321 | -4.533 | 5.093 | 62.887 | 542.651 | 2321.992 |
| 20 | 133 | 0.441 | -0.057 | -0.053 | -0.022 | 62.887 | 2.321 | 4.533 | 5.093 | -2.269 | -4.114 | 4.698 | 61.126 | 600.131 | 2441.929 |
| 21 | 133 | 0.441 | -0.057 | -0.052 | -0.024 | 61.126 | 2.269 | 4.114 | 4.698 | -2.217 | -3.696 | 4.310 | 59.048 | 660.746 | 2560.313 |
| 22 | 133 | 0.441 | -0.057 | -0.051 | -0.026 | 59.048 | 2.217 | 3.696 | 4.310 | -2.166 | -3.280 | 3.931 | 56.566 | 724.969 | 2676.779 |
| 23 | 133 | 0.441 | -0.057 | -0.050 | -0.028 | 56.566 | 2.166 | 3.280 | 3.931 | -2.116 | -2.867 | 3.563 | 53.568 | 793.374 | 2790.840 |
| 24 | 133 | 0.441 | -0.057 | -0.048 | -0.030 | 53.568 | 2.116 | 2.867 | 3.563 | -2.068 | -2.455 | 3.210 | 49.900 | 866.653 | 2901.831 |
| 25 | 133 | 0.441 | -0.057 | -0.047 | -0.033 | 49.900 | 2.068 | 2.455 | 3.210 | -2.021 | -2.047 | 2.876 | 45.363 | 945.638 | 3008.838 |
| 26 | 133 | 0.441 | -0.057 | -0.044 | -0.036 | 45.363 | 2.021 | 2.047 | 2.876 | -1.977 | -1.641 | 2.569 | 39.702 | 1031.306 | 3110.573 |
| 27 | 133 | 0.441 | -0.057 | -0.041 | -0.039 | 39.702 | 1.977 | 1.641 | 2.569 | -1.936 | -1.239 | 2.298 | 32.629 | 1124.755 | 3205.211 |
| 28 | 133 | 0.441 | -0.057 | -0.037 | -0.043 | 32.629 | 1.936 | 1.239 | 2.298 | -1.899 | -0.841 | 2.077 | 23.895 | 1227.082 | 3290.170 |
| 29 | 133 | 0.441 | -0.057 | -0.032 | -0.047 | 23.895 | 1.899 | 0.841 | 2.077 | -1.867 | -0.447 | 1.920 | 13.469 | 1339.093 | 3361.883 |
| 30 | 133 | 0.441 | -0.057 | -0.024 | -0.051 | 13.469 | 1.867 | 0.447 | 1.920 | -1.843 | -0.057 | 1.843 | 1.779 | 1460.693 | 3415.756 |
| 31 | 133 | 0.441 | -0.057 | -0.016 | -0.055 | 1.779 | 1.843 | 0.057 | 1.843 | -1.827 | 0.329 | 1.856 | -10.219 | 1590.035 | 3446.735 |
| 32 | 133 | 0.441 | -0.057 | -0.005 | -0.057 | -10.219 | 1.827 | -0.329 | 1.856 | -1.822 | 0.714 | 1.957 | -21.405 | 1722.971 | 3450.865 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 133 | 0.441 | -0.057 | 0.005 | -0.057 | -21.405 | 1.822 | -0.714 | 1.957 | -1.827 | 1.099 | 2.132 | -31.022 | 1853.861 | 3427.268 |
| 34 | 133 | 0.441 | -0.057 | 0.016 | -0.055 | -31.022 | 1.827 | -1.099 | 2.132 | -1.843 | 1.485 | 2.367 | -38.873 | 1977.687 | 3378.730 |
| 35 | 133 | 0.441 | -0.057 | 0.024 | -0.051 | -38.873 | 1.843 | -1.485 | 2.367 | -1.867 | 1.875 | 2.646 | -45.126 | 2091.664 | 3310.186 |
| 36 | 133 | 0.441 | -0.057 | 0.032 | -0.047 | -45.126 | 1.867 | -1.875 | 2.646 | -1.899 | 2.269 | 2.959 | -50.082 | 2195.210 | 3226.716 |
| 37 | 133 | 0.441 | -0.057 | 0.037 | -0.043 | -50.082 | 1.899 | -2.269 | 2.959 | -1.936 | 2.667 | 3.296 | -54.033 | 2289.048 | 3132.463 |
| 38 | 133 | 0.441 | -0.057 | 0.041 | -0.039 | -54.033 | 1.936 | -2.667 | 3.296 | -1.977 | 3.069 | 3.651 | -57.217 | 2374.392 | 3030.457 |
| 39 | 133 | 0.441 | -0.057 | 0.044 | -0.036 | -57.217 | 1.977 | -3.069 | 3.651 | -2.021 | 3.475 | 4.020 | -59.817 | 2452.505 | 2922.812 |
| 40 | 133 | 0.441 | -0.057 | 0.047 | -0.033 | -59.817 | 2.021 | -3.475 | 4.020 | -2.068 | 3.883 | 4.400 | -61.969 | 2524.518 | 2810.995 |
| 41 | 133 | 0.441 | -0.057 | 0.048 | -0.030 | -61.969 | 2.068 | -3.883 | 4.400 | -2.116 | 4.295 | 4.788 | -63.771 | 2591.385 | 2696.026 |
| 42 | 133 | 0.441 | -0.057 | 0.050 | -0.028 | -63.771 | 2.116 | -4.295 | 4.788 | -2.166 | 4.709 | 5.183 | -65.298 | 2653.889 | 2578.628 |
| 43 | 133 | 0.441 | -0.057 | 0.051 | -0.026 | -65.298 | 2.166 | -4.709 | 5.183 | -2.217 | 5.124 | 5.583 | -66.607 | 2712.670 | 2459.323 |
| 44 | 133 | 0.441 | -0.057 | 0.052 | -0.024 | -66.607 | 2.217 | -5.124 | 5.583 | -2.269 | 5.542 | 5.988 | -67.739 | 2768.249 | 2338.493 |
| 45 | 133 | 0.441 | -0.057 | 0.053 | -0.022 | -67.739 | 2.269 | -5.542 | 5.988 | -2.321 | 5.961 | 6.397 | -68.726 | 2821.055 | 2216.425 |
| 46 | 133 | 0.441 | -0.057 | 0.053 | -0.021 | -68.726 | 2.321 | -5.961 | 6.397 | -2.374 | 6.382 | 6.809 | -69.594 | 2871.440 | 2093.338 |
| 47 | 133 | 0.441 | -0.057 | 0.054 | -0.019 | -69.594 | 2.374 | -6.382 | 6.809 | -2.428 | 6.804 | 7.224 | -70.363 | 2919.696 | 1969.401 |
| 48 | 133 | 0.441 | -0.011 | 0.011 | -0.004 | -70.363 | 2.428 | -6.804 | 7.224 | -2.439 | 7.242 | 7.641 | -71.390 | 2966.069 | 1844.747 |
| 49 | 133 | 0.441 | -0.011 | 0.011 | -0.003 | -71.390 | 2.439 | -7.242 | 7.641 | -2.449 | 7.680 | 8.061 | -72.310 | 3010.765 | 1719.483 |
| 50 | 133 | 0.441 | -0.011 | 0.011 | -0.003 | -72.310 | 2.449 | -7.680 | 8.061 | -2.460 | 8.118 | 8.483 | -73.139 | 3053.209 | 1593.437 |
| 51 | 133 | 0.441 | -0.011 | 0.011 | -0.003 | -73.139 | 2.460 | -8.118 | 8.483 | -2.471 | 8.556 | 8.906 | -73.889 | 3093.624 | 1466.726 |
| 52 | 133 | 0.441 | -0.011 | 0.011 | -0.003 | -73.889 | 2.471 | -8.556 | 8.906 | -2.482 | 8.995 | 9.331 | -74.572 | 3132.200 | 1339.443 |
| 53 | 133 | 0.441 | -0.011 | 0.011 | -0.003 | -74.572 | 2.482 | -8.995 | 9.331 | -2.493 | 9.433 | 9.757 | -75.194 | 3169.107 | 1211.667 |
| 54 | 133 | 0.441 | -0.011 | 0.011 | -0.003 | -75.194 | 2.493 | -9.433 | 9.757 | -2.504 | 9.872 | 10.185 | -75.765 | 3204.489 | 1083.459 |
| 55 | 133 | 0.441 | -0.011 | 0.011 | -0.003 | -75.765 | 2.504 | -9.872 | 10.185 | -2.516 | 10.311 | 10.613 | -76.289 | 3238.476 | 954.875 |
| 56 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -76.289 | 2.516 | -10.311 | 10.613 | -2.527 | 10.750 | 11.043 | -76.773 | 3271.181 | 825.959 |
| 57 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -76.773 | 2.527 | -10.750 | 11.043 | -2.538 | 11.189 | 11.473 | -77.221 | 3302.705 | 696.749 |
| 58 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -77.221 | 2.538 | -11.189 | 11.473 | -2.549 | 11.628 | 11.904 | -77.636 | 3333.136 | 567.277 |
| 59 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -77.636 | 2.549 | -11.628 | 11.904 | -2.560 | 12.067 | 12.336 | -78.022 | 3362.556 | 437.572 |
| 60 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -78.022 | 2.560 | -12.067 | 12.336 | -2.571 | 12.506 | 12.768 | -78.382 | 3391.035 | 307.657 |
| 61 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -78.382 | 2.571 | -12.506 | 12.768 | -2.583 | 12.946 | 13.201 | -78.718 | 3418.638 | 177.553 |
| 62 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -78.718 | 2.583 | -12.946 | 13.201 | -2.594 | 13.385 | 13.634 | -79.033 | 3445.423 | 47.278 |
| 63 | 133 | 0.441 | -0.011 | 0.011 | -0.002 | -79.033 | 2.594 | -13.385 | 13.634 | -2.605 | 13.825 | 14.068 | -79.329 | 3471.443 | -83.152 |
| | | | | | | | | | | | | | | 3496.745 | -213.723 |

| Segment no. | Height of Segment | DL + LL(3/4PL) | Wind Load (Cpi=0) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 82.700 | 1.678 | 13.096 | 13.203 | -1.723 | -12.647 | 12.764 | 82.244 | 0 | 0 |
| 2 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 82.244 | 1.723 | 12.647 | 12.764 | -1.768 | -12.198 | 12.325 | 81.755 | 16.900 | 131.922 |
| 3 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 81.755 | 1.768 | 12.198 | 12.325 | -1.812 | -11.749 | 11.888 | 81.230 | 34.849 | 263.705 |
| 4 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 81.230 | 1.812 | 11.749 | 11.888 | -1.857 | -11.299 | 11.450 | 80.665 | 53.923 | 395.330 |
| 5 | 133 | 0.441 | 0.046 | 0.045 | 0.009 | 80.665 | 1.857 | 11.299 | 11.450 | -1.902 | -10.849 | 11.014 | 80.056 | 74.200 | 526.775 |
| 6 | 133 | 0.441 | 0.046 | 0.045 | 0.009 | 80.056 | 1.902 | 10.849 | 11.014 | -1.947 | -10.398 | 10.579 | 79.396 | 95.773 | 658.014 |
| 7 | 133 | 0.441 | 0.046 | 0.045 | 0.009 | 79.396 | 1.947 | 10.398 | 10.579 | -1.991 | -9.948 | 10.145 | 78.680 | 118.741 | 789.016 |
| 8 | 133 | 0.441 | 0.046 | 0.045 | 0.010 | 78.680 | 1.991 | 9.948 | 10.145 | -2.036 | -9.497 | 9.713 | 77.900 | 143.216 | 919.745 |
| 9 | 133 | 0.441 | 0.046 | 0.044 | 0.010 | 77.900 | 2.036 | 9.497 | 9.713 | -2.081 | -9.045 | 9.282 | 77.047 | 169.323 | 1050.157 |
| 10 | 133 | 0.441 | 0.046 | 0.044 | 0.010 | 77.047 | 2.081 | 9.045 | 9.282 | -2.125 | -8.594 | 8.852 | 76.111 | 197.203 | 1180.202 |
| 11 | 133 | 0.441 | 0.046 | 0.044 | 0.011 | 76.111 | 2.125 | 8.594 | 8.852 | -2.169 | -8.141 | 8.425 | 75.081 | 227.015 | 1309.818 |
| 12 | 133 | 0.441 | 0.046 | 0.044 | 0.011 | 75.081 | 2.169 | 8.141 | 8.425 | -2.213 | -7.689 | 8.001 | 73.940 | 258.940 | 1438.930 |
| 13 | 133 | 0.441 | 0.046 | 0.044 | 0.012 | 73.940 | 2.213 | 7.689 | 8.001 | -2.257 | -7.235 | 7.579 | 72.672 | 293.182 | 1567.446 |
| 14 | 133 | 0.441 | 0.046 | 0.044 | 0.012 | 72.672 | 2.257 | 7.235 | 7.579 | -2.301 | -6.781 | 7.161 | 71.256 | 329.975 | 1695.255 |
| 15 | 133 | 0.441 | 0.046 | 0.044 | 0.013 | 71.256 | 2.301 | 6.781 | 7.161 | -2.345 | -6.327 | 6.747 | 69.664 | 369.588 | 1822.219 |
| 16 | 133 | 0.441 | 0.046 | 0.043 | 0.014 | 69.664 | 2.345 | 6.327 | 6.747 | -2.388 | -5.871 | 6.339 | 67.865 | 412.327 | 1948.165 |
| 17 | 133 | 0.441 | -0.068 | -0.065 | -0.022 | 67.865 | 2.388 | 5.871 | 6.339 | -2.324 | -5.452 | 5.926 | 66.917 | 458.548 | 2072.875 |
| 18 | 133 | 0.441 | -0.068 | -0.064 | -0.023 | 66.917 | 2.324 | 5.452 | 5.926 | -2.259 | -5.034 | 5.518 | 65.829 | 508.661 | 2196.073 |
| 19 | 133 | 0.441 | -0.068 | -0.064 | -0.025 | 65.829 | 2.259 | 5.034 | 5.518 | -2.196 | -4.617 | 5.113 | 64.569 | 560.806 | 2318.425 |
| 20 | 133 | 0.441 | -0.068 | -0.063 | -0.027 | 64.569 | 2.196 | 4.617 | 5.113 | -2.133 | -4.203 | 4.713 | 63.095 | 615.264 | 2439.765 |
| 21 | 133 | 0.441 | -0.068 | -0.062 | -0.028 | 63.095 | 2.133 | 4.203 | 4.713 | -2.070 | -3.790 | 4.318 | 61.351 | 672.377 | 2559.878 |
| 22 | 133 | 0.441 | -0.068 | -0.061 | -0.031 | 61.351 | 2.070 | 3.790 | 4.318 | -2.009 | -3.379 | 3.931 | 59.263 | 732.561 | 2678.481 |
| 23 | 133 | 0.441 | -0.068 | -0.060 | -0.033 | 59.263 | 2.009 | 3.379 | 3.931 | -1.949 | -2.971 | 3.553 | 56.726 | 796.326 | 2795.199 |
| 24 | 133 | 0.441 | -0.068 | -0.058 | -0.036 | 56.726 | 1.949 | 2.971 | 3.553 | -1.891 | -2.565 | 3.187 | 53.600 | 864.303 | 2909.515 |
| 25 | 133 | 0.441 | -0.068 | -0.056 | -0.039 | 53.600 | 1.891 | 2.565 | 3.187 | -1.835 | -2.163 | 2.837 | 49.687 | 937.272 | 3020.710 |
| 26 | 133 | 0.441 | -0.068 | -0.053 | -0.043 | 49.687 | 1.835 | 2.163 | 2.837 | -1.782 | -1.765 | 2.508 | 44.719 | 1016.197 | 3127.761 |
| 27 | 133 | 0.441 | -0.068 | -0.049 | -0.047 | 44.719 | 1.782 | 1.765 | 2.508 | -1.733 | -1.371 | 2.209 | 38.346 | 1102.243 | 3229.177 |
| 28 | 133 | 0.441 | -0.068 | -0.044 | -0.052 | 38.346 | 1.733 | 1.371 | 2.209 | -1.688 | -0.981 | 1.953 | 30.166 | 1196.748 | 3322.761 |
| 29 | 133 | 0.441 | -0.068 | -0.038 | -0.057 | 30.166 | 1.688 | 0.981 | 1.953 | -1.651 | -0.597 | 1.755 | 19.882 | 1301.057 | 3405.274 |
| 30 | 133 | 0.441 | -0.068 | -0.029 | -0.062 | 19.882 | 1.651 | 0.597 | 1.755 | -1.621 | -0.217 | 1.636 | 7.633 | 1416.045 | 3472.108 |
| 31 | 133 | 0.441 | -0.068 | -0.019 | -0.066 | 7.633 | 1.621 | 0.217 | 1.636 | -1.603 | 0.158 | 1.610 | -5.643 | 1541.118 | 3517.338 |
| 32 | 133 | 0.441 | -0.068 | -0.006 | -0.068 | -5.643 | 1.603 | -0.158 | 1.610 | -1.596 | 0.532 | 1.682 | -18.423 | 1672.940 | 3535.005 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 133 | 0.441 | -0.068 | 0.006 | -0.068 | -18.423 | 1.596 | -0.532 | 1.682 | -1.603 | 0.905 | 1.840 | -29.455 | 1805.295 | 3521.926 |
| 34 | 133 | 0.441 | -0.068 | 0.019 | -0.066 | -29.455 | 1.603 | -0.905 | 1.840 | -1.621 | 1.281 | 2.066 | -38.305 | 1931.478 | 3479.893 |
| 35 | 133 | 0.441 | -0.068 | 0.029 | -0.062 | -38.305 | 1.621 | -1.281 | 2.066 | -1.651 | 1.660 | 2.341 | -45.167 | 2047.288 | 3414.493 |
| 36 | 133 | 0.441 | -0.068 | 0.038 | -0.057 | -45.167 | 1.651 | -1.660 | 2.341 | -1.688 | 2.045 | 2.652 | -50.452 | 2151.656 | 3332.053 |
| 37 | 133 | 0.441 | -0.068 | 0.044 | -0.052 | -50.452 | 1.688 | -2.045 | 2.652 | -1.733 | 2.434 | 2.988 | -54.553 | 2245.426 | 3237.733 |
| 38 | 133 | 0.441 | -0.068 | 0.049 | -0.047 | -54.553 | 1.733 | -2.434 | 2.988 | -1.782 | 2.828 | 3.343 | -57.783 | 2330.111 | 3135.179 |
| 39 | 133 | 0.441 | -0.068 | 0.053 | -0.043 | -57.783 | 1.782 | -2.828 | 3.343 | -1.835 | 3.227 | 3.712 | -60.368 | 2407.244 | 3026.830 |
| 40 | 133 | 0.441 | -0.068 | 0.056 | -0.039 | -60.368 | 1.835 | -3.227 | 3.712 | -1.891 | 3.629 | 4.092 | -62.471 | 2478.150 | 2914.308 |
| 41 | 133 | 0.441 | -0.068 | 0.058 | -0.036 | -62.471 | 1.891 | -3.629 | 4.092 | -1.949 | 4.034 | 4.480 | -64.208 | 2543.910 | 2798.702 |
| 42 | 133 | 0.441 | -0.068 | 0.060 | -0.033 | -64.208 | 1.949 | -4.034 | 4.480 | -2.009 | 4.442 | 4.876 | -65.663 | 2605.382 | 2680.761 |
| 43 | 133 | 0.441 | -0.068 | 0.061 | -0.031 | -65.663 | 2.009 | -4.442 | 4.876 | -2.070 | 4.853 | 5.276 | -66.896 | 2663.251 | 2561.010 |
| 44 | 133 | 0.441 | -0.068 | 0.062 | -0.028 | -66.896 | 2.070 | -4.853 | 5.276 | -2.133 | 5.266 | 5.681 | -67.954 | 2718.061 | 2439.829 |
| 45 | 133 | 0.441 | -0.068 | 0.063 | -0.027 | -67.954 | 2.133 | -5.266 | 5.681 | -2.196 | 5.681 | 6.090 | -68.869 | 2770.250 | 2317.496 |
| 46 | 133 | 0.441 | -0.068 | 0.064 | -0.025 | -68.869 | 2.196 | -5.681 | 6.090 | -2.259 | 6.097 | 6.502 | -69.669 | 2820.173 | 2194.221 |
| 47 | 133 | 0.441 | -0.068 | 0.064 | -0.023 | -69.669 | 2.259 | -6.097 | 6.502 | -2.324 | 6.515 | 6.917 | -70.372 | 2868.119 | 2070.164 |
| 48 | 133 | 0.941 | -0.023 | 0.022 | -0.007 | -70.372 | 2.324 | -6.515 | 6.917 | -2.345 | 7.449 | 7.810 | -72.526 | 2914.330 | 1945.450 |
| 49 | 133 | 0.441 | -0.023 | 0.022 | -0.007 | -72.526 | 2.345 | -7.449 | 7.810 | -2.367 | 7.884 | 8.232 | -73.290 | 2959.005 | 1820.178 |
| 50 | 133 | 0.441 | -0.023 | 0.022 | -0.007 | -73.290 | 2.367 | -7.884 | 8.232 | -2.389 | 8.319 | 8.655 | -73.979 | 2998.942 | 1693.316 |
| 51 | 133 | 0.441 | -0.023 | 0.022 | -0.006 | -73.979 | 2.389 | -8.319 | 8.655 | -2.411 | 8.754 | 9.080 | -74.604 | 3037.184 | 1565.932 |
| 52 | 133 | 0.441 | -0.023 | 0.022 | -0.006 | -74.604 | 2.411 | -8.754 | 9.080 | -2.433 | 9.189 | 9.506 | -75.173 | 3073.891 | 1438.098 |
| 53 | 133 | 0.441 | -0.023 | 0.022 | -0.006 | -75.173 | 2.433 | -9.189 | 9.506 | -2.455 | 9.625 | 9.933 | -75.693 | 3109.201 | 1309.871 |
| 54 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -75.693 | 2.455 | -9.625 | 9.933 | -2.477 | 10.061 | 10.362 | -76.170 | 3143.237 | 1181.300 |
| 55 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -76.170 | 2.477 | -10.061 | 10.362 | -2.499 | 10.497 | 10.791 | -76.609 | 3176.103 | 1052.425 |
| 56 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -76.609 | 2.499 | -10.497 | 10.791 | -2.521 | 10.934 | 11.221 | -77.015 | 3207.896 | 923.280 |
| 57 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -77.015 | 2.521 | -10.934 | 11.221 | -2.544 | 11.370 | 11.651 | -77.391 | 3238.697 | 793.896 |
| 58 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -77.391 | 2.544 | -11.370 | 11.651 | -2.566 | 11.807 | 12.083 | -77.739 | 3268.582 | 664.297 |
| 59 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -77.739 | 2.566 | -11.807 | 12.083 | -2.588 | 12.244 | 12.515 | -78.064 | 3297.617 | 534.505 |
| 60 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -78.064 | 2.588 | -12.244 | 12.515 | -2.611 | 12.681 | 12.947 | -78.367 | 3325.860 | 404.538 |
| 61 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -78.367 | 2.611 | -12.681 | 12.947 | -2.633 | 13.119 | 13.380 | -78.651 | 3353.367 | 274.414 |
| 62 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -78.651 | 2.633 | -13.119 | 13.380 | -2.656 | 13.556 | 13.814 | -78.917 | 3380.184 | 144.146 |
| 63 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -78.917 | 2.656 | -13.556 | 13.814 | -2.678 | 13.994 | 14.248 | -79.166 | 3406.357 | 13.746 |
| | | | | | | | | | | | | | | 3431.925 | -116.773 |

| Segment no. | Height of | DL + LL(3/4PL) | Wind Load | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 132 | 0.441 | 0.057 | 0.056 | 0.009 | 83.500 | 1.517 | 13.314 | 13.400 | -1.573 | -12.863 | 12.959 | 83.027 | 0 | 0 |
| 2 | 132 | 0.441 | 0.057 | 0.056 | 0.010 | 83.027 | 1.573 | 12.863 | 12.959 | -1.629 | -12.412 | 12.519 | 82.522 | 14.943 | 131.151 |
| 3 | 132 | 0.441 | 0.057 | 0.056 | 0.010 | 82.522 | 1.629 | 12.412 | 12.519 | -1.685 | -11.961 | 12.079 | 81.979 | 30.967 | 262.175 |
| 4 | 132 | 0.441 | 0.057 | 0.056 | 0.010 | 81.979 | 1.685 | 11.961 | 12.079 | -1.741 | -11.509 | 11.640 | 81.396 | 48.147 | 393.052 |
| 5 | 132 | 0.441 | 0.057 | 0.056 | 0.011 | 81.396 | 1.741 | 11.509 | 11.640 | -1.797 | -11.057 | 11.202 | 80.766 | 66.566 | 523.761 |
| 6 | 132 | 0.441 | 0.057 | 0.056 | 0.011 | 80.766 | 1.797 | 11.057 | 11.202 | -1.853 | -10.604 | 10.765 | 80.086 | 86.315 | 654.275 |
| 7 | 132 | 0.441 | 0.057 | 0.056 | 0.012 | 80.086 | 1.853 | 10.604 | 10.765 | -1.909 | -10.151 | 10.329 | 79.349 | 107.495 | 784.565 |
| 8 | 132 | 0.441 | 0.057 | 0.056 | 0.012 | 79.349 | 1.909 | 10.151 | 10.329 | -1.965 | -9.698 | 9.895 | 78.546 | 130.221 | 914.594 |
| 9 | 132 | 0.441 | 0.057 | 0.056 | 0.012 | 78.546 | 1.965 | 9.698 | 9.895 | -2.021 | -9.244 | 9.462 | 77.670 | 154.619 | 1044.320 |
| 10 | 132 | 0.441 | 0.057 | 0.055 | 0.013 | 77.670 | 2.021 | 9.244 | 9.462 | -2.076 | -8.790 | 9.031 | 76.711 | 180.831 | 1173.691 |
| 11 | 132 | 0.441 | 0.057 | 0.055 | 0.014 | 76.711 | 2.076 | 8.790 | 9.031 | -2.131 | -8.335 | 8.603 | 75.655 | 209.018 | 1302.646 |
| 12 | 132 | 0.441 | 0.057 | 0.055 | 0.014 | 75.655 | 2.131 | 8.335 | 8.603 | -2.187 | -7.879 | 8.177 | 74.490 | 239.360 | 1431.112 |
| 13 | 132 | 0.441 | 0.057 | 0.055 | 0.015 | 74.490 | 2.187 | 7.879 | 8.177 | -2.242 | -7.423 | 7.754 | 73.196 | 272.064 | 1558.996 |
| 14 | 132 | 0.441 | 0.057 | 0.055 | 0.016 | 73.196 | 2.242 | 7.423 | 7.754 | -2.296 | -6.966 | 7.334 | 71.754 | 307.362 | 1686.189 |
| 15 | 132 | 0.441 | 0.057 | 0.055 | 0.016 | 71.754 | 2.296 | 6.966 | 7.334 | -2.351 | -6.508 | 6.919 | 70.137 | 345.523 | 1812.553 |
| 16 | 132 | 0.441 | 0.057 | 0.054 | 0.017 | 70.137 | 2.351 | 6.508 | 6.919 | -2.405 | -6.049 | 6.510 | 68.316 | 386.852 | 1937.916 |
| 17 | 132 | 0.441 | -0.057 | -0.054 | -0.018 | 68.316 | 2.405 | 6.049 | 6.510 | -2.351 | -5.626 | 6.098 | 67.318 | 431.702 | 2062.063 |
| 18 | 132 | 0.441 | -0.057 | -0.054 | -0.019 | 67.318 | 2.351 | 5.626 | 6.098 | -2.298 | -5.204 | 5.689 | 66.177 | 480.475 | 2184.722 |
| 19 | 132 | 0.441 | -0.057 | -0.053 | -0.021 | 66.177 | 2.298 | 5.204 | 5.689 | -2.245 | -4.783 | 5.284 | 64.861 | 531.376 | 2306.513 |
| 20 | 132 | 0.441 | -0.057 | -0.053 | -0.022 | 64.861 | 2.245 | 4.783 | 5.284 | -2.192 | -4.364 | 4.884 | 63.329 | 584.693 | 2427.266 |
| 21 | 132 | 0.441 | -0.057 | -0.052 | -0.024 | 63.329 | 2.192 | 4.364 | 4.884 | -2.140 | -3.946 | 4.489 | 61.526 | 640.769 | 2546.763 |
| 22 | 132 | 0.441 | -0.057 | -0.051 | -0.026 | 61.526 | 2.140 | 3.946 | 4.489 | -2.089 | -3.530 | 4.102 | 59.382 | 700.020 | 2664.717 |
| 23 | 132 | 0.441 | -0.057 | -0.050 | -0.028 | 59.382 | 2.089 | 3.530 | 4.102 | -2.040 | -3.117 | 3.725 | 56.800 | 762.952 | 2780.750 |
| 24 | 132 | 0.441 | -0.057 | -0.048 | -0.030 | 56.800 | 2.040 | 3.117 | 3.725 | -1.991 | -2.705 | 3.359 | 53.647 | 830.180 | 2894.348 |
| 25 | 132 | 0.441 | -0.057 | -0.047 | -0.033 | 53.647 | 1.991 | 2.705 | 3.359 | -1.944 | -2.297 | 3.009 | 49.747 | 902.459 | 3004.800 |
| 26 | 132 | 0.441 | -0.057 | -0.044 | -0.036 | 49.747 | 1.944 | 2.297 | 3.009 | -1.900 | -1.891 | 2.681 | 44.863 | 980.703 | 3111.110 |
| 27 | 132 | 0.441 | -0.057 | -0.041 | -0.039 | 44.863 | 1.900 | 1.891 | 2.681 | -1.859 | -1.489 | 2.382 | 38.696 | 1065.996 | 3211.853 |
| 28 | 132 | 0.441 | -0.057 | -0.037 | -0.043 | 38.696 | 1.859 | 1.489 | 2.382 | -1.822 | -1.091 | 2.124 | 30.915 | 1159.557 | 3304.968 |
| 29 | 132 | 0.441 | -0.057 | -0.032 | -0.047 | 30.915 | 1.822 | 1.091 | 2.124 | -1.791 | -0.697 | 1.921 | 21.274 | 1262.579 | 3387.493 |
| 30 | 132 | 0.441 | -0.057 | -0.024 | -0.051 | 21.274 | 1.791 | 0.697 | 1.921 | -1.766 | -0.307 | 1.793 | 9.869 | 1375.826 | 3455.309 |
| 31 | 132 | 0.441 | -0.057 | -0.016 | -0.055 | 9.869 | 1.766 | 0.307 | 1.793 | -1.751 | 0.079 | 1.752 | -2.596 | 1498.831 | 3503.203 |
| 32 | 132 | 0.441 | -0.057 | -0.005 | -0.057 | -2.596 | 1.751 | -0.079 | 1.752 | -1.745 | 0.464 | 1.806 | -14.891 | 1628.878 | 3525.827 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 132 | 0.441 | -0.057 | 0.005 | -0.057 | -14.891 | 1.745 | -0.464 | 1.806 | -1.751 | 0.849 | 1.945 | -25.866 | 1760.742 | 3519.849 |
| 34 | 132 | 0.441 | -0.057 | 0.016 | -0.055 | -25.866 | 1.751 | -0.849 | 1.945 | -1.766 | 1.235 | 2.155 | -34.971 | 1888.310 | 3485.928 |
| 35 | 132 | 0.441 | -0.057 | 0.024 | -0.051 | -34.971 | 1.766 | -1.235 | 2.155 | -1.791 | 1.625 | 2.418 | -42.230 | 2007.085 | 3428.340 |
| 36 | 132 | 0.441 | -0.057 | 0.032 | -0.047 | -42.230 | 1.791 | -1.625 | 2.418 | -1.822 | 2.019 | 2.720 | -47.938 | 2115.251 | 3352.682 |
| 37 | 132 | 0.441 | -0.057 | 0.037 | -0.043 | -47.938 | 1.822 | -2.019 | 2.720 | -1.859 | 2.417 | 3.049 | -52.437 | 2212.991 | 3263.964 |
| 38 | 132 | 0.441 | -0.057 | 0.041 | -0.039 | -52.437 | 1.859 | -2.417 | 3.049 | -1.900 | 2.819 | 3.400 | -56.019 | 2301.423 | 3165.965 |
| 39 | 132 | 0.441 | -0.057 | 0.044 | -0.036 | -56.019 | 1.900 | -2.819 | 3.400 | -1.944 | 3.225 | 3.766 | -58.911 | 2381.895 | 3061.331 |
| 40 | 132 | 0.441 | -0.057 | 0.047 | -0.033 | -58.911 | 1.944 | -3.225 | 3.766 | -1.991 | 3.633 | 4.143 | -61.277 | 2455.671 | 2951.873 |
| 41 | 132 | 0.441 | -0.057 | 0.048 | -0.030 | -61.277 | 1.991 | -3.633 | 4.143 | -2.040 | 4.045 | 4.530 | -63.241 | 2523.832 | 2838.833 |
| 42 | 132 | 0.441 | -0.057 | 0.050 | -0.028 | -63.241 | 2.040 | -4.045 | 4.530 | -2.089 | 4.459 | 4.924 | -64.891 | 2587.268 | 2723.075 |
| 43 | 132 | 0.441 | -0.057 | 0.051 | -0.026 | -64.891 | 2.089 | -4.459 | 4.924 | -2.140 | 4.874 | 5.324 | -66.294 | 2646.699 | 2605.211 |
| 44 | 132 | 0.441 | -0.057 | 0.052 | -0.024 | -66.294 | 2.140 | -4.874 | 5.324 | -2.192 | 5.292 | 5.728 | -67.499 | 2702.712 | 2485.685 |
| 45 | 132 | 0.441 | -0.057 | 0.053 | -0.022 | -67.499 | 2.192 | -5.292 | 5.728 | -2.245 | 5.711 | 6.137 | -68.544 | 2755.782 | 2364.823 |
| 46 | 132 | 0.441 | -0.057 | 0.053 | -0.021 | -68.544 | 2.245 | -5.711 | 6.137 | -2.298 | 6.132 | 6.548 | -69.458 | 2806.298 | 2242.871 |
| 47 | 132 | 0.441 | -0.057 | 0.054 | -0.019 | -69.458 | 2.298 | -6.132 | 6.548 | -2.351 | 6.554 | 6.963 | -70.264 | 2854.580 | 2120.019 |
| 48 | 132 | 0.941 | -0.011 | 0.011 | -0.004 | -70.264 | 2.351 | -6.554 | 6.963 | -2.362 | 7.492 | 7.855 | -72.500 | 2900.897 | 1996.411 |
| 49 | 132 | 0.441 | -0.011 | 0.011 | -0.003 | -72.500 | 2.362 | -7.492 | 7.855 | -2.373 | 7.930 | 8.277 | -73.340 | 2945.472 | 1872.165 |
| 50 | 132 | 0.441 | -0.011 | 0.011 | -0.003 | -73.340 | 2.373 | -7.930 | 8.277 | -2.384 | 8.368 | 8.701 | -74.099 | 2985.165 | 1746.274 |
| 51 | 132 | 0.441 | -0.011 | 0.011 | -0.003 | -74.099 | 2.384 | -8.368 | 8.701 | -2.395 | 8.806 | 9.126 | -74.786 | 3023.007 | 1619.815 |
| 52 | 132 | 0.441 | -0.011 | 0.011 | -0.003 | -74.786 | 2.395 | -8.806 | 9.126 | -2.406 | 9.245 | 9.553 | -75.413 | 3059.173 | 1492.866 |
| 53 | 132 | 0.441 | -0.011 | 0.011 | -0.003 | -75.413 | 2.406 | -9.245 | 9.553 | -2.417 | 9.683 | 9.980 | -75.986 | 3093.813 | 1365.493 |
| 54 | 132 | 0.441 | -0.011 | 0.011 | -0.003 | -75.986 | 2.417 | -9.683 | 9.980 | -2.428 | 10.122 | 10.409 | -76.511 | 3127.058 | 1237.748 |
| 55 | 132 | 0.441 | -0.011 | 0.011 | -0.003 | -76.511 | 2.428 | -10.122 | 10.409 | -2.439 | 10.561 | 10.839 | -76.995 | 3159.024 | 1109.677 |
| 56 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -76.995 | 2.439 | -10.561 | 10.839 | -2.450 | 11.000 | 11.269 | -77.442 | 3189.813 | 981.318 |
| 57 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -77.442 | 2.450 | -11.000 | 11.269 | -2.461 | 11.439 | 11.700 | -77.856 | 3219.518 | 852.703 |
| 58 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -77.856 | 2.461 | -11.439 | 11.700 | -2.472 | 11.878 | 12.132 | -78.241 | 3248.217 | 723.861 |
| 59 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -78.241 | 2.472 | -11.878 | 12.132 | -2.484 | 12.317 | 12.565 | -78.599 | 3275.985 | 594.815 |
| 60 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -78.599 | 2.484 | -12.317 | 12.565 | -2.495 | 12.756 | 12.998 | -78.934 | 3302.886 | 465.585 |
| 61 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -78.934 | 2.495 | -12.756 | 12.998 | -2.506 | 13.196 | 13.431 | -79.247 | 3328.978 | 336.189 |
| 62 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -79.247 | 2.506 | -13.196 | 13.431 | -2.517 | 13.635 | 13.865 | -79.540 | 3354.314 | 206.644 |
| 63 | 132 | 0.441 | -0.011 | 0.011 | -0.002 | -79.540 | 2.517 | -13.635 | 13.865 | -2.529 | 14.075 | 14.300 | -79.815 | 3378.943 | 76.962 |
| | | | | | | | | | | | | | | 3402.908 | -52.845 |

| Segment no. | Height of Segment | DL + LL (1/2PL) | Wind Load (Cpi=0) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 82.050 | 1.846 | 13.221 | 13.349 | -1.891 | -12.772 | 12.911 | 81.577 | 0.000 | 0.000 |
| 2 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 81.577 | 1.891 | 12.772 | 12.911 | -1.936 | -12.323 | 12.474 | 81.070 | 18.395 | 131.722 |
| 3 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 81.070 | 1.936 | 12.323 | 12.474 | -1.981 | -11.874 | 12.038 | 80.527 | 37.877 | 263.287 |
| 4 | 133 | 0.441 | 0.046 | 0.045 | 0.008 | 80.527 | 1.981 | 11.874 | 12.038 | -2.026 | -11.424 | 11.602 | 79.943 | 58.522 | 394.675 |
| 5 | 133 | 0.441 | 0.046 | 0.045 | 0.009 | 79.943 | 2.026 | 11.424 | 11.602 | -2.071 | -10.974 | 11.167 | 79.314 | 80.411 | 525.862 |
| 6 | 133 | 0.441 | 0.046 | 0.045 | 0.009 | 79.314 | 2.071 | 10.974 | 11.167 | -2.115 | -10.523 | 10.734 | 78.634 | 103.635 | 656.818 |
| 7 | 133 | 0.441 | 0.046 | 0.045 | 0.009 | 78.634 | 2.115 | 10.523 | 10.734 | -2.160 | -10.073 | 10.302 | 77.896 | 128.297 | 787.512 |
| 8 | 133 | 0.441 | 0.046 | 0.045 | 0.010 | 77.896 | 2.160 | 10.073 | 10.302 | -2.205 | -9.622 | 9.871 | 77.094 | 154.509 | 917.903 |
| 9 | 133 | 0.441 | 0.046 | 0.044 | 0.010 | 77.094 | 2.205 | 9.622 | 9.871 | -2.249 | -9.170 | 9.442 | 76.219 | 182.397 | 1047.946 |
| 10 | 133 | 0.441 | 0.046 | 0.044 | 0.010 | 76.219 | 2.249 | 9.170 | 9.442 | -2.294 | -8.719 | 9.015 | 75.261 | 212.102 | 1177.587 |
| 11 | 133 | 0.441 | 0.046 | 0.044 | 0.011 | 75.261 | 2.294 | 8.719 | 9.015 | -2.338 | -8.266 | 8.591 | 74.208 | 243.783 | 1306.758 |
| 12 | 133 | 0.441 | 0.046 | 0.044 | 0.011 | 74.208 | 2.338 | 8.266 | 8.591 | -2.382 | -7.814 | 8.169 | 73.046 | 277.620 | 1435.382 |
| 13 | 133 | 0.441 | 0.046 | 0.044 | 0.012 | 73.046 | 2.382 | 7.814 | 8.169 | -2.426 | -7.360 | 7.750 | 71.757 | 313.815 | 1563.362 |
| 14 | 133 | 0.441 | 0.046 | 0.044 | 0.012 | 71.757 | 2.426 | 7.360 | 7.750 | -2.470 | -6.906 | 7.335 | 70.321 | 352.599 | 1690.582 |
| 15 | 133 | 0.441 | 0.046 | 0.044 | 0.013 | 70.321 | 2.470 | 6.906 | 7.335 | -2.514 | -6.452 | 6.924 | 68.714 | 394.235 | 1816.897 |
| 16 | 133 | 0.441 | 0.046 | 0.043 | 0.014 | 68.714 | 2.514 | 6.452 | 6.924 | -2.557 | -5.996 | 6.519 | 66.906 | 439.022 | 1942.129 |
| 17 | 133 | 0.441 | -0.068 | -0.065 | -0.022 | 66.906 | 2.557 | 5.996 | 6.519 | -2.492 | -5.577 | 6.109 | 65.921 | 487.303 | 2066.056 |
| 18 | 133 | 0.441 | -0.068 | -0.064 | -0.023 | 65.921 | 2.492 | 5.577 | 6.109 | -2.428 | -5.159 | 5.702 | 64.797 | 539.472 | 2188.397 |
| 19 | 133 | 0.441 | -0.068 | -0.064 | -0.025 | 64.797 | 2.428 | 5.159 | 5.702 | -2.364 | -4.742 | 5.299 | 63.502 | 593.735 | 2309.824 |
| 20 | 133 | 0.441 | -0.068 | -0.063 | -0.027 | 63.502 | 2.364 | 4.742 | 5.299 | -2.301 | -4.328 | 4.901 | 61.998 | 650.371 | 2430.163 |
| 21 | 133 | 0.441 | -0.068 | -0.062 | -0.028 | 61.998 | 2.301 | 4.328 | 4.901 | -2.239 | -3.915 | 4.510 | 60.232 | 709.710 | 2549.192 |
| 22 | 133 | 0.441 | -0.068 | -0.061 | -0.031 | 60.232 | 2.239 | 3.915 | 4.510 | -2.178 | -3.504 | 4.126 | 58.136 | 772.155 | 2666.621 |
| 23 | 133 | 0.441 | -0.068 | -0.060 | -0.033 | 58.136 | 2.178 | 3.504 | 4.126 | -2.118 | -3.096 | 3.751 | 55.619 | 838.188 | 2782.071 |
| 24 | 133 | 0.441 | -0.068 | -0.058 | -0.036 | 55.619 | 2.118 | 3.096 | 3.751 | -2.060 | -2.690 | 3.388 | 52.558 | 908.399 | 2895.028 |
| 25 | 133 | 0.441 | -0.068 | -0.056 | -0.039 | 52.558 | 2.060 | 2.690 | 3.388 | -2.004 | -2.288 | 3.042 | 48.788 | 983.503 | 3004.793 |
| 26 | 133 | 0.441 | -0.068 | -0.053 | -0.043 | 48.788 | 2.004 | 2.288 | 3.042 | -1.951 | -1.890 | 2.716 | 44.089 | 1064.361 | 3110.392 |
| 27 | 133 | 0.441 | -0.068 | -0.049 | -0.047 | 44.089 | 1.951 | 1.890 | 2.716 | -1.902 | -1.496 | 2.419 | 38.189 | 1151.989 | 3210.444 |
| 28 | 133 | 0.441 | -0.068 | -0.044 | -0.052 | 38.189 | 1.902 | 1.496 | 2.419 | -1.857 | -1.106 | 2.162 | 30.784 | 1247.517 | 3302.982 |
| 29 | 133 | 0.441 | -0.068 | -0.038 | -0.057 | 30.784 | 1.857 | 1.106 | 2.162 | -1.819 | -0.722 | 1.957 | 21.644 | 1352.052 | 3385.210 |
| 30 | 133 | 0.441 | -0.068 | -0.029 | -0.062 | 21.644 | 1.819 | 0.722 | 1.957 | -1.790 | -0.342 | 1.822 | 10.826 | 1466.313 | 3453.279 |
| 31 | 133 | 0.441 | -0.068 | -0.019 | -0.066 | 10.826 | 1.790 | 0.342 | 1.822 | -1.771 | 0.033 | 1.772 | -1.079 | 1589.936 | 3502.334 |
| 32 | 133 | 0.941 | -0.068 | -0.006 | -0.068 | -1.079 | 1.771 | -0.033 | 1.772 | -1.765 | 0.907 | 1.984 | -27.192 | 1720.569 | 3527.314 |

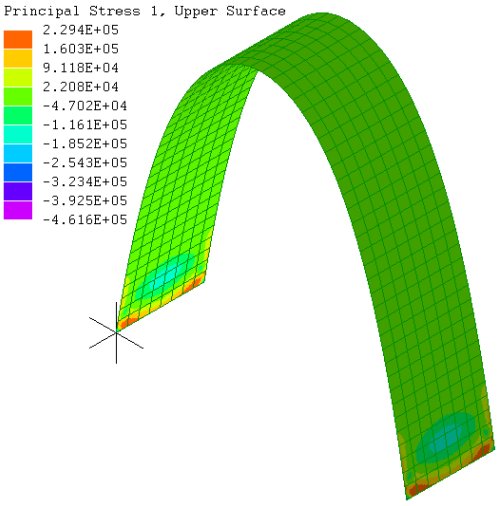
| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 133 | 0.441 | -0.068 | 0.006 | -0.068 | -27.192 | 1.765 | -0.907 | 1.984 | -1.771 | 1.280 | 2.185 | -35.854 | 1853.546 | 3524.810 |
| 34 | 133 | 0.441 | -0.068 | 0.019 | -0.066 | -35.854 | 1.771 | -1.280 | 2.185 | -1.790 | 1.656 | 2.438 | -42.767 | 1971.846 | 3464.032 |
| 35 | 133 | 0.441 | -0.068 | 0.029 | -0.062 | -42.767 | 1.790 | -1.656 | 2.438 | -1.819 | 2.035 | 2.730 | -48.207 | 2079.644 | 3386.131 |
| 36 | 133 | 0.441 | -0.068 | 0.038 | -0.057 | -48.207 | 1.819 | -2.035 | 2.730 | -1.857 | 2.420 | 3.050 | -52.494 | 2177.282 | 3295.821 |
| 37 | 133 | 0.441 | -0.068 | 0.044 | -0.052 | -52.494 | 1.857 | -2.420 | 3.050 | -1.902 | 2.809 | 3.392 | -55.905 | 2265.918 | 3196.662 |
| 38 | 133 | 0.441 | -0.068 | 0.049 | -0.047 | -55.905 | 1.902 | -2.809 | 3.392 | -1.951 | 3.203 | 3.751 | -58.657 | 2346.895 | 3091.154 |
| 39 | 133 | 0.441 | -0.068 | 0.053 | -0.043 | -58.657 | 1.951 | -3.203 | 3.751 | -2.004 | 3.602 | 4.122 | -60.907 | 2421.450 | 2981.015 |
| 40 | 133 | 0.441 | -0.068 | 0.056 | -0.039 | -60.907 | 2.004 | -3.602 | 4.122 | -2.060 | 4.004 | 4.503 | -62.773 | 2490.632 | 2867.425 |
| 41 | 133 | 0.441 | -0.068 | 0.058 | -0.036 | -62.773 | 2.060 | -4.004 | 4.503 | -2.118 | 4.409 | 4.891 | -64.340 | 2555.300 | 2751.205 |
| 42 | 133 | 0.441 | -0.068 | 0.060 | -0.033 | -64.340 | 2.118 | -4.409 | 4.891 | -2.178 | 4.817 | 5.287 | -65.672 | 2616.150 | 2632.942 |
| 43 | 133 | 0.441 | -0.068 | 0.061 | -0.031 | -65.672 | 2.178 | -4.817 | 5.287 | -2.239 | 5.228 | 5.687 | -66.816 | 2673.743 | 2513.058 |
| 44 | 133 | 0.441 | -0.068 | 0.062 | -0.028 | -66.816 | 2.239 | -5.228 | 5.687 | -2.301 | 5.641 | 6.092 | -67.807 | 2728.534 | 2391.868 |
| 45 | 133 | 0.441 | -0.068 | 0.063 | -0.027 | -67.807 | 2.301 | -5.641 | 6.092 | -2.364 | 6.056 | 6.501 | -68.674 | 2780.895 | 2269.609 |
| 46 | 133 | 0.441 | -0.068 | 0.064 | -0.025 | -68.674 | 2.364 | -6.056 | 6.501 | -2.428 | 6.472 | 6.913 | -69.437 | 2831.133 | 2146.462 |
| 47 | 133 | 0.441 | -0.068 | 0.064 | -0.023 | -69.437 | 2.428 | -6.472 | 6.913 | -2.492 | 6.890 | 7.327 | -70.115 | 2879.502 | 2022.569 |
| 48 | 133 | 0.441 | -0.023 | 0.022 | -0.007 | -70.115 | 2.492 | -6.890 | 7.327 | -2.514 | 7.324 | 7.744 | -71.057 | 2926.216 | 1898.043 |
| 49 | 133 | 0.441 | -0.023 | 0.022 | -0.007 | -71.057 | 2.514 | -7.324 | 7.744 | -2.536 | 7.759 | 8.163 | -71.903 | 2971.454 | 1772.973 |
| 50 | 133 | 0.441 | -0.023 | 0.022 | -0.007 | -71.903 | 2.536 | -7.759 | 8.163 | -2.557 | 8.194 | 8.584 | -72.666 | 3014.628 | 1647.175 |
| 51 | 133 | 0.441 | -0.023 | 0.022 | -0.006 | -72.666 | 2.557 | -8.194 | 8.584 | -2.579 | 8.629 | 9.006 | -73.358 | 3055.941 | 1520.755 |
| 52 | 133 | 0.441 | -0.023 | 0.022 | -0.006 | -73.358 | 2.579 | -8.629 | 9.006 | -2.601 | 9.064 | 9.430 | -73.988 | 3095.567 | 1393.795 |
| 53 | 133 | 0.441 | -0.023 | 0.022 | -0.006 | -73.988 | 2.601 | -9.064 | 9.430 | -2.623 | 9.500 | 9.856 | -74.563 | 3133.657 | 1266.366 |
| 54 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -74.563 | 2.623 | -9.500 | 9.856 | -2.646 | 9.936 | 10.282 | -75.091 | 3170.344 | 1138.526 |
| 55 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -75.091 | 2.646 | -9.936 | 10.282 | -2.668 | 10.372 | 10.710 | -75.576 | 3205.746 | 1010.324 |
| 56 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -75.576 | 2.668 | -10.372 | 10.710 | -2.690 | 10.809 | 11.139 | -76.025 | 3239.965 | 881.801 |
| 57 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -76.025 | 2.690 | -10.809 | 11.139 | -2.712 | 11.245 | 11.568 | -76.440 | 3273.094 | 752.994 |
| 58 | 133 | 0.441 | -0.023 | 0.022 | -0.005 | -76.440 | 2.712 | -11.245 | 11.568 | -2.735 | 11.682 | 11.998 | -76.825 | 3305.214 | 623.930 |
| 59 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -76.825 | 2.735 | -11.682 | 11.998 | -2.757 | 12.119 | 12.429 | -77.184 | 3336.398 | 494.638 |
| 60 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -77.184 | 2.757 | -12.119 | 12.429 | -2.779 | 12.556 | 12.860 | -77.519 | 3366.711 | 365.138 |
| 61 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -77.519 | 2.779 | -12.556 | 12.860 | -2.802 | 12.994 | 13.292 | -77.832 | 3396.213 | 235.452 |
| 62 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -77.832 | 2.802 | -12.994 | 13.292 | -2.824 | 13.431 | 13.725 | -78.125 | 3424.956 | 105.595 |
| 63 | 133 | 0.441 | -0.023 | 0.022 | -0.004 | -78.125 | 2.824 | -13.431 | 13.725 | -2.847 | 13.869 | 14.158 | -78.401 | 3452.990 | -24.417 |
| | | | | | | | | | | | | | | 3480.358 | -154.571 |

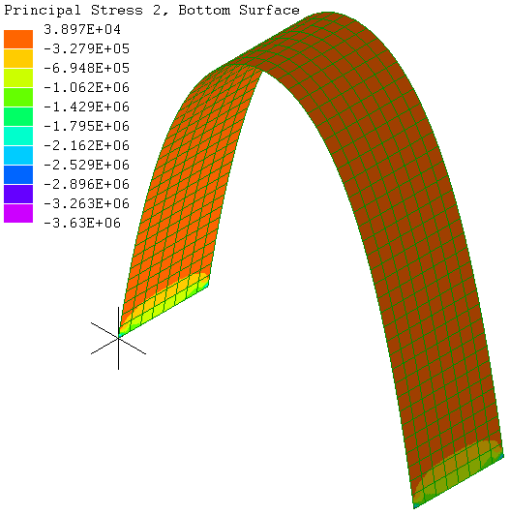
| Segment no. | Height of segment | DL + LL(1/2PL) | Wind Load (Cpi=-0.2) | WL H | WL V | Left Angle | Left Thrust x | Left Thrust y | ***Left Thrust*** | Right Thrust x | Right Thrust y | ***Right Thrust*** | Right angle | Co-ordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | X | Y |
| 1 | 132.3 | 0.441 | 0.057 | 0.056 | 0.009 | 82.800 | 1.698 | 13.439 | 13.546 | -1.754 | -12.988 | 13.106 | 82.309 | 0 | 0 |
| 2 | 132.3 | 0.441 | 0.057 | 0.056 | 0.010 | 82.309 | 1.754 | 12.988 | 13.106 | -1.810 | -12.537 | 12.667 | 81.784 | 16.582 | 131.257 |
| 3 | 132.3 | 0.441 | 0.057 | 0.056 | 0.010 | 81.784 | 1.810 | 12.537 | 12.667 | -1.866 | -12.086 | 12.229 | 81.222 | 34.287 | 262.367 |
| 4 | 132.3 | 0.441 | 0.057 | 0.056 | 0.010 | 81.222 | 1.866 | 12.086 | 12.229 | -1.922 | -11.634 | 11.792 | 80.618 | 53.193 | 393.309 |
| 5 | 132.3 | 0.441 | 0.057 | 0.056 | 0.011 | 80.618 | 1.922 | 11.634 | 11.792 | -1.978 | -11.182 | 11.355 | 79.967 | 73.383 | 524.059 |
| 6 | 132.3 | 0.441 | 0.057 | 0.056 | 0.011 | 79.967 | 1.978 | 11.182 | 11.355 | -2.034 | -10.729 | 10.920 | 79.265 | 94.950 | 654.589 |
| 7 | 132.3 | 0.441 | 0.057 | 0.056 | 0.012 | 79.265 | 2.034 | 10.729 | 10.920 | -2.090 | -10.276 | 10.487 | 78.504 | 117.999 | 784.866 |
| 8 | 132.3 | 0.441 | 0.057 | 0.056 | 0.012 | 78.504 | 2.090 | 10.276 | 10.487 | -2.146 | -9.823 | 10.055 | 77.678 | 142.643 | 914.851 |
| 9 | 132.3 | 0.441 | 0.057 | 0.056 | 0.012 | 77.678 | 2.146 | 9.823 | 10.055 | -2.201 | -9.369 | 9.624 | 76.778 | 169.010 | 1044.497 |
| 10 | 132.3 | 0.441 | 0.057 | 0.055 | 0.013 | 76.778 | 2.201 | 9.369 | 9.624 | -2.257 | -8.915 | 9.196 | 75.793 | 197.244 | 1173.749 |
| 11 | 132.3 | 0.441 | 0.057 | 0.055 | 0.014 | 75.793 | 2.257 | 8.915 | 9.196 | -2.312 | -8.460 | 8.770 | 74.713 | 227.505 | 1302.542 |
| 12 | 132.3 | 0.441 | 0.057 | 0.055 | 0.014 | 74.713 | 2.312 | 8.460 | 8.770 | -2.367 | -8.004 | 8.347 | 73.523 | 259.973 | 1430.796 |
| 13 | 132.3 | 0.441 | 0.057 | 0.055 | 0.015 | 73.523 | 2.367 | 8.004 | 8.347 | -2.422 | -7.548 | 7.927 | 72.206 | 294.854 | 1558.415 |
| 14 | 132.3 | 0.441 | 0.057 | 0.055 | 0.016 | 72.206 | 2.422 | 7.548 | 7.927 | -2.477 | -7.091 | 7.511 | 70.742 | 332.378 | 1685.282 |
| 15 | 132.3 | 0.441 | 0.057 | 0.055 | 0.016 | 70.742 | 2.477 | 7.091 | 7.511 | -2.532 | -6.633 | 7.100 | 69.108 | 372.808 | 1811.253 |
| 16 | 132.3 | 0.441 | 0.057 | 0.054 | 0.017 | 69.108 | 2.532 | 6.633 | 7.100 | -2.586 | -6.174 | 6.694 | 67.273 | 416.443 | 1936.150 |
| 17 | 132.3 | 0.441 | -0.057 | -0.054 | -0.018 | 67.273 | 2.586 | 6.174 | 6.694 | -2.532 | -5.751 | 6.284 | 66.236 | 463.623 | 2059.751 |
| 18 | 132.3 | 0.441 | -0.057 | -0.054 | -0.019 | 66.236 | 2.532 | 5.751 | 6.284 | -2.479 | -5.329 | 5.877 | 65.056 | 514.736 | 2181.779 |
| 19 | 132.3 | 0.441 | -0.057 | -0.053 | -0.021 | 65.056 | 2.479 | 5.329 | 5.877 | -2.425 | -4.908 | 5.475 | 63.703 | 568.048 | 2302.862 |
| 20 | 132.3 | 0.441 | -0.057 | -0.053 | -0.022 | 63.703 | 2.425 | 4.908 | 5.475 | -2.373 | -4.489 | 5.078 | 62.139 | 623.843 | 2422.821 |
| 21 | 132.3 | 0.441 | -0.057 | -0.052 | -0.024 | 62.139 | 2.373 | 4.489 | 5.078 | -2.321 | -4.071 | 4.687 | 60.312 | 682.454 | 2541.430 |
| 22 | 132.3 | 0.441 | -0.057 | -0.051 | -0.026 | 60.312 | 2.321 | 4.071 | 4.687 | -2.270 | -3.655 | 4.303 | 58.158 | 744.282 | 2658.394 |
| 23 | 132.3 | 0.441 | -0.057 | -0.050 | -0.028 | 58.158 | 2.270 | 3.655 | 4.303 | -2.220 | -3.242 | 3.929 | 55.592 | 809.808 | 2773.328 |
| 24 | 132.3 | 0.441 | -0.057 | -0.048 | -0.030 | 55.592 | 2.220 | 3.242 | 3.929 | -2.172 | -2.830 | 3.568 | 52.498 | 879.606 | 2885.718 |
| 25 | 132.3 | 0.441 | -0.057 | -0.047 | -0.033 | 52.498 | 2.172 | 2.830 | 3.568 | -2.125 | -2.422 | 3.222 | 48.730 | 954.367 | 2994.869 |
| 26 | 132.3 | 0.441 | -0.057 | -0.044 | -0.036 | 48.730 | 2.125 | 2.422 | 3.222 | -2.081 | -2.016 | 2.898 | 44.093 | 1034.909 | 3099.828 |
| 27 | 132.3 | 0.441 | -0.057 | -0.041 | -0.039 | 44.093 | 2.081 | 2.016 | 2.898 | -2.040 | -1.614 | 2.601 | 38.355 | 1122.176 | 3199.265 |
| 28 | 132.3 | 0.441 | -0.057 | -0.037 | -0.043 | 38.355 | 2.040 | 1.614 | 2.601 | -2.003 | -1.216 | 2.343 | 31.266 | 1217.195 | 3291.323 |
| 29 | 132.3 | 0.441 | -0.057 | -0.032 | -0.047 | 31.266 | 2.003 | 1.216 | 2.343 | -1.971 | -0.822 | 2.136 | 22.639 | 1320.941 | 3373.420 |
| 30 | 132.3 | 0.441 | -0.057 | -0.024 | -0.051 | 22.639 | 1.971 | 0.822 | 2.136 | -1.947 | -0.432 | 1.994 | 12.518 | 1434.028 | 3442.084 |
| 31 | 132.3 | 0.441 | -0.057 | -0.016 | -0.055 | 12.518 | 1.947 | 0.432 | 1.994 | -1.931 | -0.046 | 1.932 | 1.354 | 1556.134 | 3493.010 |
| 32 | 132.3 | 0.941 | -0.057 | -0.005 | -0.057 | 1.354 | 1.931 | 0.046 | 1.932 | -1.926 | 0.839 | 2.101 | -23.541 | 1685.289 | 3521.684 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 132.3 | 0.441 | -0.057 | 0.005 | -0.057 | -23.541 | 1.926 | -0.839 | 2.101 | -1.931 | 1.224 | 2.286 | -32.359 | 1817.552 | 3524.810 |
| 34 | 132.3 | 0.441 | -0.057 | 0.016 | -0.055 | -32.359 | 1.931 | -1.224 | 2.286 | -1.947 | 1.610 | 2.527 | -39.595 | 1938.842 | 3471.970 |
| 35 | 132.3 | 0.441 | -0.057 | 0.024 | -0.051 | -39.595 | 1.947 | -1.610 | 2.527 | -1.971 | 2.000 | 2.808 | -45.417 | 2050.597 | 3401.159 |
| 36 | 132.3 | 0.441 | -0.057 | 0.032 | -0.047 | -45.417 | 1.971 | -2.000 | 2.808 | -2.003 | 2.394 | 3.121 | -50.086 | 2152.543 | 3316.837 |
| 37 | 132.3 | 0.441 | -0.057 | 0.037 | -0.043 | -50.086 | 2.003 | -2.394 | 3.121 | -2.040 | 2.792 | 3.458 | -53.850 | 2245.410 | 3222.608 |
| 38 | 132.3 | 0.441 | -0.057 | 0.041 | -0.039 | -53.850 | 2.040 | -2.792 | 3.458 | -2.081 | 3.194 | 3.812 | -56.916 | 2330.299 | 3121.133 |
| 39 | 132.3 | 0.441 | -0.057 | 0.044 | -0.036 | -56.916 | 2.081 | -3.194 | 3.812 | -2.125 | 3.600 | 4.180 | -59.443 | 2408.342 | 3014.304 |
| 40 | 132.3 | 0.441 | -0.057 | 0.047 | -0.033 | -59.443 | 2.125 | -3.600 | 4.180 | -2.172 | 4.008 | 4.559 | -61.549 | 2480.560 | 2903.453 |
| 41 | 132.3 | 0.441 | -0.057 | 0.048 | -0.030 | -61.549 | 2.172 | -4.008 | 4.559 | -2.220 | 4.420 | 4.946 | -63.327 | 2547.822 | 2789.527 |
| 42 | 132.3 | 0.441 | -0.057 | 0.050 | -0.028 | -63.327 | 2.220 | -4.420 | 4.946 | -2.270 | 4.834 | 5.340 | -64.842 | 2610.849 | 2673.205 |
| 43 | 132.3 | 0.441 | -0.057 | 0.051 | -0.026 | -64.842 | 2.270 | -4.834 | 5.340 | -2.321 | 5.249 | 5.740 | -66.146 | 2670.239 | 2554.985 |
| 44 | 132.3 | 0.441 | -0.057 | 0.052 | -0.024 | -66.146 | 2.321 | -5.249 | 5.740 | -2.373 | 5.667 | 6.144 | -67.280 | 2726.482 | 2435.235 |
| 45 | 132.3 | 0.441 | -0.057 | 0.053 | -0.022 | -67.280 | 2.373 | -5.667 | 6.144 | -2.425 | 6.086 | 6.552 | -68.272 | 2779.984 | 2314.236 |
| 46 | 132.3 | 0.441 | -0.057 | 0.053 | -0.021 | -68.272 | 2.425 | -6.086 | 6.552 | -2.479 | 6.507 | 6.963 | -69.148 | 2831.083 | 2192.202 |
| 47 | 132.3 | 0.441 | -0.057 | 0.054 | -0.019 | -69.148 | 2.479 | -6.507 | 6.963 | -2.532 | 6.929 | 7.377 | -69.926 | 2880.059 | 2069.301 |
| 48 | 132.3 | 0.441 | -0.011 | 0.011 | -0.004 | -69.926 | 2.532 | -6.929 | 7.377 | -2.543 | 7.367 | 7.793 | -70.956 | 2927.152 | 1945.666 |
| 49 | 132.3 | 0.441 | -0.011 | 0.011 | -0.003 | -70.956 | 2.543 | -7.367 | 7.793 | -2.554 | 7.805 | 8.212 | -71.881 | 2972.562 | 1821.404 |
| 50 | 132.3 | 0.441 | -0.011 | 0.011 | -0.003 | -71.881 | 2.554 | -7.805 | 8.212 | -2.565 | 8.243 | 8.633 | -72.717 | 3015.731 | 1696.345 |
| 51 | 132.3 | 0.441 | -0.011 | 0.011 | -0.003 | -72.717 | 2.565 | -8.243 | 8.633 | -2.576 | 8.681 | 9.055 | -73.475 | 3056.874 | 1570.605 |
| 52 | 132.3 | 0.441 | -0.011 | 0.011 | -0.003 | -73.475 | 2.576 | -8.681 | 9.055 | -2.587 | 9.120 | 9.479 | -74.165 | 3096.180 | 1444.278 |
| 53 | 132.3 | 0.441 | -0.011 | 0.011 | -0.003 | -74.165 | 2.587 | -9.120 | 9.479 | -2.598 | 9.558 | 9.905 | -74.796 | 3133.811 | 1317.443 |
| 54 | 132.3 | 0.441 | -0.011 | 0.011 | -0.003 | -74.796 | 2.598 | -9.558 | 9.905 | -2.609 | 9.997 | 10.332 | -75.374 | 3169.912 | 1190.164 |
| 55 | 132.3 | 0.441 | -0.011 | 0.011 | -0.003 | -75.374 | 2.609 | -9.997 | 10.332 | -2.620 | 10.436 | 10.760 | -75.907 | 3204.609 | 1062.495 |
| 56 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -75.907 | 2.620 | -10.436 | 10.760 | -2.631 | 10.875 | 11.188 | -76.399 | 3238.015 | 934.482 |
| 57 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -76.399 | 2.631 | -10.875 | 11.188 | -2.642 | 11.314 | 11.618 | -76.855 | 3270.229 | 806.164 |
| 58 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -76.855 | 2.642 | -11.314 | 11.618 | -2.653 | 11.753 | 12.049 | -77.278 | 3301.340 | 677.574 |
| 59 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -77.278 | 2.653 | -11.753 | 12.049 | -2.664 | 12.192 | 12.480 | -77.672 | 3331.427 | 548.740 |
| 60 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -77.672 | 2.664 | -12.192 | 12.480 | -2.676 | 12.631 | 12.912 | -78.040 | 3360.562 | 419.688 |
| 61 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -78.040 | 2.676 | -12.631 | 12.912 | -2.687 | 13.071 | 13.344 | -78.384 | 3388.808 | 290.438 |
| 62 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -78.384 | 2.687 | -13.071 | 13.344 | -2.698 | 13.510 | 13.777 | -78.706 | 3416.225 | 161.010 |
| 63 | 132.3 | 0.441 | -0.011 | 0.011 | -0.002 | -78.706 | 2.698 | -13.510 | 13.777 | -2.709 | 13.950 | 14.210 | -79.009 | 3442.864 | 31.420 |
| | | | | | | | | | | | | | | 3468.775 | -98.318 |

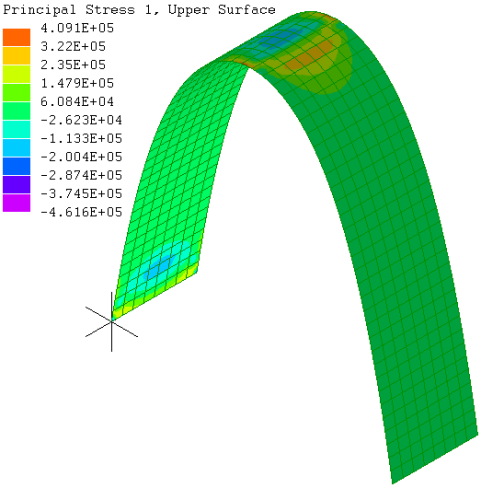
# Appendix B

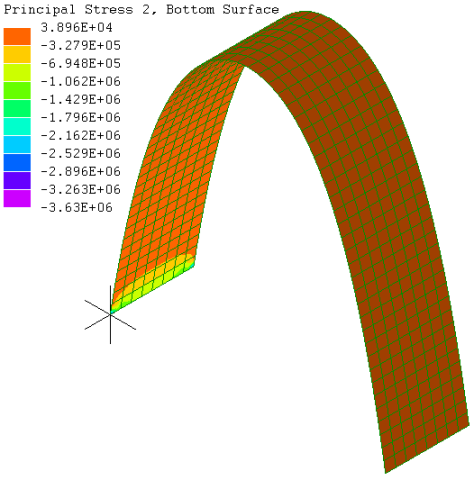
## *I. Dead Load, T=20° full*



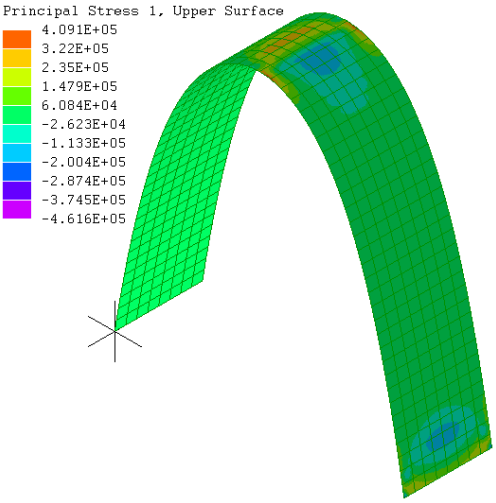



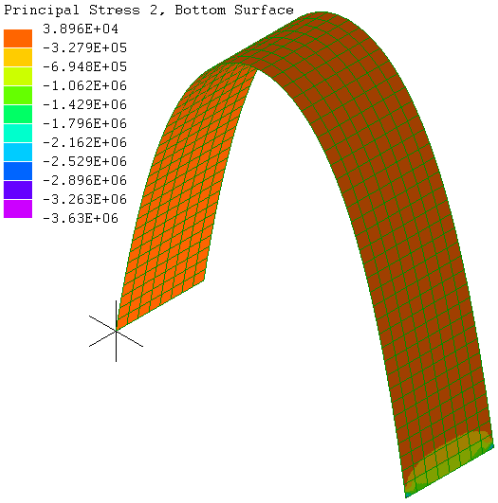

## *II. Dead Load, T=20° left half*



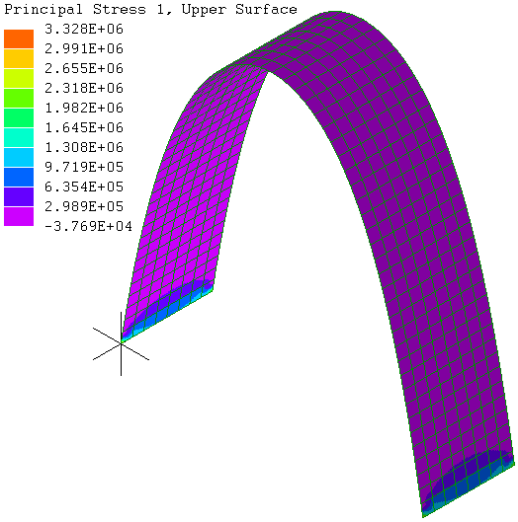



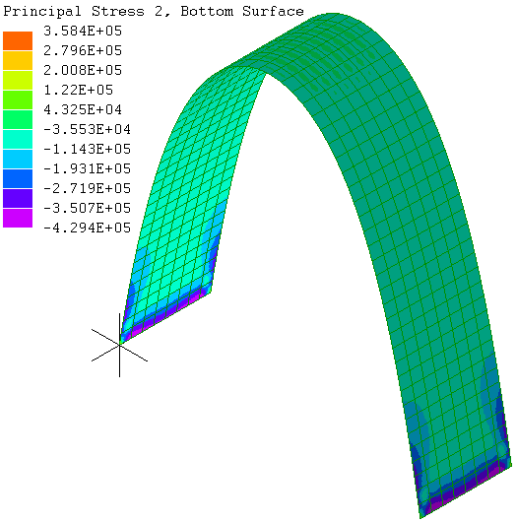
### *III. Dead Load, T=20° right half*



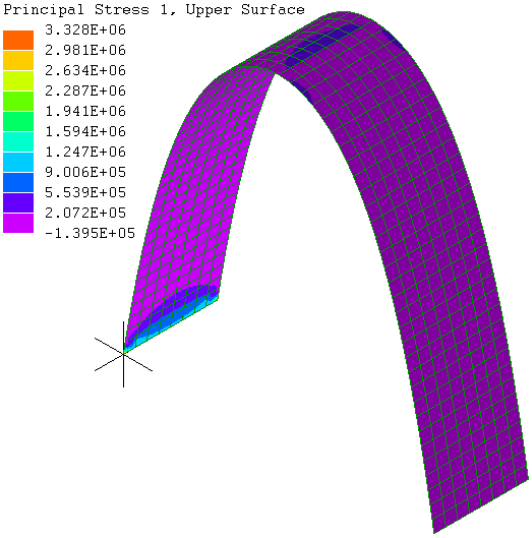



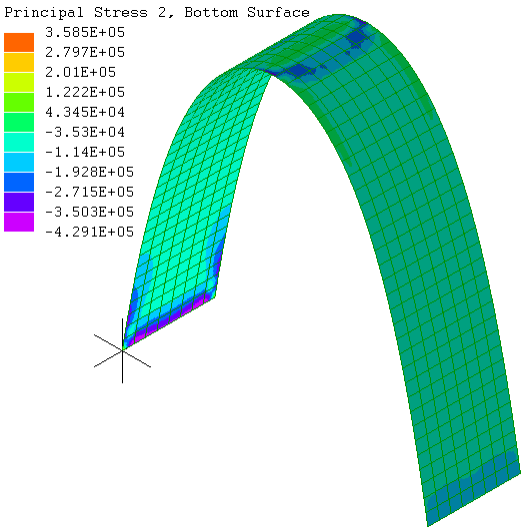

### *IV. Dead Load, T=-20° full*



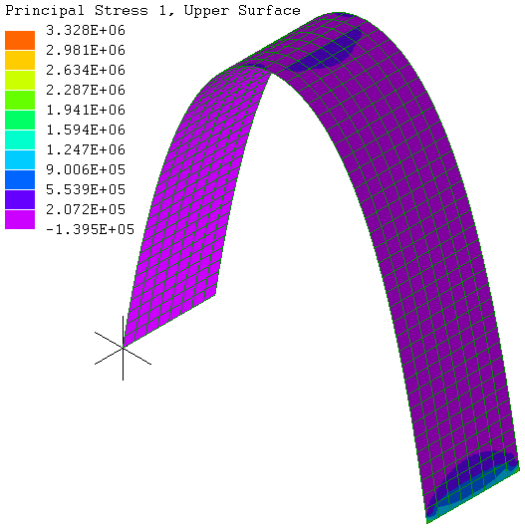



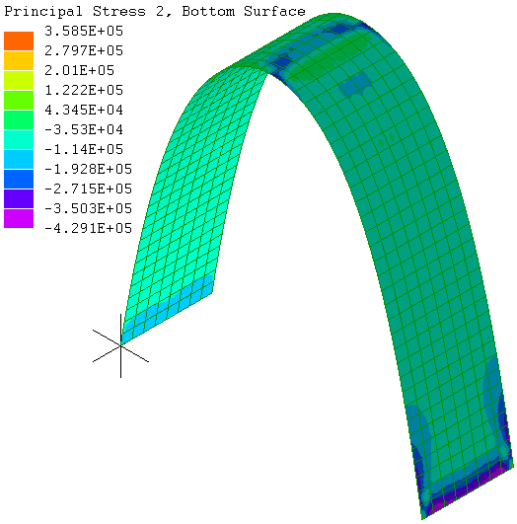

### *V. Dead Load, T=-20° left half*



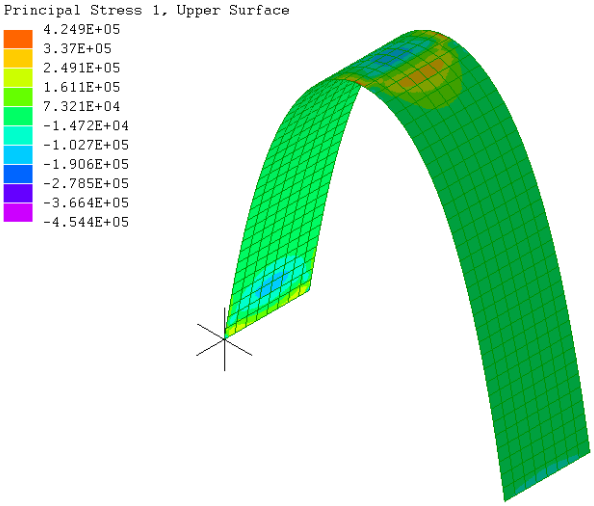



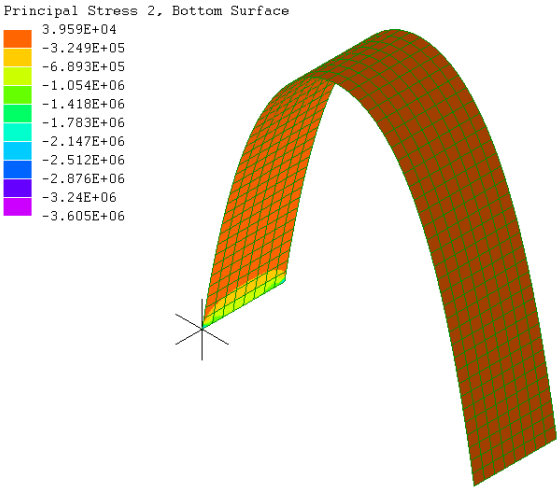
## *VI. Dead Load, T=-20° right half*



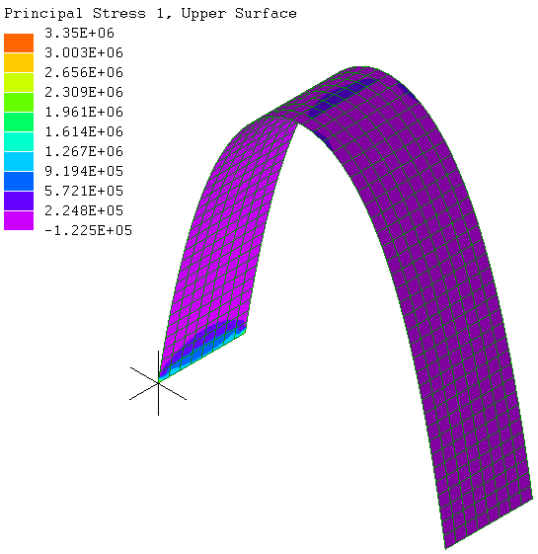



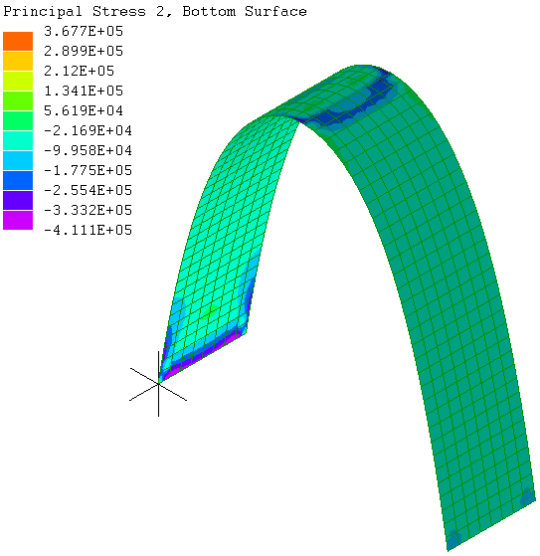

## *VII. Dead Load, Live Load full, T=20° left half*



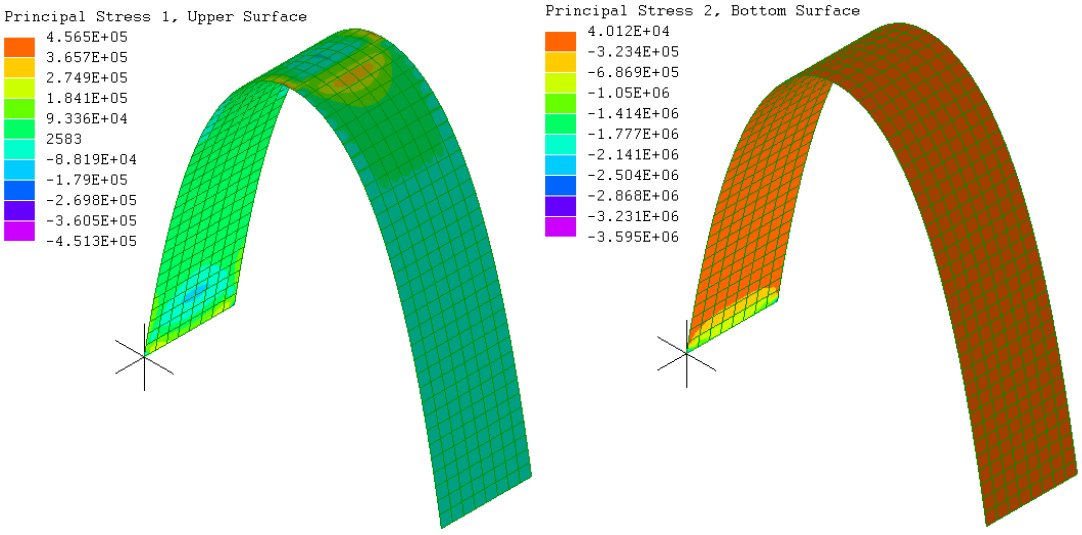




## *VIII. Dead Load, Live Load full, T=-20° left half*

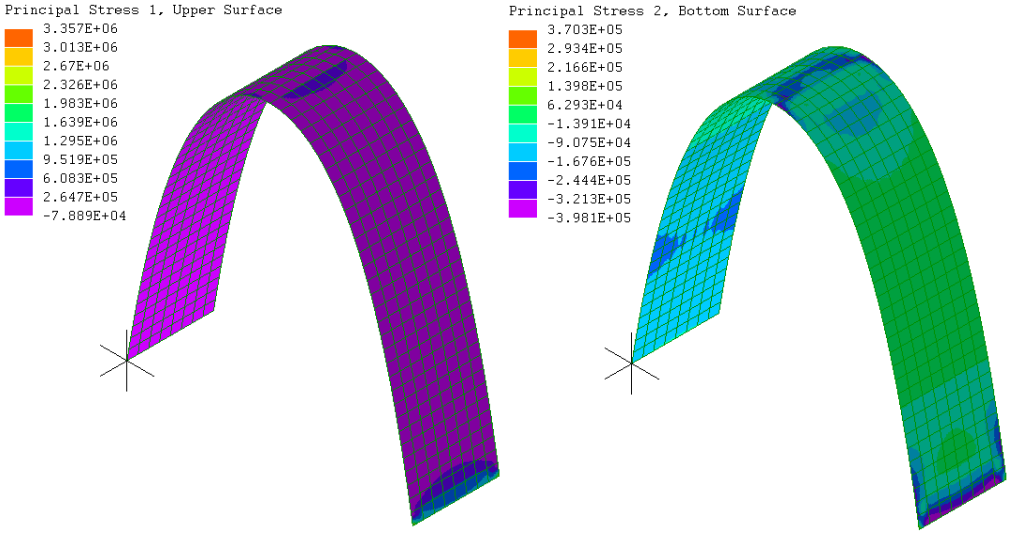


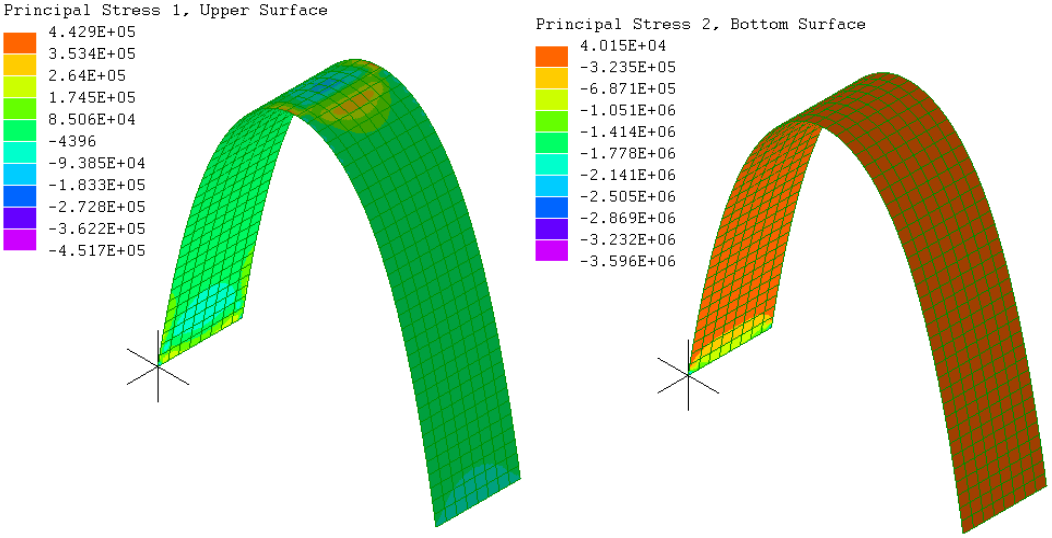
## *IX. Dead Load, Live Load full, Wind Load (Cpi=0), T=20° left half*



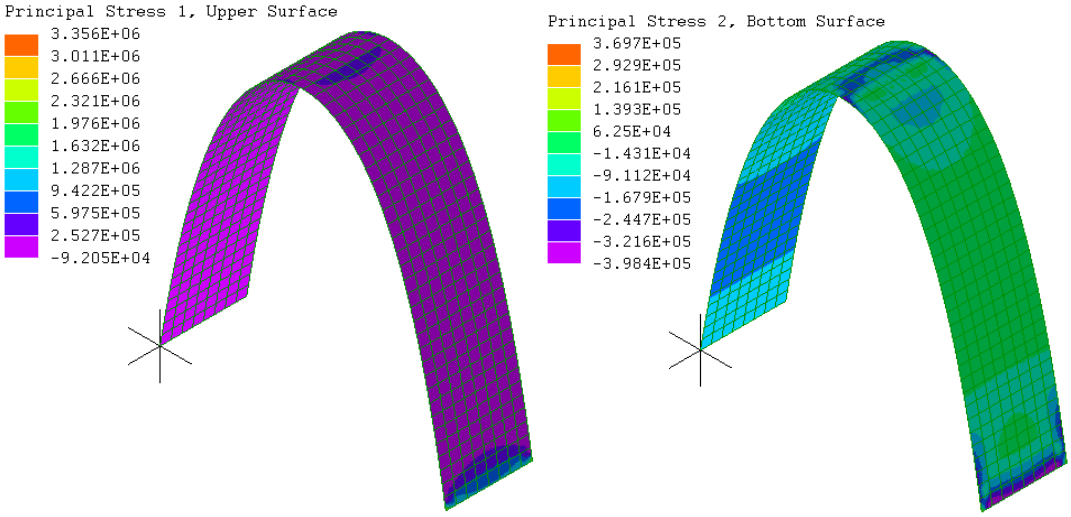

## *X. Dead Load, Live Load full, Wind Load (Cpi=0), T=-20° right half*



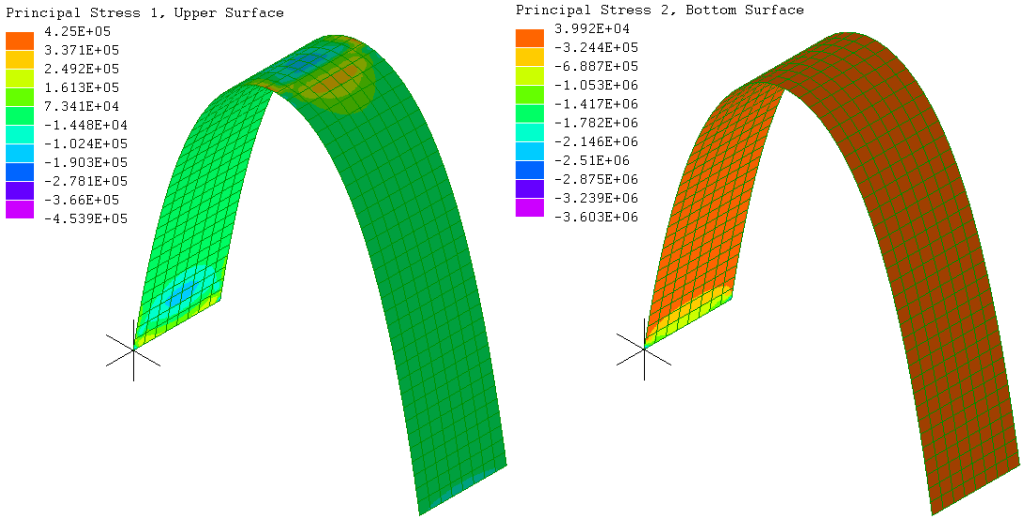
## XI. *Dead Load, Live Load full, Wind Load (Cpi=-0.2), T=20° left half*



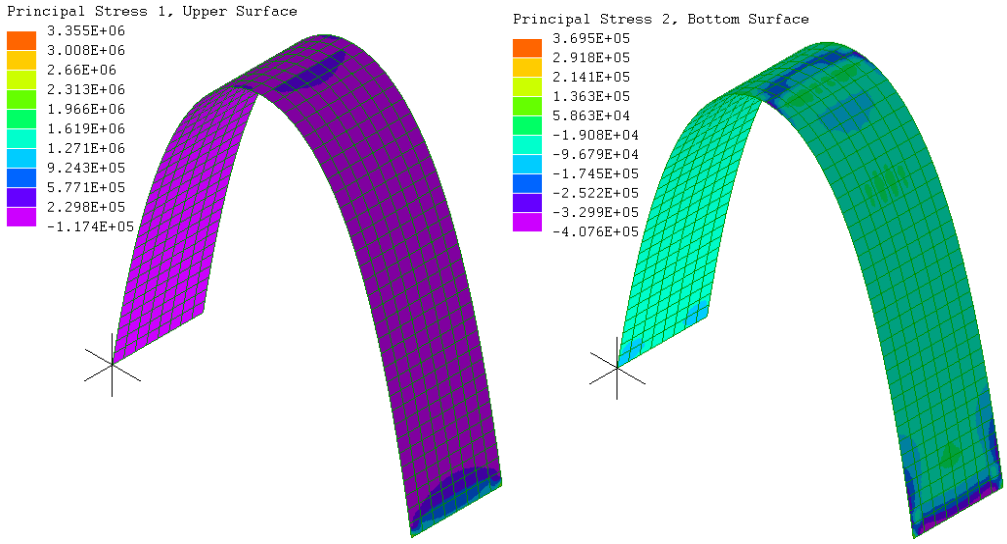

## XII. *Dead Load, Live Load full, Wind Load (Cpi=-0.2), T=-20° right half*



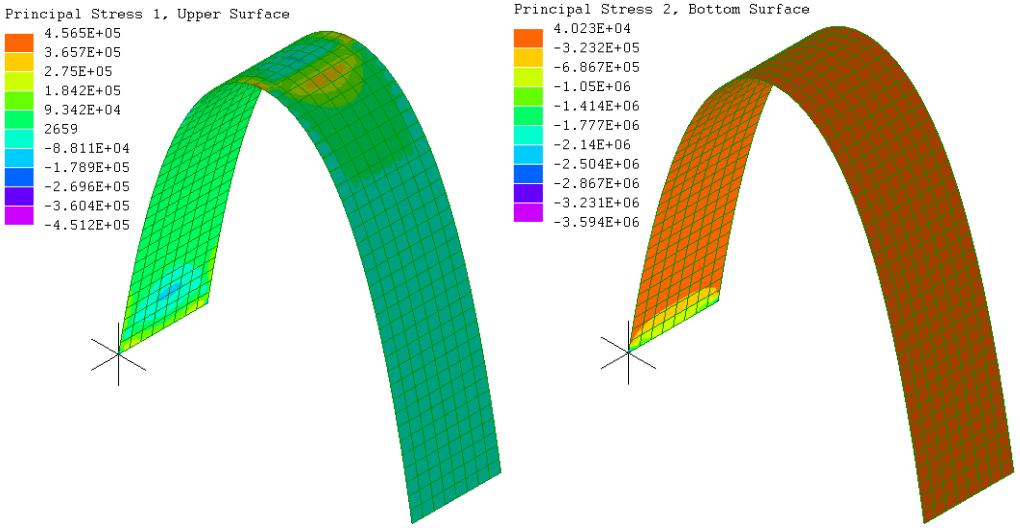

## XIII. *Dead Load, Live Load left half, T=20° left half*



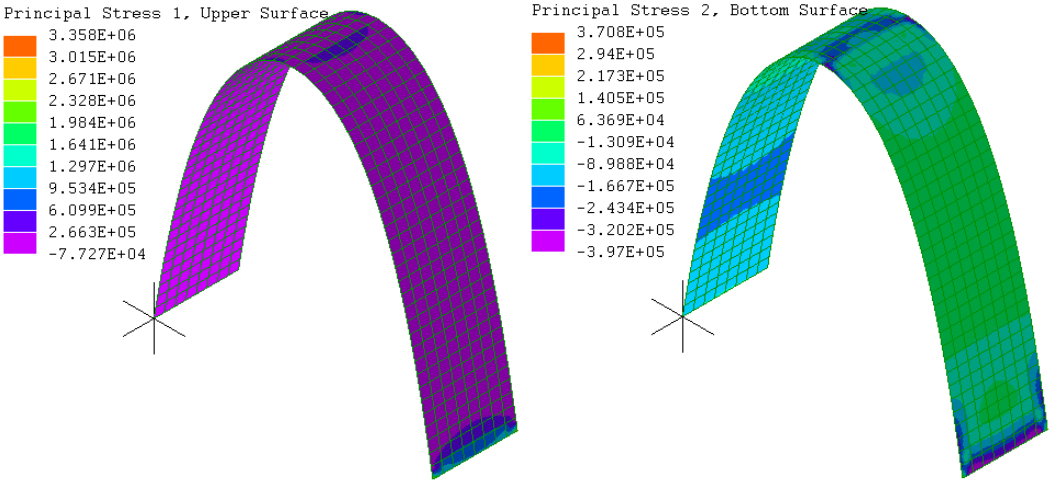
## XIV. *Dead Load, Live Load left half, T=-20° right half*



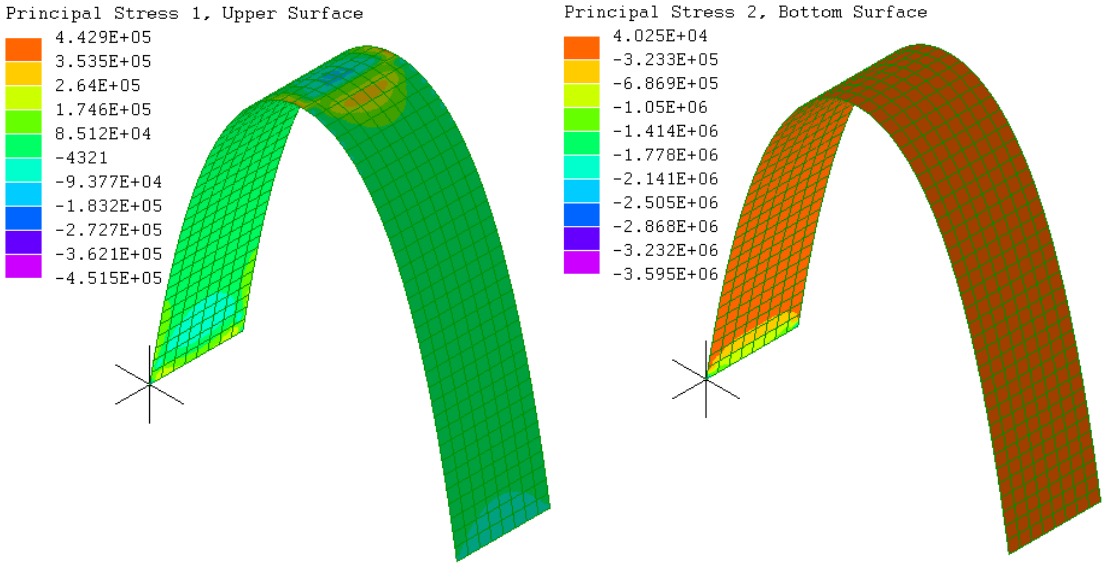

## XV. *Dead Load, Live Load left half, Wind Load (Cpi=0), T=20° left half*



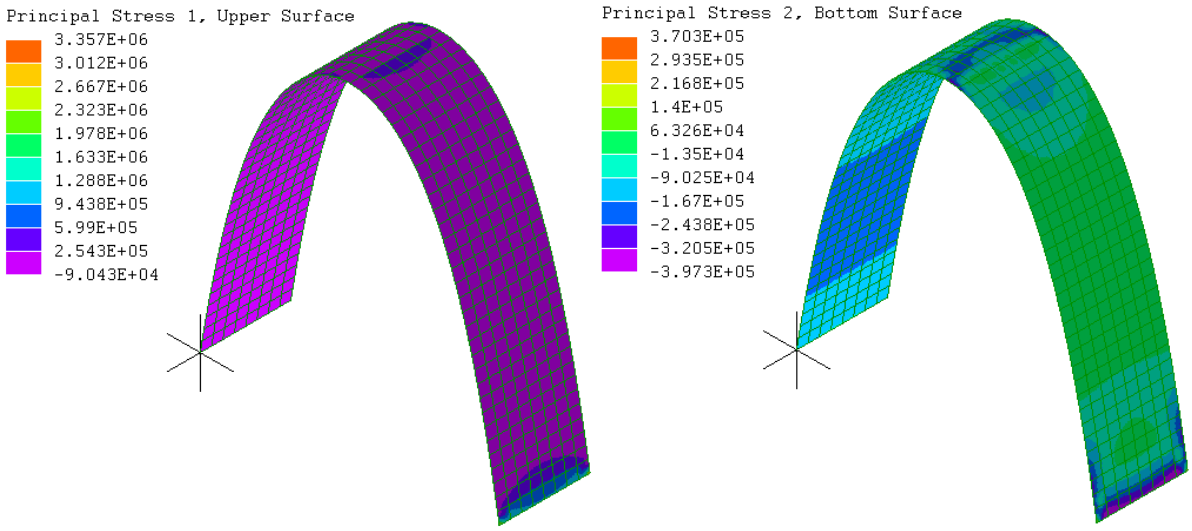

## XVI. *Dead Load, Live Load left half, Wind Load (Cpi=0), T=-20° right half*



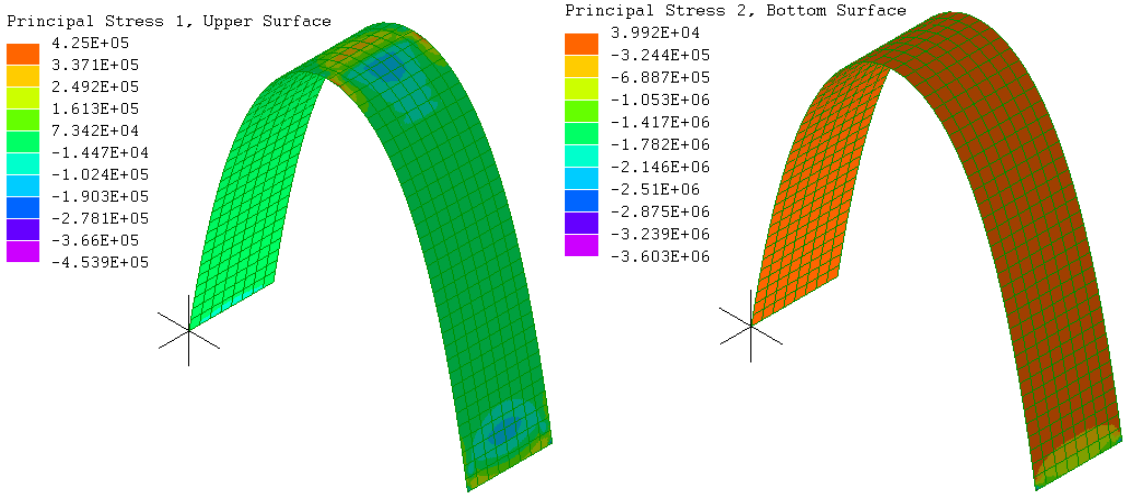
### *XVII. Dead Load, Live Load left half, Wind Load (Cpi=-0.2), T=20° left half*



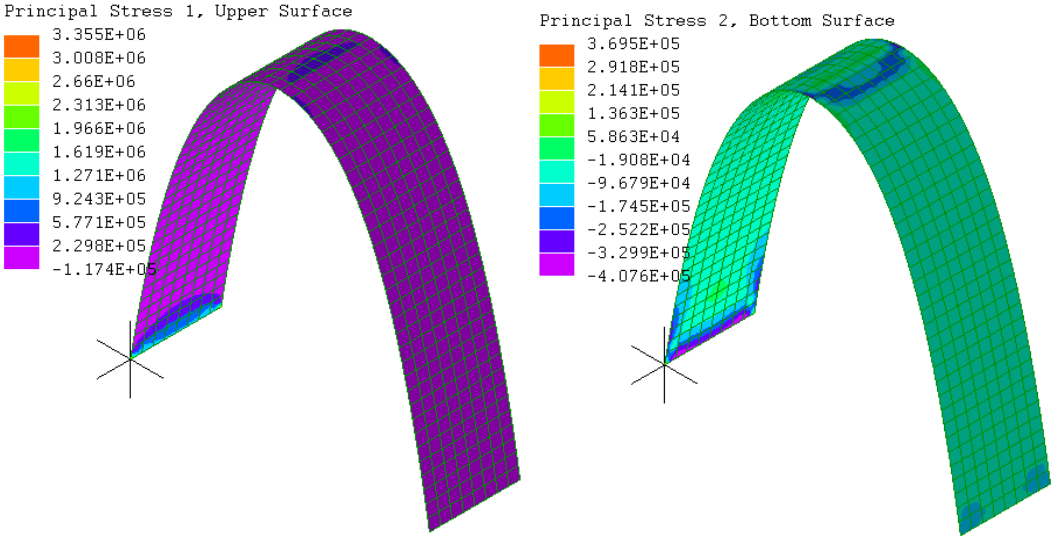

### *XVIII. Dead Load, Live Load left half, Wind Load (Cpi=-0.2), T=-20° right half*



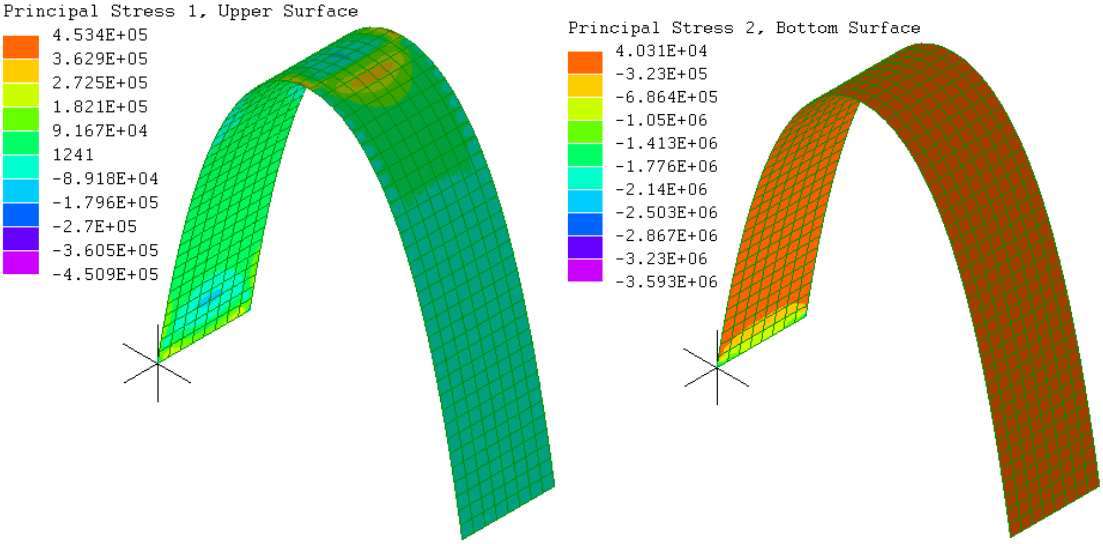
## *XIX. Dead Load, Live Load right half, T=20° right half*



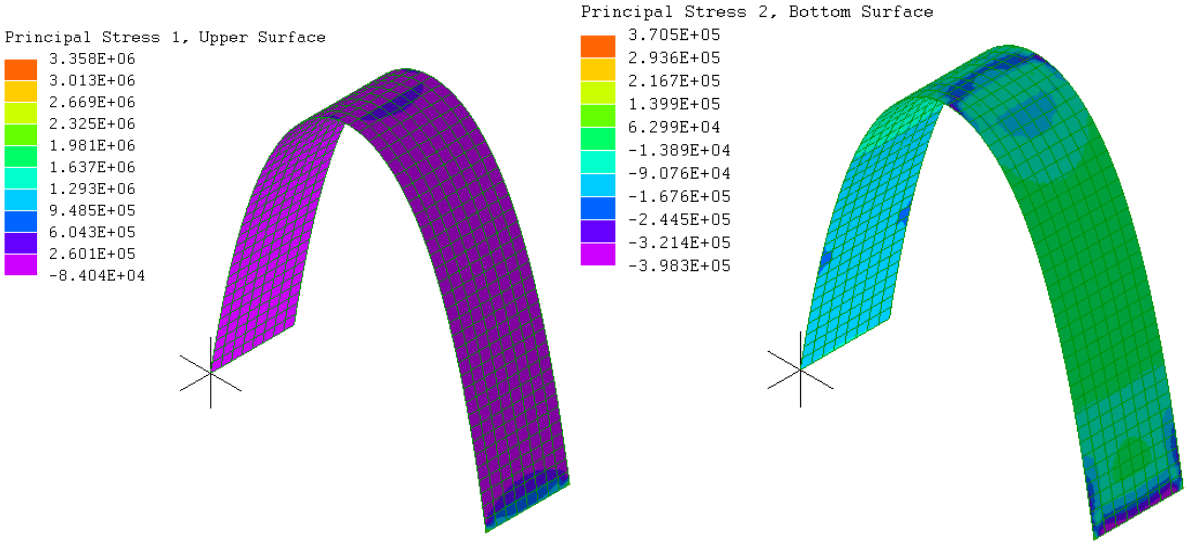

## *XX. Dead Load, Live Load right half, T=-20° left half*



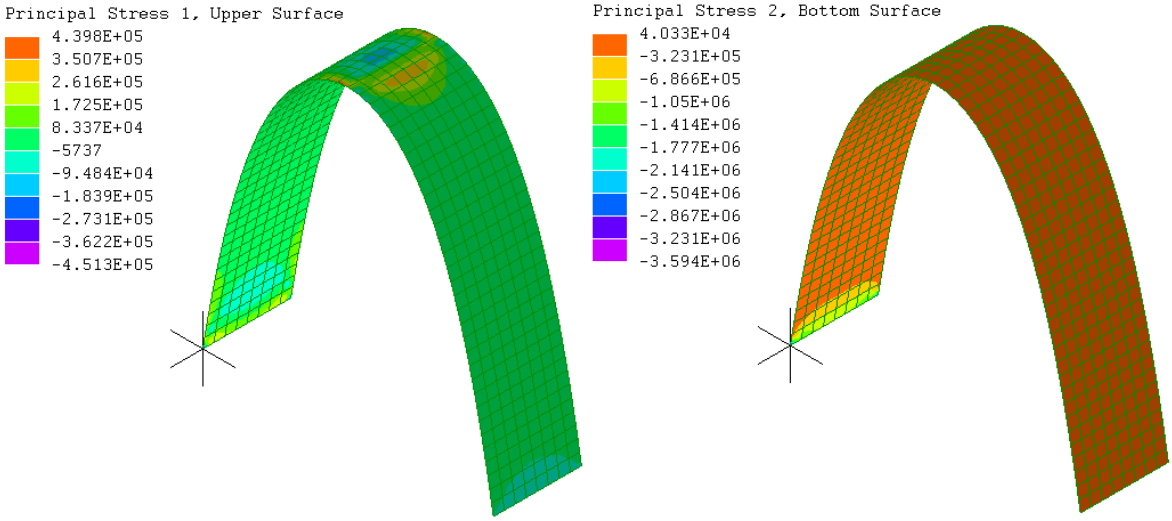

## *XXI. Dead Load, Live Load right half, Wind Load (Cpi=0), T=20° left half*



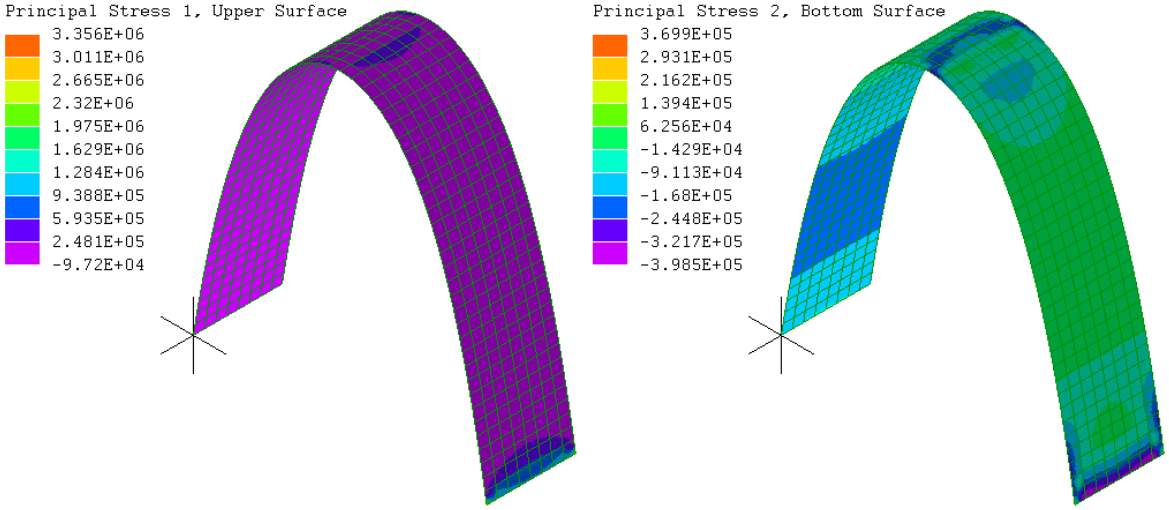
## *XXII. Dead Load, Live Load right half, Wind Load (Cpi=0), T=-20° right half*



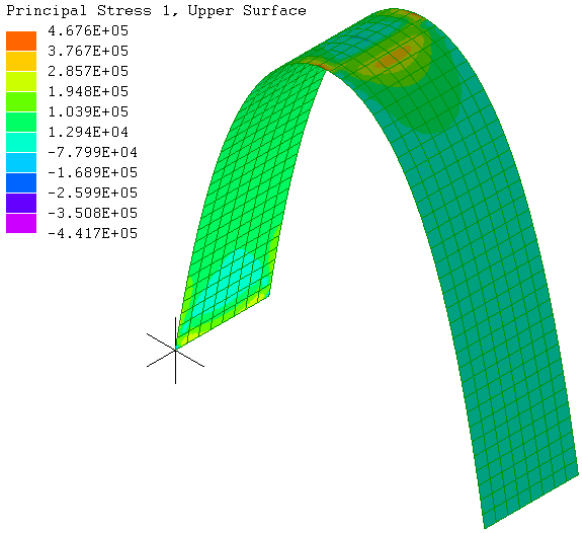

## *XXIII. Dead Load, Live Load right half, Wind Load (Cpi=-0.2), T=20° left half*

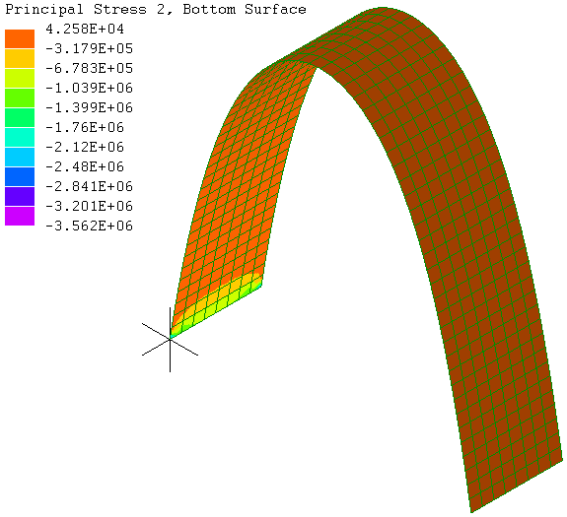



## *XXIV. Dead Load, Live Load right half, Wind Load (Cpi=-0.2), T=-20° right half*

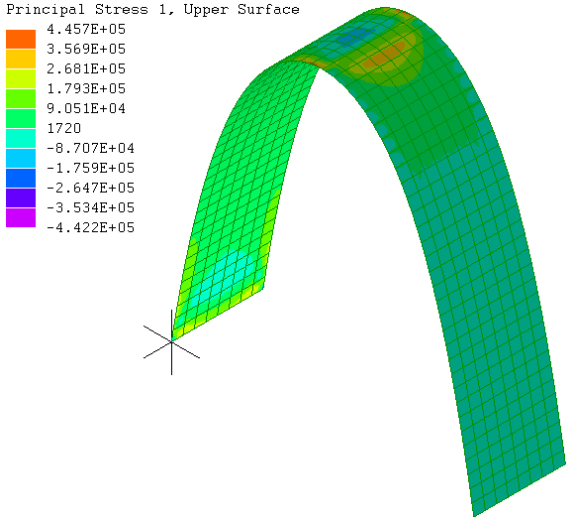


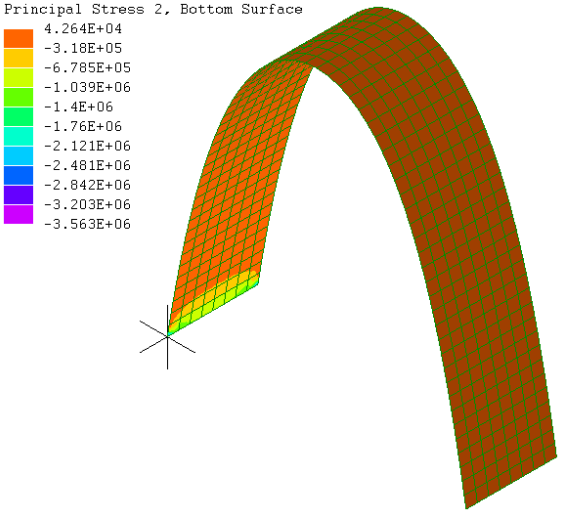
## *XXV. Dead Load, Wind Load (Cpi=0), T=20° left half*



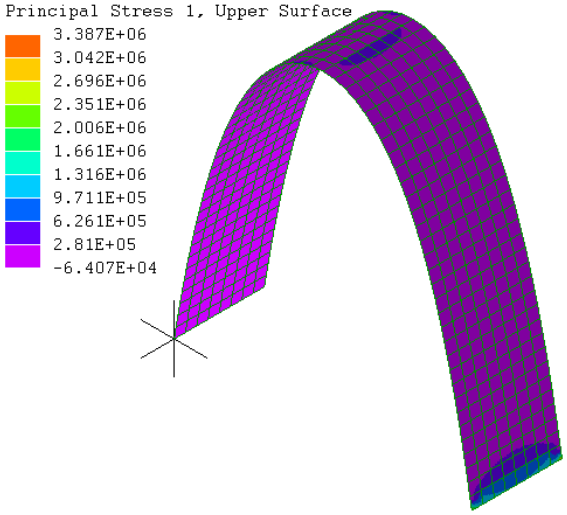



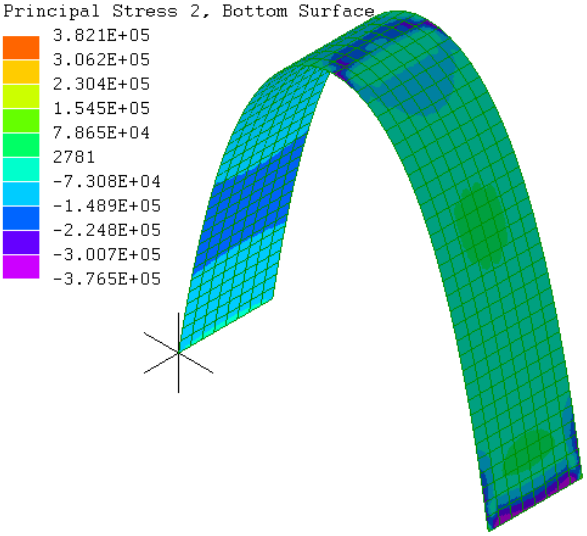

## *XXVI. Dead Load, Wind Load (Cpi=-0.2), T=20° left half*




## *XXVII. Dead Load, Wind Load (Cpi=0), T=-20° right half*



## *XXVIII. Dead Load, Wind Load (Cpi=0), T=-20° right half*

